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Public Education of Fuel Cell Development and its Impact on Society

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Abstract

FASTec is a small non-profit organization that is developing the world's first fuel cell powered airplane. The plane is being planned to fly alongside the Wright B Flyer at the Wright brother centennial celebration. During this time, FASTec will display the plane and popularize hydrogen fuel cell use. Our task was to design and build an exhibit for FASTec to use at upcoming air shows. In order to do this, we researched fuel cell technology, consumer adoption factors, and exhibit. Originally, we were supposed to pre-run the exhibit at the Sun 'N Fun air show in Lakeland, Florida. Due to reasons beyond our control, the exhibit in Florida was abruptly cancelled and we were forced to display the exhibit at several local college campuses. As a result of the project, FASTec now has a fully functional exhibit popularizing hydrogen fuel cell use and sustainability.

Executive Summary

The Foundation for Advancing Science and Technology Education (FASTec) is a small non-profit organization led by Jim Dunn and is developing the world's first fuel cell airplane in Worcester airport. The group regularly participates in air shows across the country where they present progress of their work and popularize hydrogen fuel cell use and sustainability.

The goal of our project was to provide FASTec with an effective exhibit for use at air shows. In order to create the exhibit, we had to do background research on fuel cell technology, consumer adoption, emergence of new technologies and exhibit design. Based on the results of our research we constructed the exhibit that included information on basic fuel cell operation, advantages and challenges facing fuel cells, issues of hydrogen safety as well as real-time demonstration. The exhibit was designed to be transportable, interactive, and show hydrogen use in a positive manner.

The exhibit was supposed to be pre-tested at the Sun N' Fun air show in Florida, a week-long event attended by around 700,000 people. However, two days before the show we were notified by our sponsor that due to lack of funding that we would not be able to participate in Sun N' Fun. This decision was beyond our control and forced us to change our evaluation scheme to testing the exhibit at local colleges.

With the background research that we had completed, we created a prototype exhibit to display at the college campuses. The exhibit consisted of three large posters, a functional hydrogen powered fuel cell, and a non-functional research fuel cell. We designed the demonstration fuel cell to power a propeller and a strobe light. Also, we added in a high power LED light that illuminated the actual fuel cell stack inside the fuel cell case.

The purpose of the exhibit was to teach people about key issues surrounding hydrogen fuel cells such as safety, basic operation, sustainability, applications of use, benefits, and challenges. Also, we wanted to motivate people to do more research on fuel cells on their own after viewing the exhibit. The posters were designed using Adobe Indesign and printed at Kinko's on vinyl material so that we could easily transport them and to ensure they would survive inclement weather.

We designed a survey to gather people's feedback about the effectiveness of the exhibit and to determine hydrogen adoption barriers. Additionally, the survey was designed to discover people's perception of hydrogen, to measure the change induced by our exhibit, and to determine the likeliness that people would perform more research on fuel cell development on their own.

After completing the exhibit at each college campus, the surveys were coded and into a SQL database for analysis. From analyzing the collected data, we determined that the exhibit is effective at giving people basic idea of fuel cell operation, advantages of fuel cell use, and challenges facing their development. People attending the exhibit enjoyed an interactive demonstration of an operational fuel cell. A demonstration was necessary to show the public that these devices exist in real life.

A number of suggestions was made to improve future exhibits conducted by FASTec. It was determined that more information on basic fuel cell operation as well as materials explaining what fuel cells are was necessary for the people with no or minimal exposure to the technology. We also determined that for an average viewer, five minutes spent at the exhibit were not adequate to comprehend all the information presented. In the future exhibits, we will need to present more information and extend the time that is available to people to comprehend it, as well as provide links to resources that would encourage people to do more research on their own.

From analyzing the survey data, we were able to develop recommendations that would improve the exhibit in the areas where it was found to be lacking. Our recommendation is to design a brochure that would explain what fuel cells are and how they operate, include frequently asked questions about fuel cell development and availability, and links to reputable resources of information about fuel cells.

With the completion of this project, FASTec now has a working exhibit that will educate people about fuel cell use and sustainability. They will be able to use this exhibit in conjunction with their airplane at the air shows or other events they plan on participating in.

1. Introduction

Since the year 2000, Foundation for Advancing Science and Technology Education (FASTec) and Advanced Technology Products (ATP) have been actively developing a plane powered by fuel cells. The plane has been dubbed the E-Plane and is being designed to be a high-speed and high-mobility aircraft. It is being designed around a French DynAero Lafayette III shell that was donated by American Ghiles Aircraft (AGA) and weighs roughly 300lbs with its internal combustion engine removed. What makes the E-plane stand out is the choice to use onboard fuel cells to power its operation. The design of the plane itself will have three phases; the first is to implement a pure electric version of the plane using only lithium-ion batteries as its power source. The second phase is to add fuel cell functionality in addition to the already in place batteries to add power and increase its overall range. The third and final phase is planned to only use a hydrogen fuel cell to power its entire operation.

The goals of the E-plane project are to educate the public about the benefits of fuel cells, increase overall exposure of the developing technology, prove the usage of fuel cells in aviation, and analyze the demonstrated flight performance. Before this project, building an electric or fuel cell based plane has been an engineering impossibility. However, the E-plane intends to do what no one else has done before and attempt to prove that fuel cell technology is indeed a viable option for aviation. They hope that this project will encourage greater use of hydrogen as a fuel source; especially at the commercial level. The ultimate long-term goal is to be able to transfer the technology into a commercial airliner. The group has had a lot of industry approval and assistance by receiving donations of batteries from Saft, electrical controllers from Solectria, and several grants from NASA.

The purpose of our project is to create an exhibit on the E-Plane, fuel cell technology and benefits, addressing user issues, and identifying barriers. In order to do this, background research was completed in the areas of consumer adoption, fuel cell benefits and shortcomings both in technological and societal aspects, and exhibit design. Additionally, parallels were drawn to the initial adoption of internal combustion engines to give insight to how new technologies will be adopted. Most of the research was done on automotive markets since the success of fuel cells will be largely based upon how well they are received in the specific market. There hasn't been much research in fuel cells regarding aviation; however a comparison to automotive fuel cell adoption will be relatively accurate. Fuel cells have the potential to make a huge difference in all transportation applications, but their success is largely dependent on solving three key issues: the lack of infrastructure, technological advancement, and adoption in society.

The exhibit was being built for the 2003 Sun-N-Fun Air Show in Lakeland, Florida that will be held April 2nd through the 8th. The resulting exhibit was planned to be displayed in conjunction with the exhibit that is already in place for the E-Plane. The content is based around the idea of how hydrogen is abundant and sustainable, and will perhaps be the basis of a new fuel economy. Our background research gave us the needed information to develop how to effectively convey the needed information to the public.

The developed exhibit is a prototype for future exhibits. The reason of performing the exhibit to the general public is to receive feedback and to use that feedback to improve upon the exhibit. The end result was an exhibit popularizing the use of fuel cells in a way that the people can relate to. Recommendations are later made to increase the effectiveness of the exhibit for future air shows.

However, due to circumstances beyond our control, AGA suddenly refused to fund the exhibit at the Sun 'N Fun air show. This happened because of a disagreement between AGA and FASTec and had nothing to do with the exhibit being developed. Since there was no other comparable air shows within the same timeframe as Sun 'N Fun, we were forced to develop other alternatives to show the exhibit to the public. As a result, the decision was made to visit the campuses of Worcester Polytechnic Institute, Assumption College, Worcester State College, and Quinsigamond Community College and show the exhibit to students and faculty. This is not an exact representative sample population, however given the circumstances it was the best option available to us. With the feedback from each college, we will still be able to make recommendations to improve the exhibit for FASTec for future air shows.

The content in Chapter 2 includes all the background research in the form of a literature review. Chapter 3 discusses our methodology used throughout the project execution. Chapter 4 includes all of our data analysis of our completed surveys. In chapter 5, we make conclusions about the project and give recommendations on the next steps.

2. Literature Review

The following literature review contains all of the relevant information that was found in researching the necessary areas for this project. This document is broken down into the main topics of fuel cell technology, consumer buying behavior, parallel technologies, technical and social barriers of fuel cell adoption, and exhibits. The background information on fuel cell technology establishes the operation of the main types of fuel cells, history of fuel cells, and various applications. Information on consumer buying behavior provides a look at the psychological aspect of the consumer buying process relative to an automobile purchase. The parallel technology section focuses on how the gasoline infrastructure was originally adopted and what factors determined the final outcome. Information on the technical and social barriers of fuel cell adoption provides a look at the hurdles that fuel cells still face and outlines factors that will or will not make them successful in the future. The final topic of exhibits provides the necessary information for creating a successful exhibit and efficiently passing information to visitors.

2.1 Fuel Cell Technology

Fuel cell technology has been in place since their introduction in 1839. However, they have never been used in large-scale mainstream power systems and have always been overshadowed by gasoline, steam, coal, and oil based power systems.

Despite the fact that fuel cells remain widely unused, they have numerous advantages over the conventional power systems that are current being used. Since fuel cells are a virtually clean energy source, they are a much more attractive form of power generation than their more polluting counterparts. Internal combustion engines use various forms of fossil fuels to generate energy, which require a large amount of moving parts and creates toxic chemical emissions into the atmosphere. In comparison, fuel cells create energy electrochemically without the use of combustion, which is much more efficient and does not require large amounts of moving parts nor creates toxic emissions. IC engines provide only mechanical power, not electric, so an electric motor must be added to fuel cell to provide similar function. Fuel cells have the ability to be stacked together to scale the necessary power output for the specific application. Technologically, fuel cells have the potential to provide a viable alternative to conventional systems. (National Fuel Cell Research Center 2002)

The World Bank estimates that about one billion people in the world are exposed to severe air pollution, which results in over 700,000 deaths annually. The increase in the number and size of vehicles being driven, combined with the amount of miles driven during the average commute has largely increased the pollution levels in the air. The Environmental Protection Agency has estimated that about 78 percent of carbon monoxide emissions, 45 percent nitrogen oxide emissions, and 37 percent of volatile organic compounds can be blamed on automobiles. These emissions make up about 25 percent of all greenhouse gases. (Los Alamos National Laboratories 2002)

Historically, since the beginning of the industrial revolution emissions in the air have increased significantly largely due to the burning of fossil fuels. Carbon dioxide only makes up a very small portion of the world's atmosphere; however it is one of the largest waste products today. When an automobile uses only one gallon of gasoline, about 25 pounds of carbon dioxide are produced. Since 1765, the number of particles of carbon dioxide in the atmosphere has risen from 280 to 360 parts per million. Statistics show that the average temperature on earth has risen by over 1 degree Celsius and overall precipitation has increased worldwide. Many believe that this confirms global warming and is harming the environment globally. (Los Alamos National Laboratories 2002)

With the introduction of fuel cells, they would have the potential to reduce air and water pollutants. The United States Department of Energy has predicted that "if a mere 10% of automobiles nation-wide were powered by fuel cells, regulated air pollutants would be cut by one million tons per years and 60 million tons of the greenhouse gas carbon dioxide would be eliminated" (US Department of Energy 2002).

2.1.1 General Operation of Fuel Cells

Fuel cells are electrochemical devices that utilize a chemical reaction between a fuel source and oxygen to produce electricity. The basic physical structure of a fuel cell consists of an electrolyte layer between an anode and a cathode.

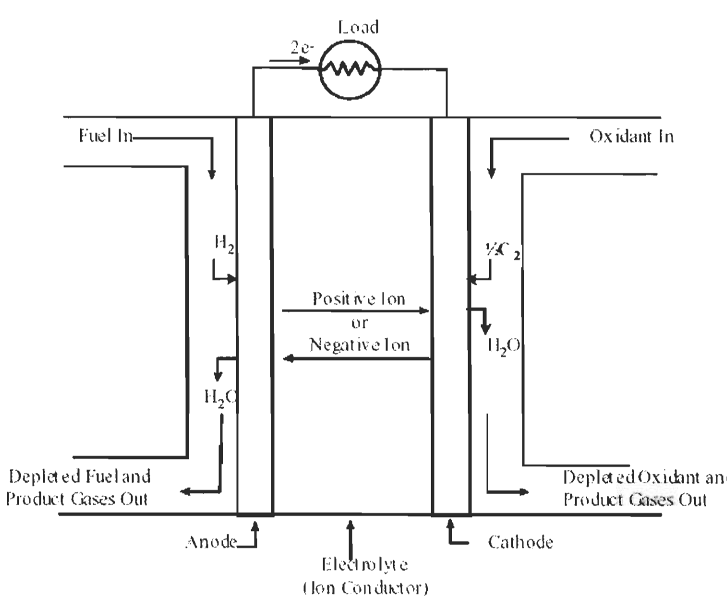

Figure 1.1 - Basic Fuel Cell Model – Source: Fuel Cell Handbook, 2000.

Fuel is continuously fed over the anode while oxygen is fed to the cathode to provide constant generation of energy. A fuel cell has very similar characteristics to that of a typical battery except that its power output is constant as long as fuel is available. Instead of having to be recharged or replaced entirely like batteries, the fuel source simply needs to be replenished. Therefore, fuel cells are capable of creating DC electricity as long as fuel is supplied to it. The only byproducts of the electrochemical reaction are water and heat if the fuel source is pure hydrogen. This is a huge significance when compared to the combustion of fossil fuels. (Fuel Cell Handbook 2000)

2.1.2 Types of Fuel Cells

Today, there are many different variations of fuel cells, although only a few specific types are commercially produced. The five major types of fuel cells will be covered, including alkaline, phosphoric acid, molten carbonate, solid oxide, and proton exchange fuel cells. These five types of fuel cells are either currently available or will be available very soon. This section draws from FuelCells.org, Los Alamos National Laboratories, and The Fuel Cell Handbook, which is considered to be an authority in the field.

