FUEL CELL EXHIBIT FOR THE NATIONAL MUSEUM OF SCIENCE & INDUSTRY

An Interactive Qualifying Project

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By

Timothy Dresser

Timothy Dresser

Andrew Jeas

Andrew Jeas

Bentley A Kern

Bentley Kern

Jason Walonoski

Jason Walonoski

Approved:

Chrysanthe Demetry

Professor Chrysanthe Demetry

Richard Vaz

Professor Richard Vaz

1. Fuel Cells
2. London
3. Science Museum

Abstract

The goal of this project was to deliver a prototype exhibit on fuel cells for the Science Museum in London. Our preliminary research included an overview of fuel cell technology, museum exhibit design, and surveying. In the design of the prototype, the museum public was surveyed on their interests in the applications of energy and for feedback on the exhibit. Additionally, the project team provided recommendations to the Science Museum for both virtual and physical exhibits on fuel cells.

Executive Summary

Fuel cells have the potential of revolutionising the way that we use and think about energy. As supplies of non-renewable energy sources dwindle on Earth, it is becoming more and more important that we look ahead for alternatives to the way we get and use our energy. The National Museum of Science and Industry in London is currently in the process of designing an Energy Gallery, which will be constructed in 2001. The museum requested a computer-based prototype exhibit on fuel cells, which will be a feature in the Energy Gallery section of the museum's web site. This has not limited the scope of the exhibit's design; our team has constructed a computer-based exhibit, which can be used both on the Science Museum's web site and within the museum gallery.

The goal of our team was to complete and present a user-friendly computer-based exhibit on fuel cells to the Science Museum, and to provide recommendations on the design of aspects of the larger physical exhibit within the Energy Gallery. Fuel cells are a very complex and technical subject; therefore, it was an objective of our team to create an exhibit that presented this technology in a way that could be understood by the layperson. Specifically, we aimed to create an exhibit that would appeal to a young audience, between the ages of 7-14, while at the same time providing more in-depth content that a diverse audience could benefit from. Another objective of our team was to design a web site that could be easily adapted to a touch screen and placed on gallery within the Science Museum.

The design of our exhibit is the final product of several methods of research. The content of our exhibit has been derived from many sources, which include textbooks, magazine articles, journals, and reputable World Wide Web sites. Our team also utilised two different methods of surveying museum visitor opinion. The first method was in the form of a museum interest survey, which served to gauge which applications and elements of energy interested museum visitors the most. We administered surveys face-to-face to 71 museum visitors of both genders and a wide range of ages and received a 90 percent response rate. One consideration from our team was that the limited number of interest surveys did not establish any concrete trends, but did provide an indicator of various interests within gender and age groups. Our second survey method gathered feedback and evaluation of our exhibit from museum staff and visitors. Feedback was collected from 6 staff members and 40 patrons, which allowed our team to revise the content and appearance of the exhibit in a way that would be appealing to the museum-going public. Overall, it was observed from the feedback process that our exhibit had a favourable reaction from every age group tested, and that the appropriate messages about fuel cells were getting conveyed.

Our final exhibit employs a cartoon theme in order to make it appealing to a young audience. This theme also serves to relate several key concepts about fuel cells to the user by associating cartoon representations of nature, fuel cells, and non-renewable energy with a virtual family. The exhibit is divided into four main sections: *Meet the Characters*, *Fuel Cells and You*, *Fuel Cells and Nature*, and the *Fuel Cell Challenge*.

The *Meet the Characters* section introduces the cartoon characters *Captain Fuel Cell, Old Fossil*, *Nature*, and *The Smith Family*. *Captain Fuel Cell* was created to represent fuel cell technologies and embodies the clean and efficient method that fuel cells use to produce energy. *Old Fossil* is the villain element of our cartoon, and is representative of non-renewable energy sources. The third character, *Nature*, represents the interests of the environment. The final character, *The Smith Family*, is composed of four different individuals: a father and mother figure, and a young boy and girl. The concept of having an entire family was implemented so that both male and female children and adults could identify with a character. Each family member has his or her own interests, so that we could relate the different applications of fuel cells to them and subsequently to our audience.

The *Fuel Cells and You* section describes four different applications of fuel cells and an explanation of each. This is also where different applications are linked with the interests of the characters in *The Smith Family.* Each section has multiple layers of information, so whoever uses the site has the option of learning more by clicking a button at the bottom of each subsection's screen. *Fuel Cells and Nature* was designed in a similar fashion, except that instead of relating fuel cells directly to people, this section relates fuel cells to the environment and describes how fuel cells can benefit the world. This also indirectly relates fuel cells to people, since benefits to the environment can been seen as benefits to humankind.

The final section, *Fuel Cell Challenge*, is an interactive quiz game that was designed to reinforce the concepts and messages of the exhibit. The quiz game consists of 10 multiple choice questions that cover many of the main points within the exhibit, and promises the reward of "saving the environment" upon correct answer of all 10 questions. A correct answer within the game brings the user to a screen where his or her response is reinforced with a statement about the answer, while a wrong answer provides a screen with a hint for that particular question and an opportunity to try again.

Our team has made several recommendations to the Science Museum that are relevant to our exhibit. Early in the construction of our computer-based exhibit we realised it had great potential to be more than just another feature in the Science Museum's Energy Gallery web site. Therefore we recommended that our exhibit be adapted so that it can be used with a touch screen display and placed on gallery in the Science Museum. Such a display takes up a very small amount of room and would allow patrons without Internet access to enjoy this exhibit and learn about fuel cells.

In the end, all of our design decisions led to the implementation of an innovative and unique web-based exhibit on fuel cells. As far as we know, our exhibit is the first of its kind in its style and medium of presentation and content, and is on the forefront of the exhibition of fuel cells.

Our project team has submitted our exhibit, findings, and recommendations to the Science Museum for its approval. We would like to acknowledge both Claire Bonham-Carter and Sophie Duncan, who have been a valuable resource during our term in London. We would also like to thank rest of the Science Museum and its staff for their feedback on our exhibit and allowing us to use their facilities for our project.