The alkaline fuel cell was the first type of fuel cell to be put to practical use. When the United States first started launching space shuttles, alkaline fuel cells were used to power the primary power systems onboard. They are still widely used in space shuttles, since their primary fuel is so accessible; both liquid hydrogen and oxygen. The alkaline fuel cell uses an alkaline hydroxide as the electrolyte. They typically operate around 60-100 degrees C using hydrogen at the anode and oxygen at the cathode. Unlike typical fuel cell operation, the alkaline fuel cell does not require use noble metals for the anode and cathode, which is beneficial since they are usually very expensive and scarce. The following equations describe the reactions that occur at the anode and cathode in an alkaline fuel cell:

$$\text{ANODE: } 2H_2 + 4OH^- \text{ -> } 2H_sO + 4e^-$$

$$\text{CATHODE: } O_2 + 2H_2O + 4e^- \text{ -> } 4OH^-$$

The hydroxide ions are the ions that flow through the electrolyte. The advantages of alkaline fuel cells are that they have a very high power density and high efficiency rating. The main shortcoming of the alkaline fuel cell is that they require pure oxygen and hydrogen as fuel and can very easily become contaminated.

Phosphoric acid fuel cells are currently being used in more large-scale power systems. Their primary application is in stationary electric power generation and is the first fuel cell to be commercially available. In the world today, there is more than 50MW of power being generated by this type of fuel cell. Phosphoric acid is typically used as the electrolyte in acid fuel cells. They usually operate around 150-200 degrees C, using hydrogen as the fuel and oxygen as the oxidant. The waste heat from the fuel cell's operation is used to free hydrogen from natural gas, which is used as the base fuel; this process is called the steam reform process. The equations that describe the reactions at the anode and cathode are:

$$\text{ANODE: } 2H_2 \text{ -> } 4H^+ + 4e^-$$

$$\text{CATHODE: } 4H^+ + O_2 + 4e^- \text{ -> } H_2O$$

Phosphoric acid fuel cells have been successful in commercial applications and have shown to be up to 80% efficient. Unlike alkaline fuel cells, it doesn't require pure oxygen as an oxidant and can simply use air. Limitations of the phosphoric acid fuel cell include the use of platinum catalysts, which can be very expensive.

Molten carbonate fuel cells are much like phosphoric acid fuel cells except that they have shown improvements with efficiency. They are also aimed at large-scale power systems and use a more efficient method for reforming methane to hydrogen. The electrolyte used in a molten carbonate fuel cell is a molten alkali mixture that is supported by a porous matrix. Typically, they operate around 650 degrees C and use reformed hydrogen as a fuel and oxygen as an oxidant. The following chemical equations are used to describe the reactions at the anode and cathode:

$$\text{ANODE: } 2H_2 + 2CO_3^{2-} \rightarrow 2H_2O + 2CO_2 + 4e^-$$

$$\text{CATHODE: } O_2 + CO_2 + 4e^- \rightarrow 2CO_3^{2-}$$

The higher operating temperature of molten carbonate fuel cells gives them certain benefits and disadvantages. The increased temperatures allow them to breakdown more complex hydrocarbons, which increases flexibility in choosing a fuel source. Also, created heat is useful for generation of energy using conventional steam turbines. Alternately, the heat also increases the corrosion rate, which largely reduces their lifetime.

Solid oxide fuel cells largely differ from other types of fuel cells mainly because they use a solid electrolyte instead of a liquid or molten one. They operate at temperatures of around 1000 degrees C and are mainly used for large and medium scale power systems. By operating at a higher temperature, it is much easier to recycle the heat produced to increase the overall efficiency rating of the system. The specific electrolyte is made of crystalline yttria-stabilized zirconia, which is ionically conductive at the operating temperature. The following equations are used to describe the reaction at the anode and cathode:

$$\text{ANODE: } 2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$$

$$\text{CATHODE: } O_2 + 4e^- \rightarrow 2O^{2-}$$

High efficiency and resistance to electrolyte poisoning make solid oxide fuel cells very attractive. However, the high heat levels also have many side effects such as shortened product lifespan and also few materials that can be used to manufacture solid oxide fuel cells.

Proton exchange membrane or, as it is sometimes called, polymer electrolyte fuel cell uses a well-hydrated polymer membrane to conduct the positively charged hydrogen atoms from anode to cathode to produce electricity. The following chemical reactions describe processes on the anode and cathode:

$$\text{ANODE: } 2H_2 \rightarrow 4H + 4e^-$$

$$\text{CATHODE: } O_2 + 4e^- \rightarrow 2H_2O$$

The PEM fuel cell has high power density and operates at a relatively low temperature ~80°C. This has its advantages and disadvantages. Due to the low operating temperature and high power density, the PEM cell meets a lot of the requirements of the automotive industry. It has a quick start-up and if used directly with hydrogen fuel can be started in ambient conditions. Polymer electrolyte used in the cell is solid by nature, which makes the packaging easier and corrosion issues less severe, yet subject to contamination. On the other hand, lower operating temperature requires the presence of expensive catalyst – platinum, which increases the cost of the cell. Operating temperature lower than 150°C also makes the cell highly sensitive to the presence of CO. (While being used as a fuel at higher temperatures, CO is a poison for a fuel cell operating at 80°C). Water management is another issue to deal with in the PEM fuel cells, because the solid polymer membranes have to stay properly hydrated for optimal conduction.

2.2 Consumer Purchasing Factors

The purpose of this section is to identify the thought process of the consumer when he or she goes to buy a new product or more specifically, a new vehicle. With the introduction of newer alternative energy vehicles based on technologies such as hybrid electric, pure electric, and soon to be fuel cells, we wanted to know why, from the consumer perspective, these vehicles will succeed or fail. Newer technologies face an upward battle with consumer adoption since they are different from their internal combustion counterparts and therefore will perform, feel, and cost differently which may be unacceptable to the general public. They also may require new infrastructure and involve significant transition costs.

Over time consumers have come to expect certain standards and features when it comes to buying a car. The product offerings currently on the market represent these expected values. Price, performance (handling, drive quality, etc.), look and feel, reliability, and functionality are all considered in the purchasing process. From the business perspective, the goal of a new product should be able to meet the needs and wants of the consumer in order to increase sales and profits. Unfortunately, the wants of the current consumer are always changing and even though data is present for previous years, it might not be accurate for today or the years to come. The ultimate challenge for alternative energy vehicles is to appeal to current consumers by offering them a very similar or better overall driving experience with no drawbacks. (Miller 2002)

As seen in Table 2.1, buyers are influenced by four main factors: culture, social, personal, and psychological. Understanding consumer culture is the most essential to determining person's wants and buying behavior. In the United States, children are exposed to values such as achievement, efficiency, progress, material comfort, individualism, and freedom. Included in this, are subcultures that can vary in age, nationality, religion, race, and geographic location. Different combinations of subcultures formulate different market segments in which products can be marketed. More specifically, there are also social classes which outline income, occupation, and completed education. People of the same social class tend to have similar values, interests, and behavior. Social classes can also indicate the feeling of superiority or inferiority when compared to other social classes. Gearing products towards specific social classes can be very effective since they show preference to different price and quality ranges. (Schiffman, Kanuk 2000)

Buyer's Characteristics	Buyer's Decision Process
• Cultural • Social • Personal • Psychological	• Problem Recognition • Information Search • Evaluation of Alternatives • Purchase Decision • Post purchase Behavior

Table 2.1 - Outline of Buyer Characteristics and Buying Decisions - Source: Kotler 2001.

Aside from cultural aspects, consumer buying behavior is also influenced by social factors such as friends, co-workers, family, and society status. People who have face-to-face interaction with the consumer have the potential to be very influential. People expose the consumer to other trends, lifestyles, and attitudes that can affect product and brand choices. Families usually have joint buying trends, where larger purchases are often thought about together even though they might only be used by one person. A family's buying behavior can be traced back to the parental influences in terms of politics, ambition, economics, and religion. Children also have a larger affect on consumer buying trends. They can either directly or indirectly affect what his or her parents buy. Parents will often know which brands and styles are preferred by their children and will buy accordingly. Alternatively, the children can request exactly what they want their parents to buy for them.

Many products will target certain social classes and also be a status symbol to the buyer. Social classes like to differentiate themselves from others by owning certain name brands that they feel represent their role or status in society. For example, upper class consumers may feel the need to buy BMW's in order to represent what they feel their place in society is. (Kotler 2001)

Psychological factors also come into play when consumers are buying products. Product perception varies from person to person and has the ability to screen out certain products or features and enhance others that are of interest. Individual perception can also change the way the product was originally intended to be viewed, since the consumers will interpret information with their individual biases and preconceived notions. It is very hard to attract consumer's attention when introducing products that they are unaware of. (Berelson, Steiner 1964)

A high involvement purchase is defined as a purchase that usually has a high monetary value and many different brand offerings and differences. For these types of purchases, the consumer buying process has five stages. An outline of the five stages can be seen in Table 2.1. The process summarizes most considerations that occur during a highly involving new purchase, such as a vehicle. The first stage is when the consumer actually recognizes needs or wants for a particular product. This decision is either made internally, or is driven by an advertisement.

This leads into the second stage where the consumer will do research for more information on the given product. There are two levels that the consumer will search for information. One is called 'heightened attention' where the consumer is simply more open to new information about it. The other is a more active approach where he or she will actually seek information through a range of sources such as the Internet, stores, or friends and family. Sources can range from commercials, dealers, websites, and consumer product sources to people with direct experience with the product. Usually the most amount of information is gained through commercial sources, but the information that has the most influence comes from unbiased sources. Through this research, the consumer will become aware of the other competitive products and establish a set list of products that will get serious consideration.

Stage 3 is the evaluation of all the seriously considered products that have been chosen. Deciding factors that go into the final product decision are specific to the product and importance is weighed according to the consumer's wants. The factors that can be generalized over all products are quality and amount of useful features compared to price, brand image, and influence of other opinions. Consumers will tend to eliminate products that do not meet their criteria in order to simplify their final decision. Once a decision is made, the purchase (stage 4) is made.

The fifth and final stage is the post purchase behavior of the consumer. The post purchase period is what determines customer satisfaction and determines if the consumer will influence others to make the same decision. Customer satisfaction will determine if the same product will be considered again for a repeat purchase. It is a long process for a product to get considered, make it through the decision process, and become the final candidate. Focusing on alternative energy cars, the main problem they currently face is gaining public acceptance. (Kotler 2001)

Aside from the consumer buying process, there is also the consumer adoption process for innovations. This attempts to explain how consumers learn about newly introduced innovations and how they will either accept or reject them. In the past, products used to be mass-marketed to everyone, assuming everyone to be a potential buyer. However, this is not the most efficient method since it requires large advertising budgets and targeted people who were not potential customers. The natural alternative to this would be to specifically target people who are early adopters of products.

Stages of Adoption	Types of Adopters	Factors of Adoption
1. Knowledge 2. Persuasion 3. Decision 4. Implementation 5. Adoption	1. Innovators 2. Early Adopters 3. Early Majority 4. Late Majority 5. Laggards	1. Relative Advantage 2. Compatibility 3. Complexity 4. Trialability 5. Communicability

Table 2.2 – Innovation Adoption Outline - Source: Rogers, 1983.

Table 2.2 outlines the innovation adoption processes; included in this are the stages of adoption, different types of adopters, and the factors that will determine whether or not adoption will occur. The innovation diffusion process is defined as "the spread of a new idea from its source of invention or creation to its ultimate users or adopters". There is a defined five stage process outlining the steps consumer's go through in product adoption.

1. Knowledge – The consumer becomes aware of the innovation's existence and gains some knowledge of how it works.
2. Persuasion – The consumer takes either a favorable or unfavorable stance towards the product.
3. Decision – The consumer decides whether or not to try the innovation.
4. Implementation – The consumer will give the innovation a trial use to establish a sense of value for the product.
5. Adoption – The consumer decides to either accept the innovation for regular use or to reject it completely.

Having something to offer for every adopter in each stage could be very important to whether or not the product will become adopted. For example, a consumer might be more likely to purchase a product if he or she could first use it on a trial basis.

The rate of innovation adoption is largely dependent on the individual. In every industry, there are certain people who always own the latest technology or fashion, but there are also people who wait till the product has established itself. People can be classified into innovators, early adopters, early majority, late majority, and laggards; the rate at which each type accepts new technology decreases respectively. For example, innovators are more willing and open to try new products, whereas laggards are extremely traditional and suspicious of change. Being able to specifically target the desired type of adopter at the correct stage of product introduction is crucial to insuring the success of the product. (Rogers 1983)

Over 90 percent of all new products fail within the first 4 years of introduction. The reasons why products fail cannot be pinpointed down to one specific reason. A standard set of independent characteristics has been created in order to explain why certain products fail or succeed. They are: relative advantage, compatibility, complexity, trialability, and observability. Studies have been done to show that relative advantage, compatibility, and complexity are more influential than trialability and observability. (Rogers 1983)

An explanation of each characteristic follows:

- Relative Advantage – The degree an innovation is perceived as being better than the idea or product it follows.
- Compatibility- The degree an innovation is able to connect with an individual's values, experiences, and needs.
- Complexity – The amount of education or how steep of a learning curve an innovation has.
- Trialability – The short term availability of an innovation that doesn't require commitment.
- Observability – The degree that the benefits or new features of the innovation that can be seen by others.