Authorship

Abstract

Author: Bentley Kern
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Bentley Kern
Editor: Jason Walonoski, Andrew Jeas

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Author: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Bentley Kern
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Bentley Kern
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

2.3 Types of Fuel Cells

Author: Timothy Dresser
Editor: Timothy, Andrew Jeas, Bentley Kern, Jason Walonoski

2.4 Modern Applications of Fuel Cells

Author: Andrew Jeas
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

2.5 Museums and Exhibit Design

Author: Jason Walonoski
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

2.6 Surveys and Data Analysis

Author: Bentley Kern, Jason Walonoski
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

3. Design Process

Author: Andrew Jeas, Bentley Kern, Jason Walonoski
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Bentley Kern
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

Appendix A – The National Museum of Science and Industry

Author: Jason Walonoski
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Timothy Dresser
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski
Editor: Timothy Dresser, Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Bentley Kern
Editor: Andrew Jeas, Bentley Kern, Jason Walonoski

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Author: Jason Walonoski
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Author: Andrew Jeas
Editor: Andrew Jeas

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1. Introduction

With the world's supply of fossil fuel dwindling and concerns over alternative energy sources such as nuclear power persisting, it is becoming increasingly apparent that the world will need new sources of energy for the future. One technology that may be a solution to these energy needs is the fuel cell. Fuel cells, which are largely unknown to the public, have been viewed by some as a way of transforming how we as humans use and think about energy. The goal of our project is to deliver a web-based exhibit on fuel cells and to provide recommendations on the construction of a physical fuel cell exhibit for the National Museum of Science and Industry's new Energy Gallery.

Fuel cell technology has been in existence for over 160 years, but it was not until the last half of the twentieth century that the technology evolved to the extent such that fuel cells became a viable alternative source of energy. A fuel cell is a simple device that operates in a similar manner to a battery, except that its fuel source is renewable. A fuel cell consists of two electrodes with an electrolyte in the middle; oxygen passes over one electrode while the fuel source, often hydrogen, passes over the other resulting in a chemical reaction that produces electricity. Unlike sources of power generation such as combustion engines and nuclear driven turbines, fuel cells do not produce any harmful emissions – only heat, water, and a small amount of methane. In addition to being environmentally friendly, fuel cells are also very efficient. Compared to conventional combustion based power generation which can be no more than 20% efficient, fuel cell power generation can be as much as 80% efficient.

This exciting technology has the potential to revolutionise how the world gets its energy in the future. The National Museum of Science and Industry requested that we design a web-based exhibit on this emerging technology for the new energy gallery under development. This gallery will showcase many different sources of energy and how energy technologies have impacted individuals and the environment on a global scale. There are a number of communication challenges inherent in museum exhibitions that are complicated by the highly technical nature of topics such as fuel cells. Therefore, the museum plans to utilise innovative methods of exhibit design throughout the gallery to communicate this information to the museum-going public in an effective manner.

Our project team concentrated on designing a web-based interactive exhibit and also on making suggestions for a physical exhibit on fuel cell technology. Before we designed the exhibit, we conducted a survey of museum patron interests to gain a better understanding on what aspects of energy the museum patrons were most interested in. With this information, we designed the exhibit more thoughtfully by tailoring its contents to the interests of the Science Museum's audience. Additionally, we employed thematic elements in our exhibit design by creating a cartoon theme to associate fuel cells with the museum visitor. We tested our exhibit with the museum staff and visitors in order to obtain feedback, which was used in revision of the exhibit. In designing and revising the exhibit, we employed computer graphics, multimedia, and web design software packages, as we found through our research that these tools would help us to effectively communicate with the user and facilitate our design process.

In the end, all of our design decisions led to the implementation of an innovative and unique web-based exhibit on fuel cells. As far as we know, our exhibit is the first of its kind in its style and medium of presentation and content, and is on the forefront of the exhibition of fuel cells.

2. Literature Review

The following literature review contains all of the relevant information that was found in researching a variety of areas found necessary for conducting this project. The subject matter is broken down into four main areas of information: fuel cells, modern museum exhibition design, surveying, and interviewing. The background information on fuel cells comprises of an introduction to fuel cells, history of fuel cells, the chemistry of how different types of fuel cells operate, and their practical applications in the world. Information on modern museum exhibition design provides an overview of museums and details about modern exhibit and web-based design. Information on surveying provides guidelines on how to design and administer surveys as well as how to analyse the resulting data, which can be useful in describing our audience. Similarly, information on interviewing, appropriate for evaluation of our final exhibit, discusses the advantages of using interviewing as a research tool.

2.1 Introduction to Fuel Cells

Fuel cells have been in development since their invention in 1839. Unlike other means of power generation such as the combustion engine or the steam turbine, the fuel cell has not seen large-scale attempts at commercialisation until the last decade of the twentieth century.

2.1.1 Advantages of Fuel Cells

Fuel cells hold many advantages over some of the conventional methods of power generation in use today. Since fuel cells are a virtually clean energy source, they are much more attractive forms of power generation than some of their more polluting counterparts. As the world becomes more industrialised, there are greater needs for clean and efficient sources of energy. Fuel cells have the potential for filling these needs over the coming decades. (National Fuel Cell Research Center).

Fuel cells have several advantages over methods of energy generation that exist today. The internal combustion engine in a vehicle, for example, uses fuel in loud and high temperature explosions to generate the energy to move it. This burning of fuels additionally results in the release of harmful chemical emissions into the environment. Since fuel cells are electrochemical, meaning that they convert chemical energy directly into electrical energy, they are a much cleaner and efficient energy source (Los Alamos National Laboratory).

Another advantage of fuel cell energy is that it is more versatile than many other energy sources because its power output can be easily varied. Since the output of the fuel cell is directly proportional to the amount of energy produced by the reaction between the fuel and oxygen, by changing the amount of fuel introduced, the output of energy also changes. Another way to adjust the amount of energy that a system produces is to change the amount of cells in the system. Fuel cells are modular in that individual cells can be added or removed easily to change the net power output (Blomen 237).