The usefulness of these attributes is mainly to predict whether or not a product will be adopted in the future. Generalizations will be able to be made about overall advantages that a product carries over others. When all the attributes are used together they are the most effective. Other determining factors include price, scientific credibility, and social approval. (Tornatzky, Klein 1981)

Buying a car is a unique consumer experience and not many other product purchases (except for probably real estate) can be directly related in terms of customer emotional and monetary involvement. Buying a car can be a huge investment to the consumer and most new car purchases cost over 15,000 dollars. It's not only a large monetary investment; it is also a long-term investment. If the consumer expects to own his or her new car for the next 7 years, they will want it to satisfy them in every possible way. The consumer will not just buy a new technology or a new feature when buying a vehicle;

they are buying the entire driving experience that fits their own specific wants and needs. (Miller 2002)

There are factors that will lead consumers into an automobile purchase as seen in Figure 2.2. This source establishes a set of specific product features that are most thought about during the buying process. Nearly half of the people who responded to the survey stated that safety, exterior styling, and the driving experience were absolutely necessary for an automobile to meet their needs. Price was rated as the second highest factor. Included in price, is the current deal that the consumer is able to achieve. Sales promotions, buying incentives, or discounts do very well to attract buyers. The two least important factors that were considered were environmental impact and fuel economy, which only 18 and 37 percent of consumers said was important for their next purchase. Emissions ratings range from poor emissions, to low, to super ultra low. Emissions have proven not to be a significant factor for automobile buying, unless they are heavily regulated like in California. Regardless of the general statistic, there is a segment of environmentally conscious customers, to whom emissions and high fuel economy would be the most

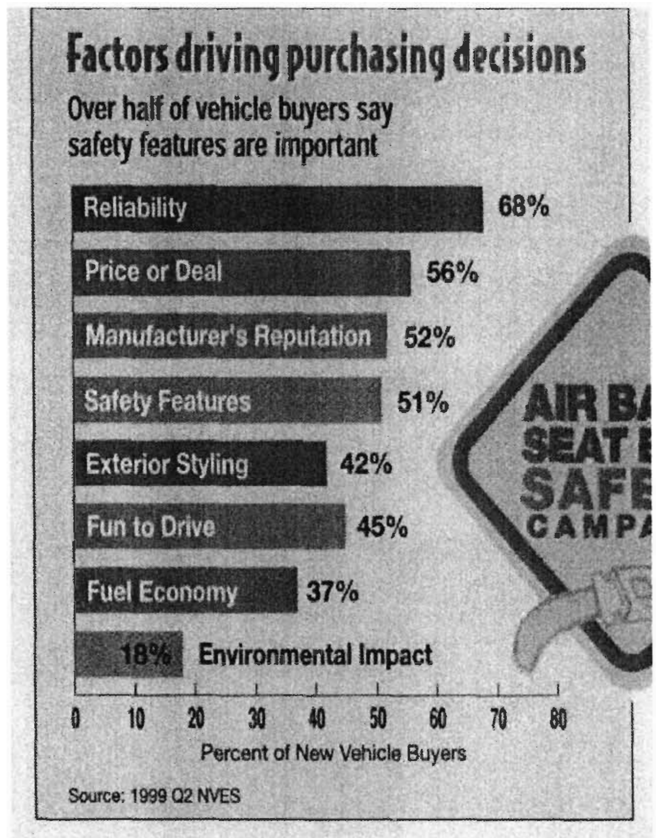

Figure 2.2 - Purchasing Factors. Source: Ford 1999.

important factor. This segment however is not representative of the general consumer population who is often already aware of new technologies on the market that reduce environmental impact of the automobile. Overall, almost all of the factors were considered very important. This would indicate that automobile consumers are very strict when it comes to making their final decision. A consumer's car of choice has to make it through a very rigorous screening before a decision can be made. (Ford 1999)

Safety has been proven to be a key selling point for automobile manufacturers. In 1997, Ford Motor Company was in a struggle to make their Windstar minivan a success against Chrysler, the market leader. The Windstar lacked a driver-side sliding door, which was believed to be the key selling point of the competitor's models. However, Ford instead focused on how their model had achieved the highest government crash test rating of 5 stars. Ford's message of safety helped the Windstar gain market share, despite its lack of other features. Ford acknowledged its success and then later required that all their automobiles should be able to pass the crash test with 5 star ratings. The majority of the other auto manufacturers took the hint, and with good reason. Daimler Chrysler's market research results showed that in 1999 over 84% of people asked said safety was "extremely important" when purchasing a vehicle. However, safety was definitely a purchase deciding factor when it comes to people in the market for minivans. (Deep 2000)

In an involved purchase such as a car, people tend to buy products that will reflect their personality or ideal self-image. A person's ideal self-image can vary from how he or she views his or her self-image. Specifically to the automobile buyer, a desirable car would be one that fit the buyer's self image or that set an ideal image that others would see. (Kotler 2000) Historically, America has had a love affair with the automobile since its mass adoption and that trend is continuing with the industry spending $7.61 billion on advertising alone in 2001. Individual companies are all fighting to connect their product line with an image the consumer wants to have. The automobile continues to be a self-expressive purchase to the buyer and people are constantly demanding more stylish and attractive models. (Mraz 2001)

All automobile buyers do not act the same and do not consider the same buying criteria as either necessary or just expected. Each auto buyer has his or her own set of values and experiences that would make them value certain features higher than others. Through a very large and selective survey, Miller Williams was able to create a profile of the different types of people. There are 5 different types of people separated into behavioral groups instead of demographics. The 5 types are:

1. Pleasants – These people are very easy to satisfy, but hard to identify. They are more receptive to the actual driving experience rather than certain features or performance numbers on paper. They are slow to learn about new technology and rely heavily on the dealer to show them what's available.
2. Deal Seekers – This group places more emphasis on the price of the product. It wouldn't be an issue if feature "X" is missing as long as the price is right.
3. Loyalists – This group will only buy from their most trusted automobile company. Attempting to sell them a new feature or different brand could be very hard since they are used to knowing what to expect from their brand of choice.
4. Doubters – They are aware of the new technology and features on the market, but tend to have trouble making decisions about what to buy. They are similar to Pleasants, but are much more aware of current features and are much less dependant on the dealer.

5. Rebels – This group is extremely aware of the newest technology and tends to buy cars based upon them, as well as performance. They will do research on their own and will buy a car based on what fits them feature, looks, and performance wise.

The profile of different automobile buyers can largely be related to the types of innovation adopters. Rebels represent the group that will adopt technology before everyone else. They are aware of what is available and want to incorporate it into their lives in order to be on the cutting edge. On the other extreme, loyalists are used to buying the same driving experience and will not feel the need to change what they buy unless absolutely necessary. Automobile makers should market towards people that would consider buying a new alternative energy vehicle. The Rebels and early adopters should be targeted less in marketing strategies since they will buy the new technology regardless of what is being marketed, once they learn about the benefits. Alternatively, loyalists and laggards should also be less targeting since they will only adopt once it clearly becomes mainstream. Pleasants, Deal Seekers, and Doubters represent the largest marketing opportunities for automakers. They are all open to new ideas, but require certain incentives in order for them to make the final purchase. These three groups represent the best opportunities for alternative energy vehicles to become widely adopted and without their support, it is more likely that the technology will fail.

Aside from what the customer wants, there are also factors that the customer expects, such as range and what each automobile buyer type expects. The exact features that consumers must have in order to make a purchase decision are specific to the person. Upcoming technologies face the large challenge of becoming accepted in a very unforgiving industry. They must offer buyers a relative advantage or be able to compete head to head with current technology without any significant drawbacks.

2.3 Parallel Technology Relation

Undoubtedly technology influences society and its development, as has been shown with the industrial revolution in the 1800s and the information revolution in the 1980s. On the other hand, society influences the development of technology. By developing a picture of the past and linking societal and technical factors at the turn of the twentieth century, we can understand why the internal combustion engine pulled ahead of steam and electric technology. In this section, we are attempting to link to today's competition of automotive technologies such as IC engines, electric power trains, hybrids, and fuel cells to what happened in the past.

By the end of the 1890's, steam vehicles prevailed and held a large share of the market. Boilers were reduced in size so it could be put under a seat. Leon Serpollet of France improved the flash boiler and set the world's land speed record for traveling at 75.06mph in his steam-powered car in 1902. Serpollet's cars also boasted fast start-up times of 2 minutes. At the time steam-powered engines offered the highest speed in the industry, little noise and exhaust fumes. Unlike gasoline or electric cars, which could use only one source of energy, steam-powered vehicles could be designed to use either hard or liquid fuel such as coal or crude oil. (Davidson 1953)

Internal combustion and diesel engines were not very popular until the 1895 Paris-Bordeaux-Paris race, where lighter gasoline-powered cars took the lead. Since then, more people became interested in developing gasoline-powered vehicles. During this time, ICE cars had a long startup time and created large amount of air and noise pollution, which was undesirable in populated areas. On the other hand, they possessed advantages over steam and electric vehicles such as high energy density of fuel, long range, and less effort to operate. (About.com)

Electric cars in the 1900's had very similar characteristics to the electric cars today. The benefits of immediate start-up, low noise levels, excellent durability, and no emissions were offset by limited range, slow speed, and long recharge time, due to low energy density of batteries. In order to address these problems, the concept of interchangeable batteries was developed. (Wakefield 1994)

In the late 19th century, infrastructure and society in Europe and America were different, which resulted in further development of different types of vehicles. America was largely centralized with most of its drivable roads within the cities. Cities were generally very compact and countryside roads were not abundant or drivable in bad weather. Refueling infrastructure and recharging stations were not extensive and were confined to larger cities. Neither noise, nor pollution was of much concern, however in cities people preferred not to inhale smoke created by gasoline cars. Coal had been mined for a while and oil drilling had just started. No rules and regulations on the use of vehicles and fuels existed at the time.

Alternately, Europe already had a higher quality road system linking major cities. Some of these were built in the days of the Roman Empire. Most European countries did not have automotive rules and regulations. British Parliament issued the "Red Flag" regulations, which put severe restrictions on the use of automobiles. Due to this fact, most of the automotive development was done on mainland Europe, which put Britain slightly behind the automotive world at the time.

Steam, gasoline, and electric cars had a fairly equal share of representation in America's automotive fleet. Europe was halfway through the transition from steam to ICEs. Because of Europe's road infrastructure and the popularity of touring, vehicles with longer range were much preferred. As can be seen in Table 2.3, gasoline-powered cars had the longest range of all the vehicles on the market at the time. This proved to be crucial to Europeans. Regardless of the drawbacks of the ICEs, they were chosen by the public because they allowed people to travel city-to-city on existing roads. (Wakefield 1994)

America lacked road infrastructure which limited car use to the city boundaries. In these conditions, the superior range of gasoline vehicles was not a visible advantage. In fact, gasoline engines proved to be inferior to electric and even steam engines because they were more difficult to start (by hand). Doctors, who were on call and had to keep a carriage ready and other people who needed to run errands around the city bought early electric cars. Cars entered taxi service replacing horse-drawn cabs. For all of these things fast start up was needed. Even though there were no regulations on emissions at the time, the public also preferred less smoke throughout the city. Under these conditions steam and electric cars prevailed over gasoline. Electric vehicles proved to be safer and more reliable. They were the vehicles of choice in cities, where range was not an issue.

All of these technologies were very successful with the public, excluding the British "Red Flag" act, because they were superior to horses. People were used to the low range, high maintenance, low speed and high preparation time of horses. Most of the automotive technology development improved all of these parameters compared in relation to the horse.

Vehicle Type	Fuel for 1 hp-hr	Weight/hp in Pounds	Control	System Durability	Efficiency Source	Maintenance	Range Miles	Start-Up Time	Noise	Fumes	Speed mph
Steam	6#coal 40# water	200	Steam valve	Good	10%	Modest	10 water	2 minutes	Little	Little	40
Gasoline	1 ounce	185	Carburetor	Fair	15%	Modest	150 gasoline	5 minutes cranking	Very noisy	Much	20
Electric	220# batteries	70	Voltage switching	Excellent	50% with battery	Little	30 charge	Immediate	Almost none	None	25
Horse	12# oats	1000	Bridle	Good	70%	Considerable	15 with buggy	15-30 minutes	Little	Much	Walk

Table 2.3 - Categories Comparing Types of Road Transportation – Source: Wakefield 1994

When better roads were finally made in the USA, the need for longer-range vehicles increased. Discovery of oil in Texas drove gasoline prices down, making it a very affordable fuel. At the same time engineers working on extending the range of electric cars, such as Edison's work on a long-range battery, failed to improve the design to the level that would allow passengers to travel outside cities. With range constraints, many manufacturers shifted to the internal combustion engine. By 1910, most of the cars manufactured in the US were gasoline powered, although women still preferred electric cars, which didn't need to be hand cranked to start. When Kettering invented the electric starter in 1914, electric vehicles lost most of their remaining interest, except for city delivery trucks.

In the beginning of the 21st century, we can group all the most promising personal transportation systems into fuel cell vehicles, hybrids, internal combustion engines and pure electric vehicles. Today's leading transportation technology is the internal combustion engine which has been ahead of all the competing technologies since 1910.

Currently in America, roads and gasoline refueling infrastructure are abundant. Improvements in engine emissions and performance have kept I.C. engines a popular choice. The price of gasoline is still low, even though it is likely to increase in the future. So far gasoline cars have all of the commercially visible advantages. They are cheaper than fuel cell, electric, and hybrid vehicles currently on the market; gasoline infrastructure is already in place as opposed to the hydrogen and recharging stations. The range of gasoline cars is superior and is beaten only by hybrids. Current vehicles based on hybrid, fuel cell, electric technology do not offer the same kind of luxury, space and power of ICE vehicles. Even though only very insignificant improvements were made in terms of energy efficiency of internal combustion engines, they are still highly competitive because of the high energy density of gasoline. By looking back to the beginning of the 20th century, we can make a prediction that in exactly the same conditions gasoline-powered cars will dominate the mainstream market, leaving little niches to the development of hybrids, fuel cell and electric cars.

On the other hand, if several changes that are visible to the average population occur, we could expect the shift that happened in the early 20th century and put internal combustion engines in the lead. Some of the factors "visible" to the population would include substantial rise in the price of gasoline, strict government emissions regulations or city bans for polluting vehicles. Change "visible" to the population could also be the technology advancement of fuel cells, hybrids or EVs that would clearly surpass the internal combustion technology in range, start-up time and ease of use in terms of maintenance, reliability and availability of fuel (and overall cost of ownership/use). Only after the change that the average consumer can see and appreciate occurs, can the mainstream commercial development of the alternative-fueled vehicles be possible.

2.4 Barriers to Fuel Cell Adoption

Fuel cells have the potential to compete with current internal combustion technology. They present many advantages; however still have numerous issues that will prevent them from capturing the market. These issues include technical limitations due to the infancy of the technology as well as problems with public acceptance. Regardless of the challenges, many people expect fuel cells to overcome these issues with time.

2.4.1 Technical Constraints of Fuel Cells in Automotive Applications

Due to the low price, excellent performance, and wide acceptance of today's internal combustion engines, it is very hard for upcoming technologies to compete and displace IC technology. The introduction of a fuel cell vehicle with lower performance than its ICE counterpart would be a marketing failure. (Stempel 1998) The question that naturally arises is whether fuel cells are capable of delivering the performance and benefits, which meets the customers purchase and performance criteria (Efficiency is the only clear advantage). (Stobart 2001)

The issues that are important to achieve the performance objectives are discussed below. Thermal management is very important in achieving highly-desired vehicle efficiency. All the heat dissipated into the air equates to wasted energy that could otherwise be used to propel the vehicle forward or recharge its batteries. This is a crucial issue to the PEM fuel cell, typically running at 80°C, the temperature not high enough to use the heat energy in the hydrogen reformer and not low enough not to worry about special packaging of the cell. Running at 80°C, the PEM fuel cell will have to dissipate 20-25kW of power in heat, however, this is still only ½ of IC engine heat loss. (Berlowitz, Darnell 2000)

Using any type of power unit in cars also requires an ability to start up quickly. No one would want to drive a car that would take more than a few seconds to warm up, or use an outside power source for that reason. The development of technology which would allow for a low start-up time of fuel cells is imperative. Since PEM fuel cells are designed to operate at a much lower temperature than other fuel cells, it makes them an ideal choice for fast, lower temperature starting conditions. In their current state, a PEM fuel cell only takes a couple of seconds to start up. However, when a reformer is used, there is a delay time to create hydrogen.

As the fuel cell stack increases the cost of the vehicle, auxiliary and control equipment as well as sensors should help to reduce the overall cost. While no fundamental breakthroughs are necessary in this area, the newly developed equipment should be very efficient to save much-needed electricity and cheap to drive fuel cell vehicles closer to the affordable price range.

2.4.2 Constraints of Fuel Cell Supporting Devices

While fuel cells have a potential of having zero emissions and efficiency of 60-80%, they need pure hydrogen fuel, which is not readily available in nature. The process of making hydrogen brings the total efficiency of the system to the level of a diesel engine and introduces overall CO_2 emissions.

Currently one of the biggest debates over the fuel cells in cars is what fuel would be used on board the vehicle. The possible options are gasoline or diesel, direct hydrogen and methanol. Each fuel has its own advantages and disadvantages in terms of technical constraints and social acceptance.

Gaseous hydrogen sounds like the most logical fuel source for fuel cells. If running directly on hydrogen fuel cells can get up to 80% fuel efficiency and produce no emissions except for water. These are the advantages that are highly advertised. With these potential advantages come significant drawbacks.

Hydrogen as a gas has low energy density per volume, which means the cars would need to have very high pressure or large fuel tanks if hydrogen is to be stored in the gaseous form. (Berlowitz, Darnell 2000) Hydrogen gas, due to its small molecule size also has a superior diffusion property. The tanks have a potential of being very costly, because of the need of special materials that would keep hydrogen from diffusing through the tank walls. Additionally, the material would have to withstand 5000-10,000 psi required to store the hydrogen. (R. Biederman 2003)

To increase the energy density of hydrogen per volume and reduce the size of the tank needed for its storage liquid form of hydrogen could be used. The downside is that either very high pressure or very low temperature (a few degrees above absolute zero) would need to be used to keep hydrogen in liquid form. This would add more complications to the design of the fuel tank. Also getting the hydrogen from gaseous to liquid form would take about as much energy as would be released by using that hydrogen in the fuel cell. Liquid hydrogen is not a viable option for automotive applications.

From the social standpoint pure hydrogen fuel would require totally new distribution infrastructure. Hydrogen refueling stations are likely to work under high pressures or ultra low temperatures. The general public, accustomed to the use of gasoline, diesel or natural gas would have to be educated about the use of hydrogen. Due to all the constraints of the use of pure hydrogen on board of the vehicle, the California Air Resources Board does not consider hydrogen to be a technically and economically feasible fuel for private cars in the near future. (Berlowitz, Darnell 2000)

An alternative to storing the hydrogen on board of the vehicle is producing it right there from liquid fuel. Such operation requires a fuel reformer as a part of the vehicle. Generally accepted hydrogen rich fuels are gasoline and methanol, and hydrides like sodium boro-hydride). The use of these fuels would eliminate the problems of hydrogen storage in the vehicle. However adding the fuel reformer can increase the vehicle's emissions and reduces the overall efficiency. In the following section, issues with usage of methanol and gasoline as fuels for the fuel cell powered vehicles will be described.

Gasoline is a logical candidate as the fuel for the first production fuel cell cars. Using gasoline as a fuel would eliminate all the additional costs of distribution infrastructure, since it is already in place. On the other hand, the use of gasoline for fuel cells will not address problems that need to be solved in order to transition to a hydrogen economy. Most of gasoline reformers will employ the method of partial oxidation, which is highly exothermic.[1] The partial oxidation reactor usually runs at 800-1100°C. Due to the fact that partial oxidation releases large amounts of heat energy, several minutes are necessary for a warm up, which is a major issue in the automotive industry. High operating temperature of the reformer allows use of other fuels like methane, ethanol, methanol, and potentially biomass fuels. Along with advantages, higher temperature reactions also bring complications of heat management. This is likely to make gasoline reformers bigger, more expensive, and complicated. CO emissions from the reforming stage are a concern and therefore another stage would have to be added to further oxidize CO to the CO_2 form, and scrub remaining CO. (Berlowitz, Darnell 2000)

Methanol (CH_3OH) can be converted to hydrogen at relatively low temperature of 250°C.[2] Due to the low temperature of the reaction, methanol reformer is very simple and requires two reaction steps before supplying hydrogen to the fuel cell. Low temperature operation requires little heat management and produces no NO_x emissions.

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[1] POX Reaction: $C_8H_{18} + 4O_2 + 16N_2 \Rightarrow 8CO + 9H_2 + 16N_2 + 659$ kJ/mol
[2] Methanol Conversion Reaction: $CH_3OH + H_2O + 122$kJ/mol $\Rightarrow CO_2 + 3H_2$

Unlike the gasoline reforming reaction of partial oxidation, methanol reformation requires additional heat. This results with start up times of up to 15 minutes, which is unacceptable for a car start-up. A lot of the current research is focused towards addressing this problem. Unique chemical structure of methanol combined with the steam reforming reaction that works exclusively for methanol, the reformer will not be able to run on different fuels like the gasoline reformer based on partial oxidation. (Berlowitz, Darnell 2000)

The issues of methanol infrastructure are not as severe to those of pure hydrogen. Methanol would need completely different infrastructure than gasoline, which would incur a large one-time investment. However the public generally familiar with liquid fuel would not need as much training as with hydrogen, where either high pressure or very low temperatures are likely to be used.

2.4.3 Social Constraints of Fuel Cell Adoption

In the previous sections, we showed that despite all the benefits an immediate adoption of fuel cell technology is unlikely because of a number of technical constraints, However even if technical problems of fuel cells are solved, major customer preparation would be necessary in order to overcome the anxiety and skepticism that surrounds introduction of any new technology and fuel cells in particular.

Safety is a major issue for the customer in every product that enters the market. This is the reason why car manufacturers have to run costly crash tests and all electric appliances have to be certified by a third party (Underwriter Laboratories). In the case of fuel cells, use and storage of hydrogen on board of the vehicle raise safety concerns from the public. American agencies list the story of the “Hindenburg” dirigible catastrophe as the first thing that goes through people's heads when they think of hydrogen. (American Hydrogen Association 2000) On the other hand, the study conducted by Dr. C Graesel from the Muenchen Institute for Educational Psychology shows very little concern about "Hindenburg" among the German public. However, people are aware of hydrogen bombs and about 18% of the public perceives hydrogen as a threat. (Hydrogen.org 2001)

It is clear that the general public should be educated about safety issues. It has been shown that people fear the unknown. New relatively unfamiliar technologies, whose safety has not been extensively studied yet, are often turned down by the general public. Mass media plays a crucial role in popularizing technology. 50 to 55% of information obtained about hydrogen and related technology by the German public was delivered by the mass media. Simultaneously, the media has the power to instill an everlasting fear of hydrogen, just like it has been done with airplane accidents. The vivid reports of spectacular crashes have shaped the views of the public that airplanes cause more deaths than the automobile accidents. (Hydrogen.org 2001)

Preconceived notions about alternative energy transportation have resulted from the introduction of electric vehicles. The environmentally friendly car is synonymous to a small hatchback or sedan that does not have much power, range, acceleration or space. Even though recent introductions of hybrid cars such as Honda Civic and Toyota Prius challenge some of these viewpoints, introduction of these vehicles did not attract the average motorist, who is looking more for comfort, performance or space for the family, rather than low emissions and fuel economy. This discussion comes to the point that people want to see cars that give them the performance, comfort and luxury that they expect from traditional gasoline-powered vehicles. The public needs to see a wide spectrum of cars with alternative fuels to be actively accepting of technology. The introduction of Ford's hybrid pick-up and a hydrogen-powered luxury sedan by BMW, which will have 135kW power output and 215km/h top speed, will help change the views of population in favor of alternative energy vehicles. (BMW Group 2002)

Infrastructure remains the biggest practical concern of potential customers. It has been an issue with any vehicle that uses fuel other than gasoline. Even the familiar diesel engine was not widely accepted in America among the general public because of the lack of diesel fuel at most gas stations for many years. The same problem occurred with early electric vehicles. Limited numbers of recharging stations combined with the low vehicle range slowed down and then virtually stopped integration of EVs into everyday life, except for neighborhood vehicles which are still well received in places like retirement communities.

Developing a hydrogen infrastructure is like a "chicken and egg" problem. Automotive producers cannot introduce hydrogen-powered vehicles on the market, because of a limited number of hydrogen refilling stations that are in place today. At the same time, energy companies cannot afford to build an extensive network of hydrogen stations if there are no hydrogen-powered cars on the roads.

To solve this problem, the new technology might have to use the existing infrastructure of gasoline, diesel or natural gas distribution and then phase-in the hydrogen distribution infrastructure. Making cars that run on multiple fuels proved to be a good approach of introducing a new fuel into the distribution grid. This was the case with natural gas-powered cars that ran on both gasoline and propane. It might prove viable for diesel and biodiesel cars as well as hydrogen and gasoline-powered vehicles that use a slight variation of the existing IC engine to burn both gasoline and hydrogen. After the development of infrastructure initiated by the multi-fuel vehicles, hydrogen-powered fuel cell technology will become more appealing to an average customer. (CNN Europe 2001)

Tied in with inadequate hydrogen infrastructure and range of modern gasoline engines, the range of hydrogen-powered vehicles remains a concern among the customers. Maximum driving range for the current hydrogen-powered vehicles in development is 300-350km, which significantly less than 500-550km with an average gasoline-powered car and even more with diesel or hybrids. Even though the driving range reflects on the consumer's perception of the technology, it is more technical than social problems that are currently being addressed by major manufacturers. (CanadianDriver.com 2002)

Besides technical feasibility and infrastructure, adoption of hydrogen will largely be controlled by the consumers. By correctly marketing towards specific groups discussed earlier, fuel cell technology would stand a better chance against more traditional technology. Early adopters need to be targeted initially, followed by the other groups in turn. Adoption will be largely based upon all three factors, all necessary for a successful adoption.

2.5 Fuel Cell Conclusions

Promotion of fuel cell technology, especially in the automotive sector, is a challenging but crucial task. With deterioration of air quality and depletion of fossil fuels, the issue is of great political, environmental, and economic importance. The primary goal of our project is to raise awareness and explain positive benefits of fuel cell technology to the general public. While many people think that environmental issues are important they are not willing to make a difference actively, particularly if it will cost more. Most people will not buy a car just because it is environmentally friendly. While it is still likely that there will be plenty of gasoline to go around for the next 15-30 years, environmental laws are fairly easy to meet and no special bans for polluting vehicles exist, except in CA, NY, and MA. (ZEV Mandate requires 2-5% of all vehicles sold to be ZERO emission). Fuel economy and environmental concerns will be at the bottom of the list of the average consumer. Such features as safety, reliability, performance and space will be decisive in the purchasing process. If in addition to that, the car will be environmentally friendly and have good fuel economy, great, but it's more of a bonus, rather than a feature that a car would be judged upon by an average consumer. Even though there are groups of people, for whom the fuel economy, low emissions and novel technologies are crucial factors in a purchasing decision, they are not representative of the majority of population.

Consumers that feel comfortable with the product are foundations for future marketing when fuel cell cars become available. Before people decide that they want or need, they first need to understand the benefits such technology as well as have a positive attitude towards it.

From reviewing the reasons of why some products have previously failed in the market, we determined that the failure occurred because the products did not offer an advantage over competing technologies, were not compatible with customer's values, experiences and needs, had a steep learning curve and did not show sufficient benefits. Even though there are no commercial automobiles available to the general consumer in the fuel cell car market yet, we could form a positive public opinion by reiterating the facts that performance, range and space will be similar to those of current gasoline cars. Specific examples and pictures of current cars that employ fuel cells and vehicles that will be developed in the near future would show that fuel cell cars look just like normal cars powered by internal combustion engines. The feeling of familiarity and little adjustment to the new product will be crucial to a lot of consumers. Currently gasoline and diesel cars are considered safe by the public. Hydrogen, however, is “unknown” to average people. Even if they don’t have any preconceived notions about it, lack of knowledge is often regarded as dangerous. Our task is to give people a positive opinion about the benefits of hydrogen and its safety. The issues of hydrogen and fuel cell safety should be addressed by comparison to the safety of gasoline cars. Additional information could be given to the interested public upon request.

Aside from people’s preferences, there are factors beyond our control that have an impact on the development of new technologies and the way the society functions in general. In the parallel technologies section, we did a comparison of fuel cell adoption with the early adoption of gasoline engines in the beginning of the 20^{th} century and the social background and atmosphere at that time that lead to the development and widespread adoption of internal combustion engines. From this section we drew the conclusion that current conditions in society are ideal for further development and use of gasoline engines. Alternative energy engines will not become popular, unless the conditions in the society change. However as it was shown in 1910-20, it is very easy to tip that balance and create a favorable atmosphere for the development of alternative technologies.