It has been estimated by the World Bank that nearly one billion people in the world are exposed to severe air pollution, resulting in over 700,000 deaths annually. The growth in the number and size of vehicles on the road, combined with an increase in the number of miles travelled each day, has contributed to this problem. The Environmental Protection Agency has estimated that nearly 78% of carbon monoxide emissions, 45% of nitrogen oxide emissions, and 37% of volatile organic compounds can be attributed to motor vehicles alone; these emissions comprise around 25% of greenhouse gases (Los Alamos National Laboratory).

Man-made greenhouse gas emissions have been added to the atmosphere on a large scale since the beginning of the Industrial Revolution, an increase due mostly to the burning of fossil fuels. Carbon dioxide, which makes up only a small amount of the earth's natural atmosphere, is among the largest waste products today. The consumption by motor vehicles of only one gallon of gasoline produces nearly 25 pounds of carbon dioxide. This rate of emission has resulted in a rise of 280 parts per million of carbon dioxide in the atmosphere for an overall total of 360 parts per million since the beginning of the Industrial Revolution in 1765. In addition, the concentration of methane has nearly doubled during the same period. These increased concentrations of greenhouse gases trap more radiation in the lower atmosphere, and some experts believe that this has led to an overall one degree Celsius increase in the average temperature on Earth. Many believe that this global warming on Earth has caused melting in the polar icecap region and has harmed ecosystems around the world (Los Alamos National Laboratory).

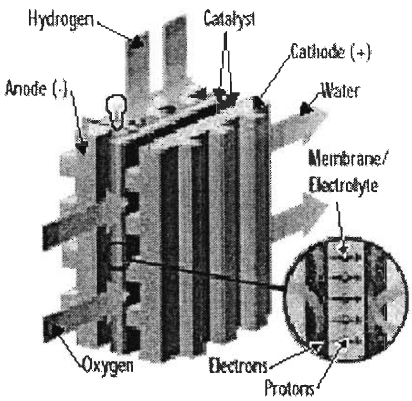
The widespread adoption of fuel cells into the world market could drastically reduce pollutants in the air and water. The United States Department of Energy has predicted that "if a mere 10% of automobiles nation-wide were powered by fuel cells, regulated air pollutants would be cut by one million tons per year and 60 million tons of the greenhouse gas carbon dioxide would be eliminated" (Breakthrough Technologies Institute).

In addition to environmental and health benefits, there are several economic advantages that fuel cells present. A projection by the Arthur D. Little consulting firm outlined several of the following economic advantages. First, oil imports in the United States could be cut by nearly 1.5 million barrels per day if only 20% of vehicles were powered by fuel cells, leading to a reduction in the trade deficit. Second, fuel cells could also create new markets for materials such as steel and products such as electronics and equipment. This alone has the potential of supplying thousands more jobs. It was predicted that 800,000 jobs would be created if only 20% of vehicles were powered by fuel cells (Breakthrough Technologies Institute).

2.1.2 General Chemistry of Fuel Cells

In comparison to other alternative energy sources such as wind and hydroelectric, the operation of fuel cells is harder to conceptualise. These other methods are similar to conventional fossil fuel power generation facilities in that they still employ turbines to generate electricity, except instead of employing combustion to make steam, which in turn propels the turbines, another source is used such as water or wind power. A fuel cell is quite different; it is an electro-chemical device that utilises a chemical reaction between a fuel source and oxygen to produce electricity. The closest analogy to a fuel cell is a battery which also is an electro-chemical device utilising a chemical reaction to produce electricity. However, there are some important differences that make fuel cells more advantageous. The most important one is that fuel cells are a renewable fuel source; unlike a battery, which becomes useless when depleted and must be disposed of, the fuel source of a fuel cell can be refilled. Because of this, it will continue to provide electricity so long as fuel is supplied to it (Breakthrough Technologies Institute).

Simply stated, a fuel cell is comprised of two electrodes with an electrolyte in between. Fuel, most often hydrogen, is supplied to the anode of the fuel cell while oxygen is supplied to the cathode. The fuel cell combines the molecules of the fuel and oxygen in a chemical reaction to produce electricity. The only emissions of this process are heat, water and a small amount of methane (Breakthrough Technologies Institute). This is a significant difference when contrasted with the harmful emissions produced by combustion of fossil fuels (National Fuel Cell Research Center). A simple diagram of a fuel cell can be seen below in Figure 1.



Fuel Cells – Green Power, Los Alamos National Laboratory

FIGURE 2.1.1 – FUEL CELL DIAGRAM

2.2 History of Fuel Cells

Since its invention, the fuel cell has been through nearly 160 years of development and improvement by several individuals since 1839. Although the commercial potential of fuel cells was not realised for nearly 100 years after invention, many physical chemists and inventors took the fuel cell to new levels of efficiency in hopes that it would eventually become a viable source of power generation.

2.2.1 The First 100 Years

The fuel cell was invented by William Grove of Great Britain in 1839. Grove's invention, a hydrogen-oxygen sulphuric acid fuel cell, was first described in Philosophical Magazine in late 1838. Grove made many improvements upon his fuel cell, including coating the electrodes with a special substance to improve chemical efficiency (Ketelaar 19-20).

In 1889 Charles Mond and Ludwig Langer made significant improvements upon Grove's hydrogen-oxygen fuel cell by creating electrodes using thin perforated platinum foil in addition to a change in the composition of the electrolyte. At this point, both Mond and Langer calculated the efficiency of the fuel cell to be "50% of the heat of combustion." Still another important advantage was recognised by Wilhelm Ostwald, a physical chemist, who recognised in 1894 the efficiency and environmental advantages of producing electricity from fuel cells (Ketelaar 21).