Communicating how easy it is to create favorable conditions for the development of the new automotive technologies could help show that fuel cells are not that far in the future. One of the best approaches to gain acceptance of fuel cell technology may be to introduce it in other less demanding areas like residential power systems or for powering portable devices like laptops. Once people become aware of the technology and its benefits, it will be easier to apply to automobiles. Small changes in current social conditions could trigger a massive development of fuel cell technology. Such change could be a steep rise of gasoline prices, oil crisis, enforcement of strict environmental policies or a technological breakthrough that would give fuel cells overwhelming advantage over IC engines.

2.6 Exhibit Information

The end result of this project will be to create an exhibit on the E-Plane, fuel cell technology, their benefits, addressing user issues, and barriers. This exhibit will have limited resources and time for it to get its message across to the visitors. It is very important to understand which type of exhibit will be the most effective and the correct procedure to making it successful. This portion of the literature review will be dedicated to doing just that.

An exhibit is designed to show an audience an idea or physical object with a predetermined purpose. The purpose of the exhibit is to affect the viewer in a predefined way. Exhibits are often considered to be an art form, since there is no established medium to present information. The possibilities for exhibits are limitless, except for imagination, practical skills, technology, physical possibilities, and budget. Exhibitions have been established as successful means of communication in most situations; however, they do have their advantages and disadvantages. (Belcher 37)

The most important and unique aspect of an exhibit is that it is able to create a link between the visitors and physical 3-d objects or services. Other technology such as television, the internet, or any type of print media, when compared to exhibits can only show images, not authentic sources and devices. Exhibits provide controlled physical contact with a real, authentic object that cannot be easily reproduced elsewhere. As a result, the object and viewer are brought together, which helps them experience the object, its surroundings, and benefits completely.

Aside from simply being a visual presentation, exhibits have the ability to put the viewer through a multi-sensory presentation. In addition to viewing, touching, hearing, smelling, and tasting can drastically add to an experience. By stimulating more senses the viewer can have a more satisfying and memorable experience and can enable communication to occur on several different levels. This can increase the number of people the exhibit communicates with since different people find different senses to be more receptive to the transfer of information. In order to stimulate different senses, exhibits have to utilize different forms presentation approaches. Exhibits can take many forms and can include dynamic and static graphics, models of all sizes, hands on material, as well as effects aided by computers and lighting. Underlying themes include the design of color, form, shape, line, texture, and light. (Belcher 38)

Exhibits are usually designed with an open space environment allowing for the visitor to roam around at their own pace. This has an advantage because they can spend more time on topics that prompt their interest and to pass over material that does not. If material is not understood initially, the time is there for the visitor to fully digest what is being displayed. Additionally, visitors are welcome to return at any time if they feel like another visit is needed to complete their experience. (Belcher 39)

Exhibits also have disadvantages. Some exhibits have the tendency to make the visitor feel tired and lethargic. Exhibitors should be aware of this and should try to take measures to help avoid it. Other problems include ergonomic issues that could physically or mentally strain the visitor over time. The most common activity the visitor will do is either looking or reading. All reading material should be easy to access and at correct heights and distances to increase comfort. Also, to help prevent the visitor from becoming mentally tired exhibits needs to encourage and attract them to learn about the exhibit in front of them. (Belcher 40)

The largest variable for an exhibit is the type of people that will come and view the presentation. Each visitor is an individual and will judge the exhibit differently. They bring a wide range of sizes, ages, background information, personal interests, conceptual skills, and sensitivities. Each person will react differently to each exhibit. Through observation and perhaps questioning, learning people's different reactions could become a possibility. This is very valuable knowledge since that information will allow an exhibit to be relevant to a greater number of visitors. (Lewis 120)

The time period that a visitor spends at an exhibit is limited and must be fully utilized. Unless the visitor is extremely interested in the subject matter, the amount of time spent on each part of the exhibit is very short. It is very important for the design of the exhibit to emphasize the most important information to ensure successful transmission of its ideas. (Arminta 36)

Understanding and meeting the needs of the visitor will help ensure transfer of information. Having material for all levels of intellect of the presented topic is very important to meet the needs of everyone. For example, someone who has no background knowledge about fuel cells should be able leave the exhibit knowing the important information about them. On the other hand, someone who is an expert in the subject matter should still be able to find something useful within the presentation. Additionally, it is very important to instill a visitor with the desire and determination to learn more upon departure. Doing this will not only get the message across to the visitor, but he or she will also be more likely to pass the information or ideas on to others. (Arminta 20)

Each exhibit needs to start with a clearly defined purpose. Defining objectives usually precedes the selection of the medium. You must define exactly what you want to accomplish with your exhibit, and then see that all decisions about design, content, and over themes are based upon these decisions. Establishing objectives will clarify planning and will also provide specific guidelines to everyone involved. Your objective should be something that is worth attaining and also capable of being measured. (Konikow, 30)

Being able to communicate your ideas effectively is one of the largest hurdles of having a successful exhibit. Being able to identify your target audience and actually have them listen is extremely important for any exhibit or advertising campaign to be successful. The first step of identifying your target audience determines what kind of action to take in the next steps. A successful exhibit will target the audience that it will have the largest effect on. For example, if most people are completely unfamiliar with fuel cell technology, then the basic fundamentals and benefits should be focused on.

However, if most people are experts on the topic, then the exhibit should focus on advanced material in order to satisfy them. (Kotler 2000)

The following step is to determine the communication objectives, otherwise known as desired audience response. This could be in the form of putting ideas into someone's head, changing an attitude, or getting them to act on something. The most effective process to get the desired response concerning high involvement products, such as an automobile, is to first educate, then gain interest, and finally experience the product. By establishing the most effective process of communication, the exhibit will be much more successful. (Ray 1986)

Once the desired response is identified, the next step in the process is to develop an effective message. The message should ideally gain attention, hold interest, arouse desire, and elicit action. However, realistically creating a message that will carry the visitor from awareness to the action stage is very rare. "Formulating the message will require solving four main problems: what to say (message content), how to say it logically (message structure), how to create it symbolically (message format), and who should say it (message source)." (Kotler 2000)

There are several different paths to choose from when deciding on how to present your message:

- Rational – This method focuses on how your product or idea is more beneficial to the other alternatives. Some ways to prove this are to demonstrate quality, value, or performance.
- Emotional – This method will either use positive or negative emotions to motivate people. Negative emotions such as guilt, fear, or shame tend to work better when they are not too strong and can be backed up with facts or figures. Positive emotions such as happiness, success, humor, or pride can express the same message just in a

different fashion. Neither one nor the other has been proven to work better, however some say positive methods will attract more attention.

- Moral – The method uses the targeted audience's sense of what is morally right. This method can be very successful if it is able to connect to a large amount of people, however, moral beliefs can vary significantly between people. (Kotler 2000)

The message structure heavily depends on whether or not the presentation should have one or two sided arguments. Two sided arguments allow the viewer to reach their own conclusion based on all the facts given. This can be very effective since it has been proven to instill a sense of trust into the viewer. Only giving one sided arguments could be seen as too simple or personal and could lead to the viewer to completely disregard the information. By mentioning the benefits and the shortcomings, the viewer will have the whole picture and will be able to drawn conclusions on their own. Additionally, two sided arguments are more effective with an educated or opposed audience. If the presentation timeframe is relatively short, it will be better to present the benefits first. By presenting the shortcomings first, the viewer might not have time to see the benefits. However, if there is a captive audience, it might be better to do the opposite and end on a positive and encouraging point. (James 1996)

Message format and source can also be very important to present in an exhibit. Formatting such as color use, bold fonts, or even sound can alter the opinions of the viewer. Presentation has to be paid attention to since the viewer will definitely pay attention to how the idea or product is styled. The credibility of the message source often represents trust and expertise. (Kelman 1953) For example, if facts and figures are backed up by well known organizations or people, viewers will accept them more easily.

In addition to well known organizations, non profit organizations are often trusted more often. (Moore 1994)

3. Methods

During the project execution stage, the original plan to display the exhibit at the Sun 'N Fun air show was cancelled. Due to circumstances beyond our control, American Ghiles Aircraft would not fund the booth needed at the Sun 'N Fun air show required to perform the exhibit. This forced us to make immediate changes in order to still have people give feedback on the exhibit and complete the project. Since there was no other air shows in the same timeframe of Sun 'N Fun, the best alternative was to display the exhibit at local college campuses. It was clearly understood that college students and faculty are not a representative sample of the people at Sun 'N Fun, however, due to the situation there was no other viable alternative. The methods and results below represent those of the college campus visits.

3.1 Exhibit

The goal of the exhibit is to communicate information to visitors and receive feedback by having people complete a survey. By analyzing the survey results, the exhibit will be improved so that FASTec will be able to use it in future air shows. By performing a literature review, the specific topics to be presented were established. These topics include safety, basic fuel cell operation, fuel cell applications, advantages and challenges of fuel cell adoption, and how a sustainable hydrogen economy would operate. In addition to these topics, the exhibit is designed to inspire people to do more research on fuel cells, convince people that fuel cells are the "next big thing", and to inform people they have the power to make a change by supporting sustainable development.

In order to present all of this information, the exhibit was constructed out of three large posters, a fully functional fuel cell stack that powered a propeller and a strobe light, a non-functional research fuel cell, and FASTec/E-Plane literature. Pictures of the entire exhibit can be seen in Appendix A.

Safety, being one of the major concerns in the car buying process, has a special place in the exhibit. The purpose of the first poster was to overcome negative preconceived notions about the safety of hydrogen use and establish a positive attitude towards it. The poster is a visual comparison of hydrogen versus gasoline in a safety test performed by Michael Swain of the University of Miami. The test visually describes the side-by-side fuel line puncture and ignition of vehicles based on hydrogen and gasoline. The poster is a timeline of the results to follow. The end result shows that the gasoline vehicle is completely destroyed and that the hydrogen vehicle is relatively unharmed and is able to be driven away after the fuel line puncture is repaired. By comparing to a gasoline vehicle, this gives the viewer something that they will be able to relate to. Poster 1 can be seen in Appendix B.

Given the fact that some of the visitors have never been exposed to fuel cells, teaching them about the basics of fuel cells and their operation was important. Additionally, an emphasis on sustainability was needed for people to realize the benefits of moving to a hydrogen economy. The 2^{nd} poster for the exhibit graphically displays the fuel cell power generation cycle when hydrogen and oxygen are combined in a fuel cell. The viewer is guided from the top of the poster through a five-step process on how hydrogen is created, stored, used with a PEM fuel cell, and what applications can benefit from their use. Regarding applications, a picture of a fuel cell powered SUV was used to educate people that fuel cells can be used in larger vehicles, since people often associate efficient power with smaller cars. The main message of the poster is that when hydrogen is paired with a fuel cell, sustainability can be achieved, unlike when fossil fuels are used. In the poster, hydrogen is created using electrolysis of water that employed electricity from renewable sources such as wind or solar power. To illustrate that hydrogen is an energy carrier and fully recyclable, a large arrow with the standard recycle symbol is used. Poster 2 can be seen in Appendix C.

Another goal of the exhibit is to make people excited about fuel cell technology and to give them information about the status of their development. To achieve this, a 3rd poster that highlighted the key benefits was needed. However, from the literature review, it was found that providing unbiased information is more effective. With this in mind, current fuel cell challenges were also included as to not mislead the visitor. With each listed challenge, solutions and examples of work being done were provided to tell the visitor that the challenges would be solved soon. Most of the focus was placed upon the positive aspects of fuel cell use in order to get people more excited and interested. Having people dwell on the challenges of fuel cells would not have accomplished the purpose of the exhibit; people would not get excited about fuel cell technology and they would not be as interested in doing further research. Poster 3 can be seen in Appendix D.

The color scheme for each poster was carefully chosen. Bright yellow was used in poster 3 to attract a lot of attention to it. For the other two posters, very high contrast was used. In the case of poster 1, using a black background with white text attracted more attention. Additionally, the black background made the explosion images more prominent. Poster 2 primarily used its large amount of images to attract attention. It was decided that a non-white background would detract from the importance of the images that were used.

All three posters were designed using Adobe Indesign, professional page layout software. Images were either created or modified using Adobe Photoshop and Microsoft Word to ensure professional image quality. Because of the very large size of each poster, high quality pictures were needed to reduce pixelization in the final product.

To give people a real world example of fuel cells, a functional fuel cell stack was included in the exhibit. The demo fuel cell provides people with a physical product that they can touch, view, and use. It confirms that fuel cell technology actually exists in the world and is not just theoretical. The setup contains a fuel cell, a bottle of compressed hydrogen, and fiberglass stands for both. The power output is about 12 watts and powers an electric motor and a strobe light simultaneously. Having the power switch on the front proved helpful when some people wanted to have direct control over fuel cell operation. The demo fuel cell clarifies many of the advantages on poster three. Reliability and no emissions are emphasized since the fuel cell provides undeniable proof of possessing such characteristics. Reliability was shown by the fact that the only moving part in the setup was the shaft of the electric motor. Pictures of the demonstration fuel cell can be seen in Appendix E.

The demo fuel cell case was purposely created from clear Plexiglas to allow people to view the inner components of the fuel cell. A high power LED was installed inside the fuel cell to illuminate the fuel cell stack. The switch for the light was located on the outside of the Plexiglas casing allowing people to turn it on and off. In addition to this, a single fuel cell was provided by the WPI Fuel Cell Research Center to give people a more hand on experience with the technology. This helped people conceptualize what fuel cells are and how they work. It provided a physical product that they could directly compare to the fuel cell diagrams on two of the posters. Pictures of the research fuel cell and its components can be seen in Appendix F.

In order to catch people's attention several methods were used. A strobe light was connected to the fuel cell which created a relatively strong flashing light. This proved to be very effective at bringing people over to the exhibit. Also being powered from the fuel cell, an electric motor spinning a model airplane propeller was mounted on the fuel cell case. This was the only moving part on the exhibit and also helped gain people's attention.