During the latter part of the first 100 years of fuel cell development, many of the improvements to fuel cells were made by E. Baur, a professor of physical chemistry at Zurich, and his students. In several experiments, they claimed to have shown that the construction of stable and powerful fuel cells was possible. Still, though, there was much doubt as to the economic viability of fuel cells. Baur continued his modification of existing fuel cells, performing experiments by changing the chemical makeup within a fuel cell as well as with the fuel itself, and publishing his results. In a final review of his work and of the previous 100 years of fuel cell development, Baur stated, "electric energy with a high efficiency from the heat of combustion of a fuel had not been reached." In the last sentence of Baur's review, citing that hope should not be given up on further development, he stated that "...even when in the end only 50% of the combustion energy of the fuels could be delivered as electric energy at the switchboard of the fuel cell power plant it would be a revolution in the energy economy of the world" (Ketelaar 26).

2.2.2 The Next 60 Years

From 1937 to 1959, F. T. Bacon, an engineer for C. A. Parsons and Co. Ltd., made considerable improvements in the efficiency of the fuel cell, as well as achieving lower temperatures within the fuel cell for the chemical reaction. Sponsored in 1956 by the National Research Development Corporation, Bacon created a fuel cell that delivered 6 kW of electrical power and could be used for both a forklift truck and for welding (Ketelaar 27).

E. W. Justi of the Technical University at Braunshweig, Germany, began his fuel cell research in 1948. Justi's studies were conducted mostly using an alkaline fuel cell, and with A. Winsel he created a battery which was only slightly less in power volume per density than Bacon's. Further development of the alkaline fuel cell was continued because it did not require noble metals, which are expensive and rare, for electrodes (Ketelaar 29).

After 1950, several new types of fuel cells were developed to meet the needs of specific applications and to improve efficiency. The molten carbonate fuel cell, first researched by J.A.A. Ketelaar and G. H. J. Broers, had impressive advances in efficiency and life of the battery. Much of this development in the molten carbonate fuel cell can be attributed to United Technologies and Energy Research Corporation. In a government-sponsored project known as "Moonlight" in 1981, Japanese companies such as

Mitsubishi Electric, Fuji, Hitachi, and Toshiba worked to develop a battery with an even longer operational life than had been achieved before (Ketelaar 30-31).

The solid oxide fuel cell was initially developed by Baur and Preis in 1951. A truly electrochemical cell, the solid oxide fuel cell was taken on by Westinghouse Electric in 1958. The American Gas Association and United Technologies Corporation (UTC) introduced the phosphoric acid fuel cell in 1967. Through much development, UTC was able to create fuel cell units capable of generating 4.8 MW of power. The solid polymer fuel cell was developed by General Electric for use in NASA's Gemini space missions. While these fuel cells were used to power much of the electronics onboard the spacecrafts, no other true application of this fuel cell has been found (Ketelaar 32).

A significant development in the field of fuel cells was the methanol fuel cell. These fuel cells were envisioned for applications in vehicles since methanol is much cheaper than other fuel alternatives such as hydrogen. This type of fuel cell could take in methanol without any kind of processing and produce electricity. Research in this area was taken on by several companies including Hitachi in Japan, as well as Shell and Exxon in the United States (Ketelaar 33).

2.3 Types of Fuel Cells

Today, many variations of fuel cells exist, although only a few specific types are commercially produced. This section covers the five major types of fuel cells, including alkaline, acid, molten carbonate, solid oxide, and solid membrane fuel cells. These five types are either currently available or will be commercially available in the near future.

In addition, this section will touch upon the direct methanol fuel cell, a theoretical fuel cell that is within the early stages of development.

2.3.1 The Alkaline Fuel Cell

The alkaline fuel cell was the first fuel cell to be put to practical use. When the United States first began launching space shuttles, alkaline fuel cells were used as the primary electrical power source for the shuttles. The alkaline fuel cells are still used on NASA's space shuttles, partially because their fuel source is so accessible; both liquid hydrogen and liquid oxygen, which are the optimal fuels and oxidants for the alkaline fuel cell, are readily available onboard.

The alkaline fuel cell uses an alkaline hydroxide, often potassium hydroxide (KOH), as the electrolyte (Blomen 42). Alkaline fuel cells typically operate around 60–100°C using hydrogen (H) fuel reacting at the anode, and oxygen (O) oxidant reacting at the cathode. Alkaline fuel cells do not need noble metal electro-catalysts, such as platinum. Combinations of nickel (Ni), titanium (Ti), silver (Ag), and bismuth (Bi) historically have been used for the anode and cathode. This is particularly advantageous since noble metals are expensive and scarce. The following chemical equations (eq. 2.3.1-2) describe the reactions that occur at the anode and cathode in an alkaline fuel cell.

$$\text{ANODE:} \quad 2H_2 + 4OH^- \rightarrow 4H_2O + 4e^- \qquad (2.3.1)$$

$$\text{CATHODE:} \quad O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \qquad (2.3.2)$$

The hydroxide ions (OH^-) are the ions that flow through the electrolyte.

The key advantages of alkaline fuel cells are that they are very energy efficient and have high power densities. The main downfall of the alkaline fuel cell is that it requires pure hydrogen and oxygen for fuel and catalyst (Blomen 47), which are very expensive. The high cost is a result of the refinement processes necessary to produce gases to the required levels of purity. Alkaline fuel cells are sensitive to contamination, especially by carbon dioxide (CO_2), and if it is present with the input gases, it will form solids that can clog the electrodes (Blomen 47).

2.3.2 The Acid Fuel Cell

Phosphoric acid fuel cells are currently being used on a larger scale than the alkaline fuel cells. Their primary application is in stationary electric power generation due to the fact that they were the first fuel cell systems to be offered for commercial use (Blomen 271). Currently there is at least 50 MW of power being generated by phosphoric acid fuel cells world wide (Hirschenhofer 23).

The acid fuel cell uses an acid as an electrolyte, with phosphoric acid (H_2PO_4) being the most commonly used. Phosphoric acid fuel cells typically operate around 150–200°C using hydrogen (H) as the fuel and oxygen (O) as the oxidant. The waste heat from the fuel cell's operation is often used in the steam reform process to produce hydrogen. In this process, steam at a high temperature and low pressure is reacted with the methane in natural gas to free hydrogen, which is used again as fuel. The following chemical equations (eq. 2.3.3–4) are used to describe what occurs at the anode and cathode in an acid fuel cell.

$$\text{ANODE:} \quad 2H_2 \rightarrow 4H^+ + 4e^- \qquad (2.3.3)$$

$$\text{CATHODE:} \quad 4H^+ + O_2 + 4e^- \rightarrow H_2O \qquad (2.3.4)$$

Phosphoric acid fuel cells have been shown to be a viable energy generator in commercial applications. When utilised to generate both electricity and heat for the hydrogen reform process, they can be up to 80% efficient (Blomen 272).

The phosphoric acid fuel cell (PAFC) has a great advantage in that it can use air as the oxidant rather than pure oxygen. However, there are some important limitations; PAFCs necessitate the use of platinum catalysts, which are expensive. Another downside of using platinum is that the resulting fuel cells are limited to low current and power densities. Despite this, PAFCs are currently the only commercially available fuel cell for use in large-scale power generation. It is expected that in the near future, other types of fuel cells will reach the stage in development that will allow them to supplement or replace PAFCs in commercial production and application. One such type of fuel cell is the molten carbonate fuel cell.

2.3.3 The Molten Carbonate Fuel Cell (MCFC)

Like PAFCs, molten carbonate fuel cells are also suitable for large-scale power generation, but are not yet commercially available. MCFCs are much newer than PAFCs, and as a result of recent improvements they are more efficient. This efficiency advantage is due the ease of recovering waste heat for reforming methane to pure hydrogen.

The electrolyte of a molten carbonate fuel cell is a molten alkali mixture supported by a porous matrix; its carrier ions come from carbonate ions (CO_3^{2-}). Typically MCFCs operate around 650°C (Blomen 54). Molten carbonate fuel cells use reformed hydrogen (H) as a fuel and oxygen (O) as an oxidant. The following chemical equations (eq. 2.3.5–6) are used to describe what happens at the anode and cathode in a molten carbonate fuel cell.

$$\text{ANODE:} \quad 2H_2 + 2CO_3^{2-} \rightarrow 2H_2O + 2CO_2 + 4e^- \qquad (2.3.5)$$

$$\text{CATHODE:} \quad O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{2-} \qquad (2.3.6)$$

The higher operating temperature of MCFCs affords them unique benefits and disadvantages. The increased temperature aids in the breakdown of more complex hydrocarbons, which allows flexibility in choosing the fuels and catalysts. Also, the waste heat is useful for co-generation using conventional steam turbines to reclaim the extra heat. However, the higher temperature accelerates corrosion, accelerating wear within the fuel cell and leading to a shorter operating lifetime.

2.3.4 The Solid Oxide Fuel Cell (SOFC)

Solid oxide fuel cells are also used primarily in medium and large scale power generation, but have some key properties that set them apart from other types discussed previously. The two main differences are that SOFCs operate at a higher temperature (1000°C) than both PAFCs and MCFCs, and they utilise a solid electrolyte rather than a molten or liquid one. By operating at a higher temperature, heat is much more abundant and can be easily recycled for use with steam turbines, resulting in up to 70% efficiency (Wiens 6). In addition, the solid electrolyte affords some unique advantages such as less maintenance of the electrolyte including fewer repairs and replacements.

The electrolyte used in a solid oxide fuel cell is composed of crystalline yttria-stabilised zirconia, which is ionically conductive at the operating temperature. Solid oxide fuel cells use reformed hydrogen (H) as a fuel and oxygen (O) as an oxidant. Modern designs of SOFCs utilise a nickel-zirconia cermet (ceramic coating) for the anode. The following chemical equations (eq. 2.3.7–8) are used to describe the reaction that occurs at the anode and cathode in a solid oxide fuel cell.

$$\text{ANODE:} \quad 2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^- \tag{2.3.7}$$

$$\text{CATHODE:} \quad O_2 + 4e^- \rightarrow 2O^{2-} \tag{2.3.8}$$

Solid oxide fuel cells will likely be a viable choice for power generation in the near future. High efficiency and resistance to electrolyte poisoning are two main advantages of SOFCs, which make them desirable. The high operating temperature of SOFCs allows the direct use of many hydrocarbons as fuel (Wiens 6). The high operating temperature has advantages, but it also has detrimental side effects; the higher temperature increases the rate at which components of the fuel cell break down. In addition, the higher thermal stresses and expansion from the high operational temperature limit the materials that can be used to build SOFCs (Blomen 467).

2.3.5 The Solid Polymer Fuel Cell (SPFC)

Unlike the different fuel cells previously described, solid polymer fuel cells' main application is not for large-scale power generation. One of the key uses of SPFCs is in automotive applications. These SPFCs are often known by other names such as PEMs - proton exchange membrane (Blomen 493) and polymer electrolyte membrane (Los Alamos National Laboratory).

Solid polymer fuel cells use a solid but semi-permeable membrane acting as the electrolyte that is pressed between two porous electrodes. The two main polymers currently used in solid polymer fuel cells are Nafion from Dupont and perfluorosulfonate isomers from Dow.

Solid polymer fuel cells use humidified hydrogen ($H + H_2O$) as the fuel and oxygen (O) as the oxidant. The hydrogen is humidified so that the proton exchange membrane does not dry out. The following chemical equations (eq. 2.3.9–10) are used to describe SPFC reactions.

$$\text{ANODE:} \qquad 2H_2 \rightarrow 4H + 4e^- \qquad (2.3.9)$$

$$\text{CATHODE:} \quad O_2 + 4e^- \rightarrow 2H_2O \qquad (2.3.10)$$

There are many advantages to solid polymer fuel cells including high efficiency, low weight to power ratio, zero emissions (water only) and long life (Blomen 68). All of these advantages, in addition to a low operating temperature, make them particularly useful in vehicular applications. However, solid polymer fuel cells have some important limitations; the operational temperature of current solid polymer fuel cells is limited to the temperature range where water is in its liquid state. A consequence of the lower operating temperature is that expensive noble metal catalysts such as platinum are required (Wiens 10). Also, the low operating temperature unfortunately does not allow for reformation of fuels. As development progresses and production levels increase, the cost of the PEMs will likely go down.