The exhibit was displayed in the respective campus centers of Worcester Polytechnic Institute, Assumption College, Worcester State College, and Quinsigamond Community College. The people surveyed at WPI represent a relatively technical population while WSC and QCC were selected because of the older population of students present there as well as more diverse economic background of the public. Assumption students were also chosen because they represent a typical person (not a technology enthusiast. College student and faculty are not representative of the people who would attend an air show, however this was understood and expected before the colleges were visited. This was unavoidable since the exhibit at Sun 'N Fun was cancelled at the last minute. The exhibit for each location was identical to limit the number of variables in feedback received.

Ideally, the information that visitors should retain from the exhibit is safety, basic fuel cell operation, fuel cell applications as well as advantages and challenges of fuel cell adoption. People should leave motivated to do more research on the topic on their own.

3.2 Survey

Aside from popularizing fuel cells and hydrogen, the purpose of performing the exhibit was to receive feedback about the exhibit's content and to find out people's initial reactions to hydrogen and fuel cell use. Each person who viewed the exhibit was asked to complete a short survey. The survey was pre-tested on WPI students, faculty, and staff to ensure its clarity and effectiveness. The purpose of the survey was to see what people thought about hydrogen-powered products and to observe the effectiveness of the exhibit content. People were asked to complete the survey according to their own opinions. Their opinions may or may not coincide with the information presented in the exhibit; the survey measures the effectiveness of the exhibit content. To offer a reward for completing a survey, WPI branded pens were given out. The survey can be seen in Appendix G.

Ideally, we would have liked people to fill out a survey before viewing the exhibit in addition to the one after. This would have allowed us to clearly measure the effectiveness of the exhibit by measuring the difference of people's opinions before and after the exhibit. However, having people fill out two surveys is not feasible due to people's time constraints and their unwillingness to fill out two surveys. By only having one survey, we are unable to isolate how the exhibit influenced people's opinions on certain topics.

The amount of time each person spends at the exhibit is relatively short; therefore the survey had to be limited to a one page maximum. A mixed-mode survey was chosen for several reasons. Multiple choice questions take very little time to complete and they enable us to ask direct questions. Short answer questions were included to allow people to freely express their opinions or concerns regarding the exhibit content. Table 3.4 includes the reasoning behind each question asked in the survey:

Question	Reasoning
Q1	To see if how much people care about emissions when purchasing a vehicle
Q2	To view if people had a preconceived notion about the viability of hydrogen use in vehicles
Q3	To view if people had a preconceived notion about the viability of hydrogen use in planes.
Q4	To see if people initially think of hydrogen as a safe fuel.
Q5	To see if people are actually interested in this technology and if they will find more information on it.
Q6	To see if people associate hydrogen powered cars with poor driving performance.
Q7	To see if people expect hydrogen powered cars to be small in size.
Q8	To see if people actually care about fuel efficiency compared to high driving performance.
Q9	To see the public's reasons for not purchasing hydrogen based products. These reasons should be the main topics of information in the exhibit.
Q10	To see people's initial word association to "hydrogen". Check what portion of population thinks hydrogen is dangerous.
Q11	To see people's initial word association to "fuel-cell".
Q12	To find out what people thought was lacking from the exhibit.
Q13	To allow people to express any other thoughts or opinions.

Table 3.4 - Survey Question Reasoning

4. Data Analysis

During our exhibits we used surveys to get feedback. These surveys provided us with data that would help us improve our exhibit and give more insight to the barriers of fuel cell adoption. 105 representatives from Worcester Consortium Colleges took part in the survey after viewing our exhibit. 77% of respondents were male and 23% female. College representation chart is shown in Figure 4.2.

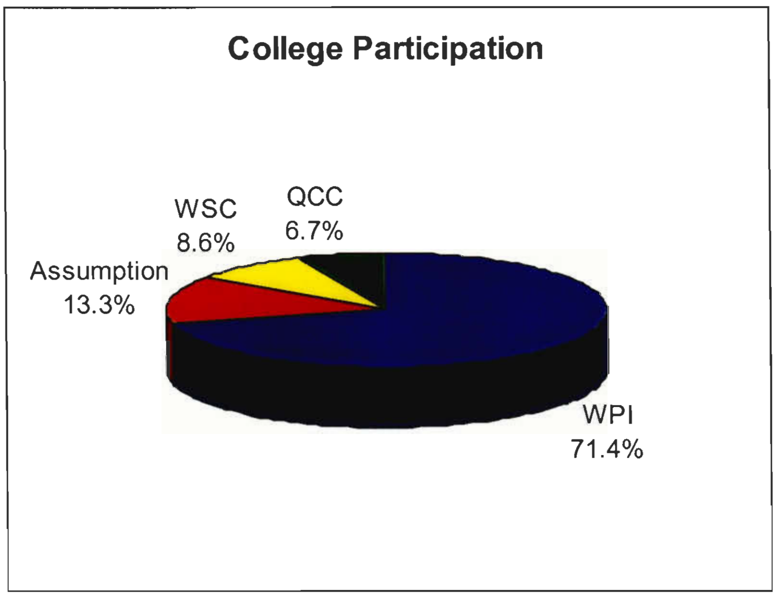

Figure 4.2 – Percentage of College Participants from Worcester Area

Respondents were mostly students (87.6%), although some faculty (3.8%), staff (6.7%) and passers by (1.9%) took part as well. People of the ages 17 through 61 were represented with an average age of 22 with a standard deviation of 2.15 years.

In order to analyze the completed surveys, a standard interpretation had to be developed; this is called coding. The quantitative section of the survey was coded by assigning values of 1 through 5 respectively to the scale of strongly disagree through strongly agree.

Qualitative (free response) questions were coded using categories. By assigning categories corresponding with the type of reply received, we were able to simplify the number of different responses. With this in place, data analysis of qualitative data is possible. The coding criteria used for our survey can be seen in Appendix H.

Safety is thought to be one of the major barriers to fuel cell adoption. However, by analyzing data from our surveys we established that only 12.3% of respondents indicated that safety would be one of the reasons stopping them from purchasing hydrogen-powered products. At the same time, all of these people agreed or strongly agreed that hydrogen is a safe fuel when properly used. 15.4% of this group stated that they associated the word "hydrogen" with various explosions.

From analyzing the responses to question 10, we found out that 27.6% of all respondents associated hydrogen with explosion. Alternately, 96.5% of them stated that hydrogen was safe when properly used. Only 3.5% of people in this category said that safety issues would stop them from buying hydrogen-powered products. This suggests that first association of the word "hydrogen" does not significantly relate to their opinion of the subject matter. Resulting from this, we treat responses to question 10 as data showing just general association as opposed to having serious implications on consumer behavior.

An interesting finding was the fact that all of the people who indicated safety to be an issue stopping them from purchasing hydrogen-powered products agreed that hydrogen was safe when properly used as a fuel. We think this happened because most of the people paid close attention to our safety poster while they were answering a direct question on whether they consider hydrogen to be safe fuel when properly used. At the same time, when answering an open-ended question on reasons stopping them from buying hydrogen-powered products, people wrote the opinion they had before the exhibit.

Only 2% indicated that they viewed hydrogen as unsafe fuel. All of these findings show that most of people do not have preconceived notions against use of hydrogen, and those who do are fairly easy to influence when sufficient proof is shown.

Fuel cells are often popularized as an environmentally friendly solution to the widespread use of fossil fuels. Environmental aspects of fuel cells such as: zero emissions and efficient power generation are often emphasized. In order to be effective, these aspects have to coincide with people's beliefs. Even though our background research suggested that people mostly care about performance and functionality, we still added an environmental aspect to our exhibit for the group of people who felt it was important. To see how large that group was and whether information on the environmental impact was necessary we analyzed responses to the survey. Questions 1 and 8 were analyzed to establish whether people were concerned about fuel economy and if so, whether their concerns were driven by purely economic or both environmental and economic reasoning.

From our analysis, we established that fuel economy mattered to 70.5% of respondents. 54.3% of all respondents stated that both fuel economy and emissions had significant impact on their purchase decisions. This suggests that out of 70.5% of respondents who cared about fuel economy 23% did so because of purely economic reasons and 77% because of environmental impact as well as economic reasons. These results are summarized in Figure 4.3.

These results state that aspects of efficiency and environmental impact of fuel cells would resonate with more than a half of our respondents.

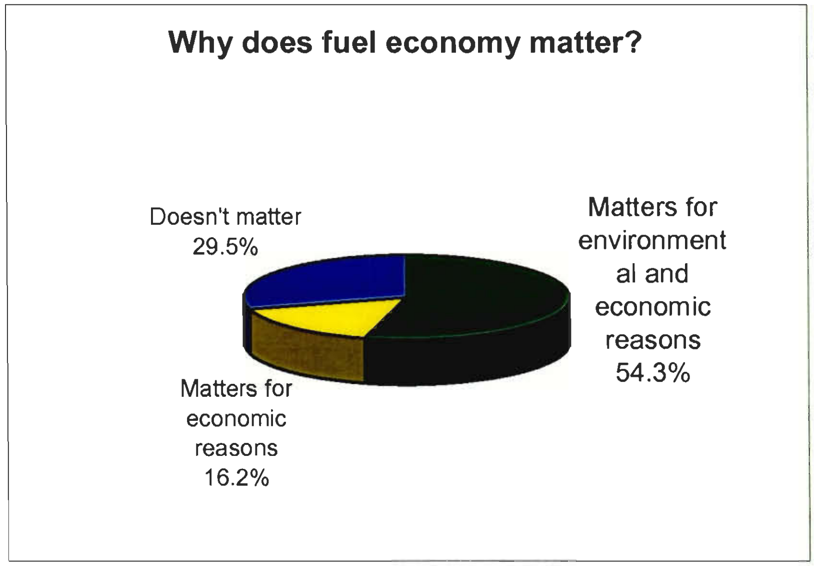

Figure 4.3 - Fuel Economy

The process and effects of hydrogen production sparked people's attention during the exhibit. 20% of respondents indicated that they would like to see more information on commercial production of hydrogen such as cost of hydrogen production, environmental impact, and storage of hydrogen. 23% of people also wanted to see more actual information about hydrogen performance, such as gas mileage, size and weight of fuel cells going into vehicles and power in comparison to internal combustion engines powered by gasoline. 9.5% wanted to see more information on future development of fuel cells, such as big corporations participating in fuel cell research or investing money in it, possible future applications of fuel cells, and examples of long-term programs for fuel cell testing. This information is reflected in Figure 4.4

21% of respondents wanted to see more information on fuel cell cost and list of efforts to make fuel cells cheaper. From analyzing the survey, we determined that cost was the biggest issue (indicated by 54% of respondents) that would prevent people from buying hydrogen-powered products in the future.

The lack of hydrogen infrastructure and possible high cost and low availability of hydrogen would stop 20% of respondents from buying hydrogen-powered products. Only 3.8% of people who completed the survey would like to see more information on infrastructure development. This could be explained that either the information that we provided on the development of hydrogen stations in Europe was sufficient to satisfy the curiosity of most people viewing the exhibit, or the exhibit was too overwhelming. People with little or no exposure to fuel cells might not have had enough time to think about distribution of hydrogen at the time of exhibit.

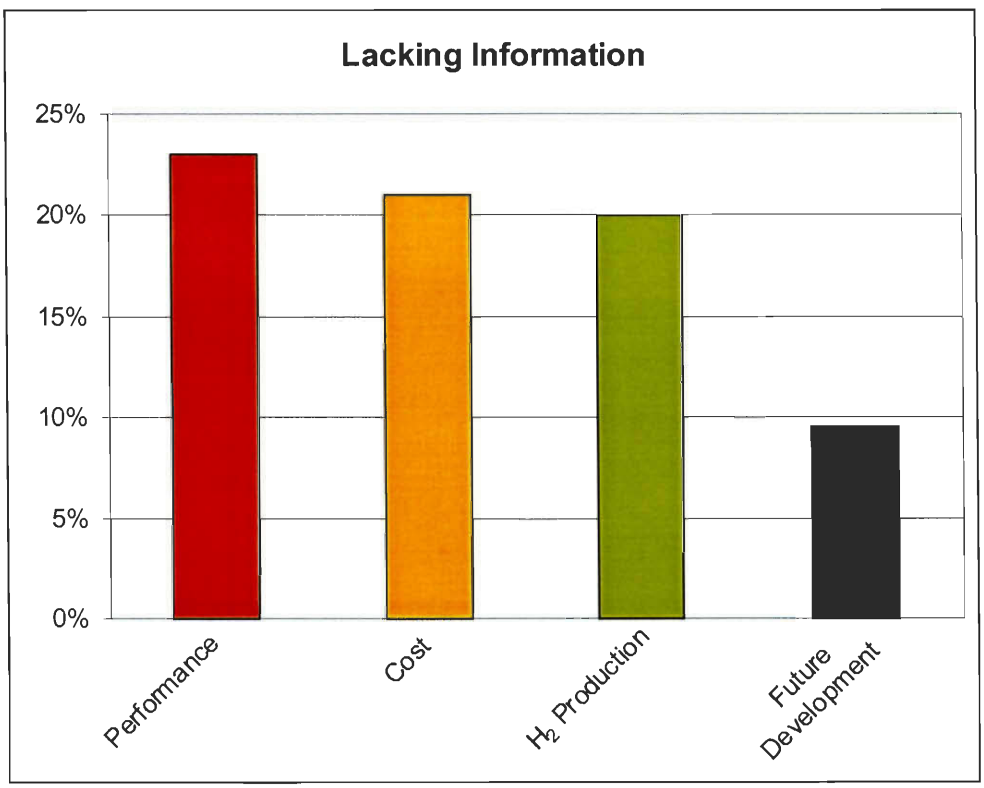

Figure 4.4 – Information People Would Like to See in the Future Exhibits

70.4% of respondents felt that hydrogen-powered vehicles will not be too small for their use. 4.7% indicated the opposite. When it came to performance difference in opinion became much smaller. 50.4% believed hydrogen vehicles would have good performance, whereas 12.3% thought hydrogen-powered vehicles would have poor performance. Correlation of these results can be seen in Figure 4.5. These numbers however might not be representative of the general population because of the specific sample population on college campuses.