Parallel to automotive applications, some important work is being done with PEMs for portable applications such as mobile phones and laptops. Though such miniaturised applications are still years from fruition, the commercial use of fuel cells in automobiles seems imminent considering ever-strengthening anti-pollution legislation.

2.3.6 Direct Methanol Fuel Cells (DMFC)

As the name implies, direct methanol fuel cells are able to process methanol (CH_3OH) directly without first reforming it to hydrogen. Great strides have recently been made in the research of direct methanol fuel cells; for example, the power density has been increased 20 fold in the past decade (Wiens 9).

Direct methanol fuel cells employ a proton exchange membrane, similar to the one used in the SPFC. The chemical formulas below (eq. 2.3.9–10) describe what happens at the anode and cathode in a direct methanol fuel cell.

ANODE: $2CH_3OH + 2H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$ (2.3.11)

CATHODE: $3O_2 + 12H^+ + 12e^- \rightarrow 6H_2O$ (2.3.12)

A direct methanol fuel cell provides many advantages over contemporary fuel cells. One advantage is that methanol is one of the simplest of all hydrocarbon fuels and an abundant resource that can easily be produced from grain and petroleum products. Another key advantage is that methanol, unlike hydrogen, can easily and safely be transported. A direct methanol fuel cell can cleanly produce electrical energy without the need of special fuel processing, which makes it an economically attractive option (Los Alamos National Laboratory). Prototypes of DMFCs have been plagued by a fuel problem when the fuel crosses over from the anode to the cathode. One problem hindering prototypes of DMFCs is that they have a lower power density than SPFCs because methanol is much less electrochemically active than hydrogen (Blomen 68).

2.3.7 Comparison of Fuel Cell Types

The key similarities and differences between the different types of fuel cells are summarised in Table 2.3.1. The following characteristics are of particular importance: availability, efficiency, sensitivity to catalyst poisoning, operating temperature, and purchase cost.

TABLE 2.3.1 SUMMARY OF FUEL CELL CHARACTERISTICS

	Alkaline Fuel Cell	Acid Fuel Cell	Molten Carbonate Fuel Cell	Solid Oxide Fuel Cell	Solid Polymer Fuel Cell	Direct Methanol Fuel Cell
Electrolyte	KOH (aq)	H_2PO_4 (aq)	Li_2CO_3 & K_2CO_3 or Li_2CO_3 & Na_2CO_3	Doped ZrO_2 matrix	proton exchange membrane	Proton exchange membrane
Operating Temperature	60-100°C	180-210°C	600-700°C	900-1000°C	60-100°C	60-100°C
Efficiency (electrical)	40-60%	35-45%	40-50%	40-50%	30-45%	30-40%
Efficiency (with co-generation)	N/A	85%	50-60%	60-70%	N/A	N/A
Fuel	H_2	H_2	H_2 & CO	H_2 & CO	H_2	CH_3OH
Internal reforming of fuels?	No	Yes	Yes	Yes	No	N/A
Can air be used as the oxidant?	No	Yes	Yes	Yes		Yes
Exhaust (fuel cell only)	H_2O	H_2O	H_2O & CO_2	H_2O & CO_2	H_2O	H_2O & CO_2
Poisoning agents	CO_2	CO	trace metals, halogens, sulphides, hydrocarbons		S & CO	
Tolerant to ...		CO_2		>200ppm H_2S	CO_2	
Availability	1960	1980			Mainly prototyping	Still in research
Power Density (max per cell)	0.33 W/cm^2	0.24 W/cm^2	0.12 W/cm^2	0.3 W/cm^2	0.35 W/cm^2	0.2 W/cm^2
System Output Power	30W-200kW	1kW-5MW		1kW-	25W-100kW	N/A
Advantages		Air can be used as an oxidant		Solid electrolyte, no expensive catalysts		Effective small scale operation
Disadvantages	Pure O_2 and H_2 required		Corrosive electrolyte		Hydrogen storage, or fuel reformer required	

Information located in Table 2.3.1 was drawn from Blomen (48, 70), Los Alamos National Laboratories, Wiens, and Ren (55).

2.4 Modern Applications of Fuel Cells

Much has changed since 1839 when fuel cells were first conceived and experimented with. In the recent past, advances in science have produced new technologies allowing fuel cells to be more powerful and efficient while taking up less space than ever before. As a result there are currently as many engineers working on ways to apply fuel cell technologies to practical use as there are scientists working on furthering the actual fuel cell technologies. But before fuel cells can become a widespread technology, there are a few problems that must be overcome: current construction methods are expensive, there is no distribution network for the fuel, and refining fuel into hydrogen is expensive. Thankfully, all of these problems can realistically be addressed by the end of the decade.

Currently there are four major areas of application for fuel cells: large-scale power generation, vehicular applications, portable power, and the space program. Each of these areas presents unique challenges for fuel cell engineers and is best considered separately.

2.4.1 Large Scale Power Generation

Given the advantages of fuel cell power generation compared with conventional methods, it would be highly desirable to replace or at least supplement the power plants of today with the fuel cells of tomorrow. In conventional large-scale power generation, a fuel source such as oil or natural gas is combusted to produce steam. This steam in turn powers a turbine, which generates electricity as it turns. From an engineering perspective, this process has quite a bit of loss by nature in the step where the fuel is combusted to heat water to produce steam. Also, from an environmental standpoint, the combustion process produces a noticeable amount of pollution, which is undesirable. In direct fuel cell power generation, these problems are minimised. The fuel source, which differs depending on the type of fuel cell, is fed into the fuel cell and the fuel cell simply produces power directly (Advanced Technologies Group, Feature Comparison). The combustion step is completely eliminated, so there is no loss incurred from this stage;

furthermore, the fuel cell is much more environmentally friendly. The only resulting by-products are heat, water, and a small amount of methane. Clearly fuel cells are a preferable method of large-scale power generation; however, current technological and scientific difficulties are hindering their commercialisation.