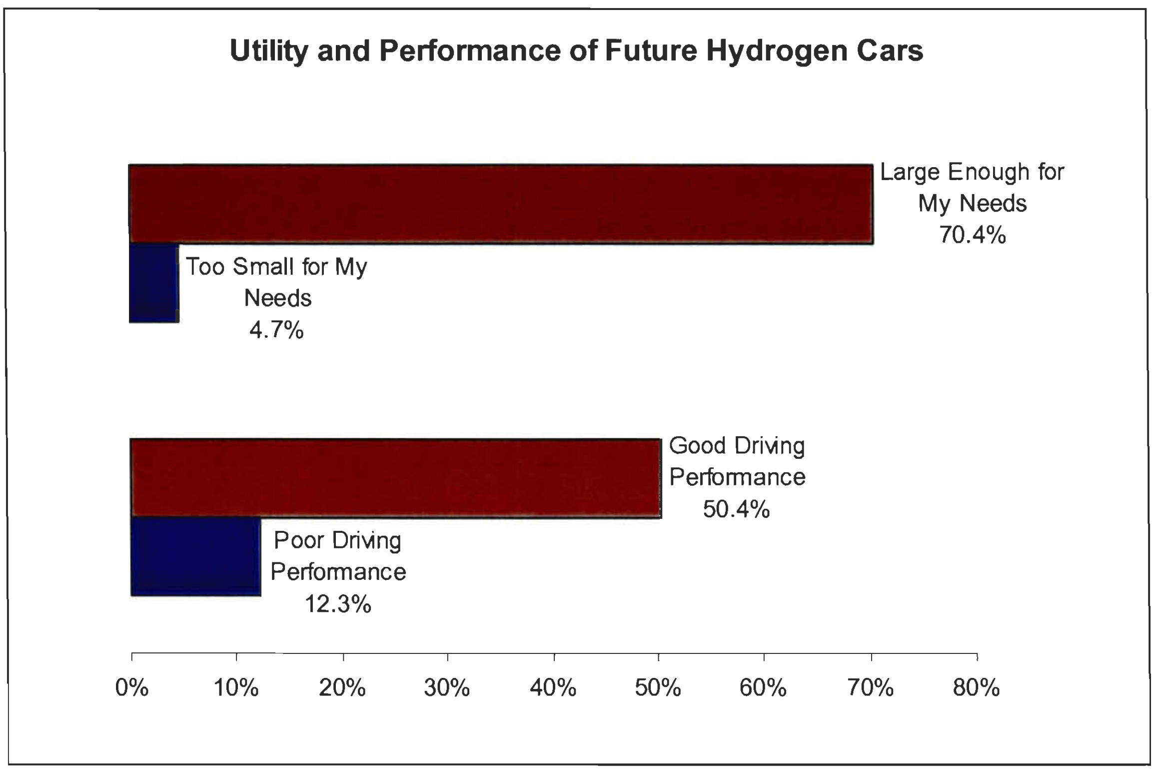

Figure 4.5 – Public Opinion on Hydrogen Car Size and Performance

The major point of the exhibit was to get people interested and encourage them to do more research on fuel cells. As a result of the poll, 51.4% of people indicated they were planning on doing more research on fuel cell development later. This figure however cannot be solely attributed to the effect of our exhibit. Some of those respondents have been already interested in technological development before attending our booth. Using our survey we have no means of measuring the number of people who were actually inspired by our exhibit to do more research. The only way to make that measurement would be to get people's response before and after seeing our exhibit. However, in the early stage of development we ruled out the possibility of designing our survey this way. It wouldn't be feasible to have people who only want to spend 5 minutes on exhibit to fill out a survey before and after.

We established that 85.2% of people who were intending to do more research on fuel cell technology did not have any negative connotation with the words "fuel cell". Their first associations were tied with neutral aspects such as power generation, environmental aspects such as lack of pollution, clean power and fuel efficiency or beliefs that fuel cells will supply the power of the future. This implies that the majority of people who are planning to do more research on fuel cells do not have bad preconceived notions against them.

Most people agree that hydrogen-powered cars will appear earlier than planes with similar technology. Our survey asked people what they thought of feasibility of using hydrogen to power cars and planes. 86.7% of people taking the survey stated that they would eagerly accept use of hydrogen as fuel in cars. Similarly 68.5% of the respondents believed hydrogen was viable fuel for airplanes. Only people who thought hydrogen was viable for use in cars answered that it was viable for the use in airplanes. This finding suggests that most people are ready to accept hydrogen cars as well as planes; however cars would have to be the initial stage of fuel cell application development.

5. Conclusions

Our project focused on creating an exhibit on fuel cells and hydrogen for FASTec. To make a meaningful exhibit, we had to do background research in fuel cell development, consumer behavior, technology adoption and exhibit design. After all the information was gathered and documented, we constructed an exhibit as well as a survey that measured its effectiveness. We were able to determine where the exhibit succeeded and needed improvement. Based on this we were able to make recommendations on improving the exhibit for future use by FASTec. We also came to a number of conclusions about the public perception of hydrogen and fuel cells.

5.1 Exhibit Performance

Studies on public acceptance of hydrogen are often done using a word association method, which asks people to state their first association with the word "hydrogen". From the first associations, conclusions are drawn on whether public viewed hydrogen as an unsafe fuel. For example, if the person thought of a hydrogen bomb or "Hindenburg" when they thought of hydrogen, it was concluded that they were afraid of hydrogen and therefore would be reluctant to use it.

We did a similar test, but also asked 2 other control questions. As a result, we found that the first association with the word "hydrogen" cannot be linked to real world hydrogen use. In our study, the majority of people who associated hydrogen with explosions stated that hydrogen was safe fuel when properly used and safety was not a concern stopping them from buying hydrogen-powered products.

Based on our results, we concluded that most people did not have any preconceived notions against use of hydrogen and the people who did found our poster on safety very helpful and convincing. The combination of colorful graphics, a credible source, and a visual comparison to gasoline was very effective at attracting people and convincing them that hydrogen is a safe alternative to gasoline. Personal discussion and explanation of the nature of hydrogen and hydrogen tanks was necessary to provide more information. Poster 1 combined with knowledgeable exhibit staff would be sufficient to cover issues of hydrogen safety in the exhibit.

Aspects of environment and efficiency that were put into exhibit, despite our background research, proved to be very effective. Almost three quarters of our audience cared about efficiency and more than a half cared about the environment. Additionally, people wanted to see more information on hydrogen production such as its cost, environmental impact, storage, and actual numbers on hydrogen performance such as gas mileage, size and weight of fuel cells going into cars, and power generated compared to gasoline engines.

Summing up the results above, we conclude that the exhibit did not have an adequate amount of information on issues concerning production of hydrogen as well as actual performance figures for fuel cells. This information should be displayed in the next edition of the exhibit. There are several challenges to include this type of information in the exhibit. Both hydrogen production and fuel cell research are at an early stage of development. Just like with any new technology, we cannot provide any information that would get people excited about fuel cells. Hydrogen is still made primarily out of fossil fuels; storage of hydrogen requires extremely high pressures or cryogenic temperatures, fuel cells that are made today are bulky, require very pure hydrogen and are very expensive due to use of noble metals and absence of mass production. As soon as more optimistic data appears it should be incorporated into the exhibit.

Even though infrastructure remains a major concern and our exhibit only briefly covered issues of infrastructure in poster 3, a very small portion of respondents indicated they would like to see more information on infrastructure. From this we concluded that the information presented on infrastructure was sufficient for the exhibit, however if we get more definite information on infrastructure development it should be included in the exhibit. People with limited exposure to fuel cells did not think of the problems of the hydrogen infrastructure. People were too overwhelmed with the amount of information presented to them over 5 minutes spent at the exhibit.

5.2 Exhibit Recommendations

The exhibit that we developed is very effective; however it can be improved significantly to further educate people about fuel cells and hydrogen. To solve the problems we identified above, we recommend that an informational fuel cell brochure should be made. The brochure should include the very basics of fuel cells, frequently asked questions, and references to where people would be able to do more research.

The purpose of the brochure will differ from the posters in many ways. By using posters, people have about 5 minutes to digest the information being presented which impacts people's ability to retain it. Introducing a brochure would allow people to read and understand the information at their own pace. Unlike the posters, the brochure has a greater potential to convey its information since people could look at it for the rest of the day, not just the 5 minutes they spend at the exhibit booth. Additionally, the brochure could be passed on to others which could also increase its exposure.

The brochure would help achieve the goal of having people do more research at home. By including website URLs or the names of journals that contain information about hydrogen and fuel cells, people would not have to memorize or manually write down this information.

With the completion of this project, FASTec now has a working exhibit that they can use at future air shows. Our studies have shown that people are generally very open to the idea of using hydrogen and fuel cells in cars and aviation, at a later date. The exhibit will help deliver their positive message of hydrogen fuel cell use and sustainability. A slightly modified version of the exhibit could be used in high schools with their DOE grant. Due to the fact that our exhibit was tested in an academic setting this adjustment would be easy to make. Our recommendations are practical and achievable and we hope that they could be implemented in the near future.

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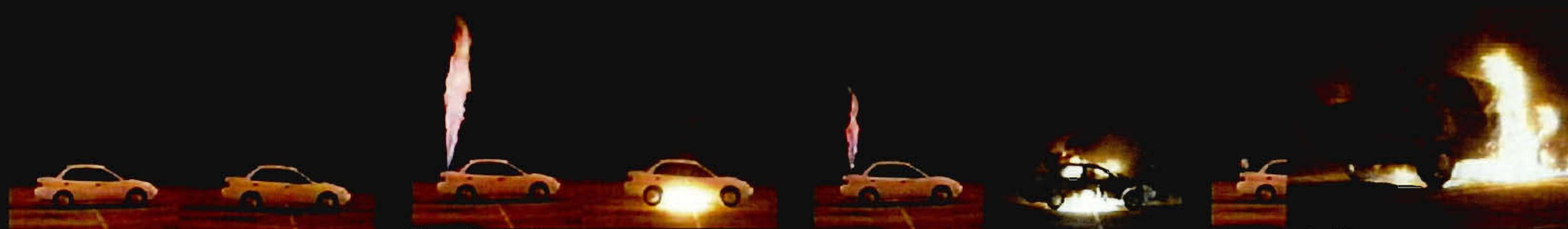
Appendices
Appendix A

Exhibit at WPI Campus Center

Exhibit at WSC Campus Center

Hydrogen vs. Gasoline Safety Test

Performed by Michael Swain of the University of Miami. The fuel lines in both cars were punctured and ignited. The results for the hydrogen (left) and gasoline (right) cars are shown below. After the test was complete, the hydrogen car was able to drive away while the gasoline car was totaled.



Time: 0 min 0 sec
Hydrogen car is on the left. Gasoline car is on the right.

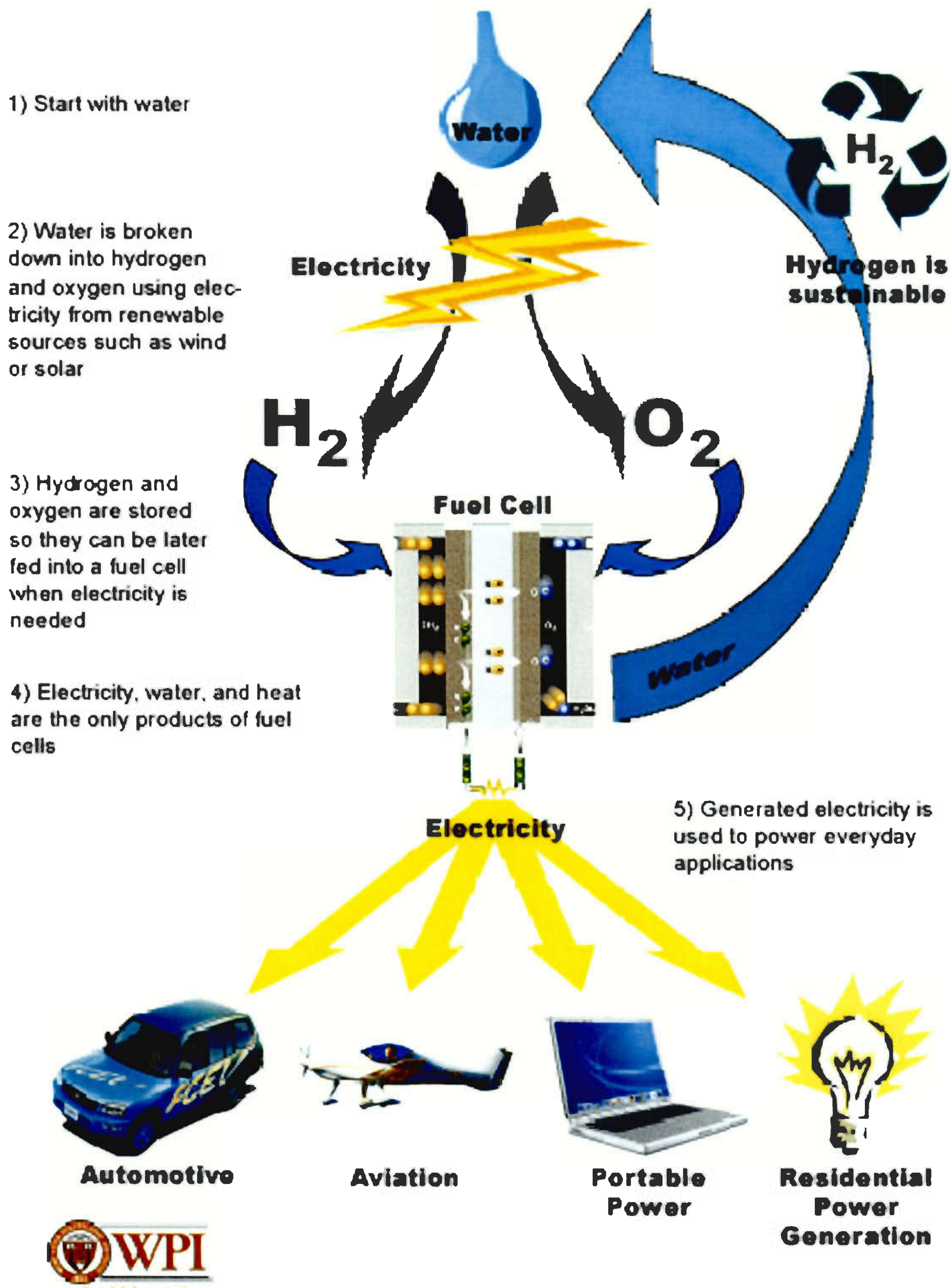
Time: 0 min 3 sec
Ignition of both fuels occurs.