There are two different fuel cell technologies currently being used to develop large-scale power generation systems – molten carbonate fuel cells (MCFCs) and phosphoric acid fuel cells (PAFCs). The MCFCs are in limited use due to electrode longevity concerns, which are currently being addressed. On the other hand, PAFCs have been used to produce stationary power generation units. One popular PAFC unit is made by the Onsi Corporation and is called the PC25 Fuel Cell Power Plant. This product makes the claim of being the first mass-produced fuel cell power system (PC25 Info Page, Onsi Corporation). This system can run for more than one year without any user intervention or maintenance, which makes it a highly reliable technology. Moreover, these systems can be grouped together for redundancy. Currently the technology does not exist to make a truly large-scale fuel cell power plant, but units in the range of 200kW such as the PC25 are being built. Units on this scale can be used at rooftop power generation facilities for factories and high-rise office buildings (Onsi Corporation, Stationary Power). As fuel cell science and technology progress, larger scale systems are likely to become a reality, but currently these smaller systems are all that is available.

2.4.2 Vehicular Applications

With over 200 million automobiles on the road in the US alone, it is safe to say that cars are key contributors to the global problem of pollution. This is one area that quite obviously is suitable for alternative power methods. Ever since the late 1970s, automobile manufacturers have been experimenting with the idea of a fuel cell powered electric vehicle. There are already fuel cell powered electric vehicles in use today including larger vehicles such as buses. A good example of this can be seen in Chicago, which in March of 1998 became the first city to put hydrogen fuel cell buses into use (US Department of Energy, Green Power). The challenge to automobile manufacturers is to utilise current fuel cell technology to produce a safe and reliable electric vehicle with similar range and performance as its internal-combustion counterparts. The number of automobile manufacturers who have taken this challenge is impressive. A small sampling of them are Chrysler, General Motors, Ford, Ballard Power Systems, International Fuel Cells, Daimler-Chrysler, Peugeot, Volkswagen, Volvo, Toyota, Nissan, Mazda, and Honda.

One of the larger players in the fuel cell vehicle market is Daimler-Chrysler. On March 17th 1999 Daimler-Chrysler's chairmen Eaton and Schrempp demonstrated the first fuel cell car in the United States to offer almost a 50 percent increase in fuel cell power and triple the range of a comparable battery-powered electric vehicle. The NECAR 4 (New Electric Car) can reach a top speed of nearly 90 miles per hours and travel about 280 miles before it needs refuelling (New Review, August 1999). Reviewers say that the car is actually pleasant to drive thanks to the electric motor with optimised torque curve designed by DaimlerChrysler (Daimler Chrysler, News Release 1-26-00). The NECAR 4 is based on the Mercedes A-Class design that employs an innovative design to house the drive system in a sandwiched configuration underneath the car. Never before has it been possible to mount the entire fuel cell system in the floor of the car, so this new design allows much more cargo space and room for five passengers, all definitely valuable selling points in a compact car. The vehicle is powered by proton exchange membrane fuel cells (PEMFCs) developed by Ballard Power Systems. Mercedes-Benz has been working with Ballard since 1993 on the development of the NECAR 1, and has found the Ballard's PEMFCs to work well with their designs. Already being tested world-wide, the NECAR4 is slated for release in 2004.

Also the engineers at DaimlerChrysler are working on the fuel cell Jeep Commander, the first fuel cell powered off-road vehicle. The vehicle's body mouldings have been designed to make the vehicle more aerodynamic and to allow greater cooling for the fuel cell system, which can produce a great amount of heat. The body of this vehicle is composed of carbon fibre composite mounted on an aluminium frame. The complete vehicle will have a curb weight of only 3900 pounds (Jeep Corporation, Concept Vehicles Division). These two products from the DaimlerChrysler Corporation are only two examples of the kind of vehicles that are to come as a result of fuel cell technology advances. With most of the world's automotive manufacturers stepping towards better fuel cell powered electronic vehicles, possibilities of commercially availability seem likely.

2.4.3 Portable Power

Compared with the other areas of fuel cell applications, portable power is by far the newest field of application. In 1988, Robert Hockaday, who is now considered the father of the micro-fuel cell, began experimenting with the concept of producing a small fuel cell to power portable devices. Twelve years later, his vision is becoming closer and closer to reality (Hockaday, Micro Fuel Cells for Portable Electronics).

After taking an entrepreneurial leave from Sandia National Laboratories in 1994, Hockaday formed a small company – Energy Related Devices – that was largely operated from the basement of his home. The vision is simple: the micro-fuel cell that he patented is believed to be capable of providing power up to 50 times longer than its traditional nickel-cadmium counterpart. Although Hockaday does not hold the only patent on this technology, he is certainly a key player. His fuel cell is designed differently than the conventional fuel cell. Normally fuel cell scientists and engineers focus most of their energies on the electrodes and the electrolyte. Hockaday, on the other hand, concerned himself more with the actual fuel cell container material and construction.

The Hockaday micro-fuel cell electrolyte flows through an etched nuclear particle track plastic membrane (Manhattan Scientifics, Hockaday Micro Fuel Cell). Simply stated, the membrane is a 25-micron thick piece of plastic etched like a circuit board, through which the electrolyte flows. This membrane-encased electrolyte, sandwiched between the electrodes, forms the basic construction of the micro-fuel cell. The advantage of the way the plastic is etched is that a very long piece can be etched and then cut for use, making the production process much easier. Currently only working prototypes exist, but Manhattan Scientific anticipates a commercially viable product to be developed within the next year (Manhattan Scientific). Until the day arrives that mobile phones and portable laptop computers use an input of liquid hydrogen fuel, the world will have to continue using conventional batteries limited with their conventional charging and use times.

2.4.4 Space Program

NASA has been a major catalyst for the fuel cell industry since the industry's inception. International Fuel Cells built the world's first operational fuel cell for NASA in the 1960s. Three 28V fuel cells using molten KOH technology provided all the power for the command and service modules of virtually every NASA spacecraft for decades, from when the rockets cleared the tower until return to Earth. Each 250-pound unit was in service for 18 missions, providing 1.5kW – 2.2kW without any incident whatsoever (International Fuel Cells).