Time: 1 min 0 sec
Hydrogen flow is subsiding. Gasoline car is in heavy flames.

Time: 1 min 30 sec
Hydrogen flow is almost finished. View of the gasoline car is expanded on the right.

Appendix C

Fuel Cell Power Generation Cycle

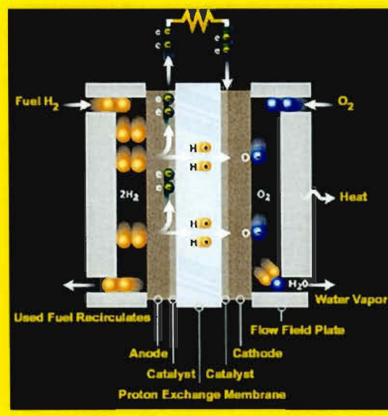


Appendix D

Fuel Cells Today

Advantages

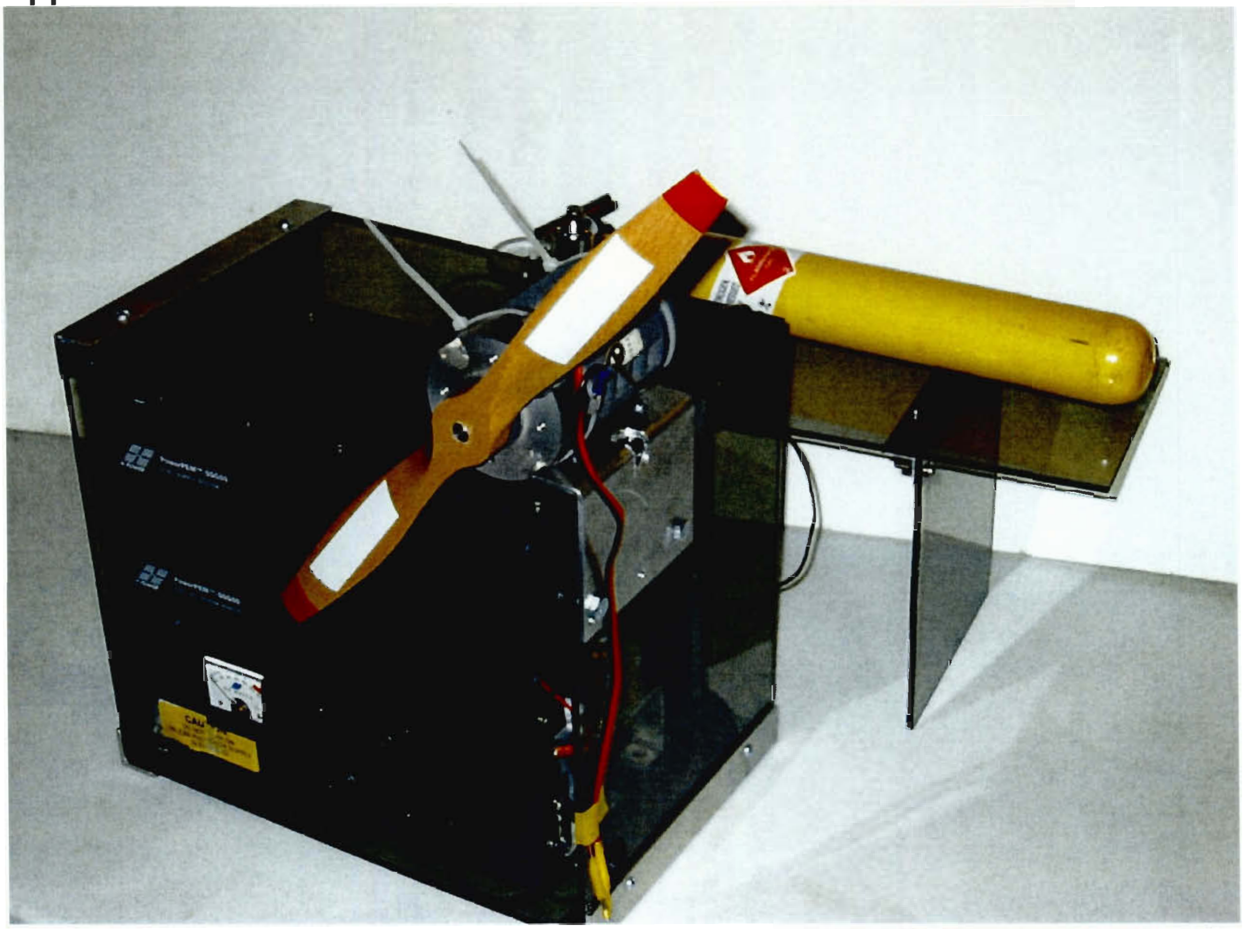
- Environmentally Friendly
  - Sustainable development
  - Zero pollution
- Reliable
  - No moving parts
  - Low heat
- Quiet
  - No combustion
- High Efficiency
  - Up to 60%
  - Potential to improve
- Supported by Government and Automobile Manufacturers
  - $1.2 Billion allocated for fuel cell development



Challenges

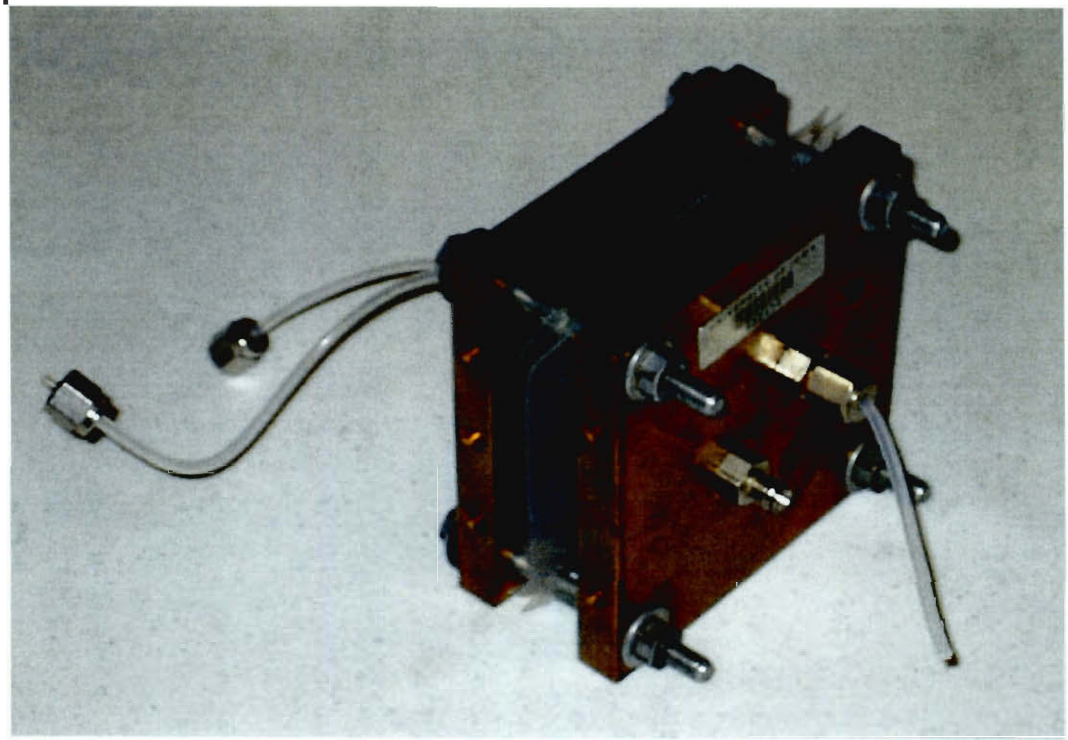
- Infrastructure
  - H_2 station in every European capital by 2005
- Cost/Availability
  - Will become cheaper when mass produced
  - Cheaper catalyst material in development
- Public Acceptance
- Technology Performance
  - Driving range is improving
  - Efficient hydrogen storage methods are being researched

Appendix E

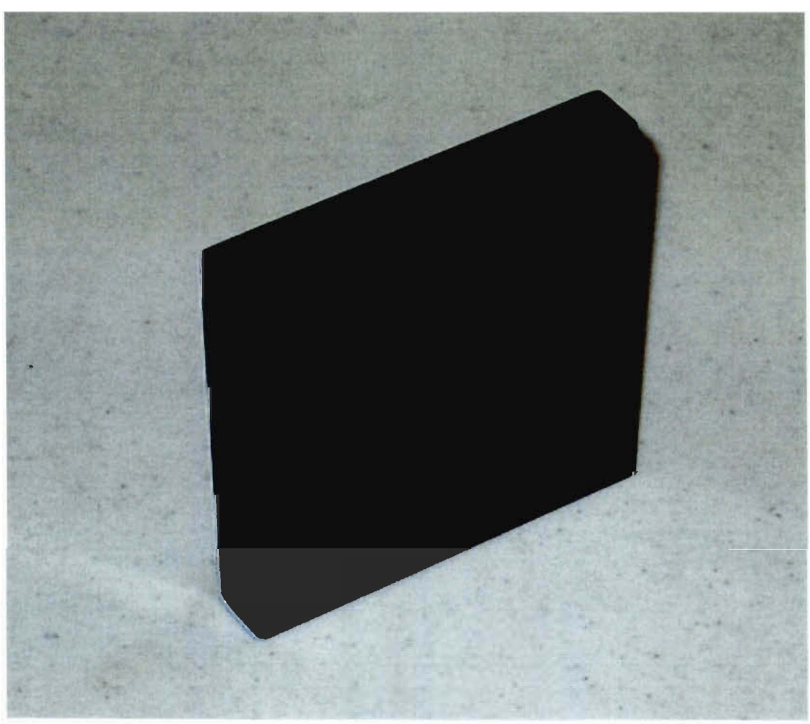


Demonstration Fuel Cell with Casing

Appendix F



Research Fuel Cell



Fuel Cell Graphite Plate

Appendix G

FASTec and Worcester Polytechnic Institute Student Fuel Cell and Hydrogen Survey

This survey is part of a project being conducted by WPI students and FASTec to understand attitudes towards fuel cells. The survey is anonymous. The information gathered will be used to improve our future exhibit on hydrogen and fuel cells. Please take the time to fill it out and feel free to ask questions at any time. Thank you for helping us graduate!

Please circle the option that best describes your opinion:

Emissions will be an important factor in my next vehicle purchase	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Hydrogen is a viable fuel for vehicles	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Hydrogen is a viable fuel for planes	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Hydrogen is a safe fuel when properly used	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am interested in fuel cells and plan on doing more research in the near future	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Vehicles powered by hydrogen will have poor driving performance	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Vehicles powered by hydrogen will be too small for my needs	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Fuel economy doesn't matter as long as my vehicle has high performance	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Please give short answers to the following questions:

- What would be reasons stopping you from purchasing a hydrogen powered product?

- What is your first reaction to the word "hydrogen"?

- What is your first reaction to the word "fuel-cell"?

- What issues about hydrogen and fuel cells would you like to see clarified?

- Please feel free to add any comments and suggestion

This is anonymous data that is collected for classification purposes only.

Age: ____ Gender (Circle One): Male Female

Occupation (Circle One): Student Faculty Staff Other:________________

Appendix H

Q1-Q8

- 1 = Strongly Disagree
- 5 = Strongly Agree

Q9: What would be reasons stopping you from purchasing a hydrogen powered product?

- Cost
  - Price
- Performance
  - Size (car, fuel cell)
  - Efficiency
  - Range
- Safety
- Reliability
- Infrastructure
  - Availability
  - Fuel cost
  - Convenience
- Accepted
  - Not proven by time
  - Not traditional
  - Not developed
  - Not available
  - Needs to be tested more
- Information
  - Don't know enough information
  - Need more education
- Environment
  - Pollution caused by hydrogen production

Q10: What is your first reaction to the word "hydrogen"?

- Explosion
  - Bomb
  - Hindenburg
  - Blimp on fire
- Future
  - Next big thing
  - Alternative fuel
  - Exciting
- Environment
  - Clean
  - Efficient
- Neutral
  - Chemistry
  - Light
  - Zeppelin
  - Other

- Information
    - Don't know enough information
    - Need more education

Q11: What is your first reaction to the word "fuel-cell"?

- Environment
    - Clean
    - Efficient
    - Pollution
- Neutral
    - Power
    - Other
- Future
    - Next big thing
    - Alternative fuel
    - New energy
- Skeptical
    - Will never catch on
    - Large size/weight
    - Too expensive
    - Is it feasible?
- Cost
    - How much a fuel cell would cost
- Information
    - Don't know enough information
    - Need more education

Q12: What issues about hydrogen and fuel cells would you like to see clarified?

- Reliability
    - Lifespan of fuelcells
- Fuelproduction
    - Cost of hydrogen production
    - Supply of hydrogen
    - Effects of producing hydrogen
    - Is hydrogen the best fuel for fuel cells?
    - Storage of hydrogen
    - Energy conversion issues
- Renewable
    - Pollution
    - Environment
- Operation
    - How do fuel cells work?
- Challenges
    - Why aren't fuel cells widely used
- Performance
    - Efficiency (mpg)
    - Size/weight
    - Power

    - Energy generated
    - Comparison to gasoline
- Timeframe
    - When will fuel cells be available?
- Cost
    - How to make fuel cells cheaper?
- Infrastructure
    - Gasoline to hydrogen conversion
- Safety
- Development
    - Corporate Acceptance
    - Applications
    - Time tested
- Future
    - Long-term effects