Much has changed since the 1960s, but what remains is the fact that NASA is still an important motivator for the industry. To this day, International Fuel Cells provides the power for the shuttle; only now the power is supplied by three 260-pound units providing 12kW at 28V of power each (NASA, Shuttle Electrical Technology). In space there is not any alternative to a closed chemical process for power generation. Combustion based generation is virtually impossible as the gas or diesel engine requires oxygen intake, and in space oxygen is a precious commodity. The fuel cell units in service provide a high rate of redundancy and are 70% efficient compared to a combustion engine that can be only 25% efficient. So far the cells have gone through 2600 hours of flight time over 13 missions without any problems whatsoever. In total, fuel cells have been in use on the shuttle for 93 missions operating for more than 70,000 hours (United Technologies, Shuttle Program). Although the government may not be a large volume consumer of fuel cell technology, there is no doubt that NASA will be a driving force in future fuel cell development.

2.5 Museums and Exhibit Design

In order to design a prototype exhibit concerning fuel cells, it was first necessary to understand the current role of museums and how an exhibit fulfils that purpose. Within the broad topic of exhibits and museums we focused our attention on existing computer based exhibits and more specifically on those that can be used via the World Wide Web. In general, one of the most important topics researched was how to effectively communicate through whatever design method chosen.

2.5.1 Introduction to Museums

The modern museum has its historical roots in the personal collections of the rich and powerful. A trophy room or curio gallery once displayed its owner's wealth, power, and prestige. As time went on, public demand for scientific knowledge prompted the creation of fairs and festivals highlighting a variety of curiosities acquired from expeditions. This laid the foundation for the first museums, usually little more than warehouses of displayed artefacts and primarily used as research for scientists and academics (Neal 5).

Today, museums have many objectives, including preservation and conservation, documentation, research, and education (Belcher 13). Successful exhibits in museums educate and stimulate interest by presenting information in a relevant and exciting manner (Neal 11).

Science museums, in particular, often present very complex technical information to an audience with little knowledge of the subject matter. Thus, science museums frequently have different roles from other traditional museums and require specific techniques to present information in an effective manner (Belcher 13).

2.5.2 Purpose of Exhibits

The purpose of an exhibit is to aid a museum in accomplishing its objectives. Encountering an exhibit helps people learn by giving them an experience beyond written words and ideas. Exhibits can clarify and make concrete ideas that may have been previously abstract and confusing, making them relevant to the visitor. This unique mode of communication can be achieved by a variety of design methods (Lewis 113).

An exhibit is considered successful when visitors retain an abundance of information; employing the senses through demonstrations or increasing interaction can accomplish this goal. Demonstrations provide examples of what objects do or how principles work, and can sometimes also provide textures, sounds, and odours to the visitors (Lewis 118). Providing a multi-sensory encounter has been found to have a more satisfying and memorable effect on visitors. The information reaches a larger audience with more intensity when it activates a range of senses. Multiple senses working together have a larger mental impression on the brain, making the subject of the person's interaction more memorable than just seeing or hearing alone (Belcher 38).

An exhibition will often make use of a wide range of methods to appeal to the senses. These include interactive displays, dynamic scenes, graphics, and animation. Additionally, scaled models, real and replica objects, and modern theatre special effects are often utilised. According to Belcher, using a combination of methods is the best approach to reach different levels of the audience more effectively (Belcher 38). These methods can be used to attract attention, start a train of thought, provide specific information, illustrate a conclusion, kindle intended feelings, or generate a combination of effects (Lewis 120). Because of these advantages, exhibitions have the potential to be a medium of communication with a great range of possibilities and superior effectiveness (Belcher 37).

Exhibits are especially useful in scientific education, where they can help stimulate interest into scientific topics, and inform the public on how science affects their everyday lives through an entertaining and pleasurable multi-sensory experience (Belcher 39).

2.5.3 Communication Challenges in Exhibits

Exhibition is a unique medium of communication, with certain highly advantageous characteristics. However, it also has limitations and disadvantages that must be carefully considered throughout the design process (Belcher 37).

No matter what kind of design methods are being used, or the intended audience, designers must keep in mind that visitors have the luxury of proceeding at their own pace and moving freely about. The advantage to this is that they can spend more time on the areas that interest them, and less on those that do not (Belcher 39). However, visitors usually also have short amounts of time to spend at each exhibit, so the design must emphasise the most important information to ensure successful transmission of those ideas (Neal 36).

Time spent in museums has been found to tire visitors, with the larger exhibitions and galleries having the most exhausting effects. These effects are the results of extended periods of reading, standing, and moving about the galleries. Design and positioning, as well as providing a manageable amount of information at a time, are especially important to reduce ergonomic problems such as backache and neck strain (Belcher 40).

A large amount of information is usually supplied through written words, either by labels, captions, or display screens. These words function as sources of information on displays, sets of instructions, or interpretations. In addition to physical effects resulting from positioning, labels are also challenging because they need to be readable. A typical recommendation concerning label length is that they should have a comfortable length of about 50 words, supply significant and interesting content, and capture attention at the same time (Lewis 122).

Another challenge of printed text and readability is typeface and colour schemes. Effective typefaces are wide with lots of white space and large enough for comfortable reading. The use of italics or boldface slows down reading, as does writing that consists solely of upper-case letters. Additionally, the difference between the brightness of a background and letter colouring is an important factor in legibility (Gammon, Text and Letters 3-4).

In order to write labels that can be understood by a large audience, it should be acknowledged that some visitors may be experts and others novices in a particular subject matter. Relating to knowledgeable visitors and the uneducated often requires different approaches. Bridging the gap between multiple audiences requires careful planning (Belcher 87).

When catering to a varied audience, designs should accommodate a range of audience characteristics, including physical sizes, ages, backgrounds, and interests. Reasoning skills and sentiments may also need to be considered. Different audience members will be interested in some exhibits and disregard others (Lewis 120). These are all challenges designers must keep in mind when planning an exhibit. If the audience is able to retain information and is perhaps stimulated to pursue a subject, then the exhibit has achieved its purpose. However, educational exhibits cannot explore any particular subject in great depth because of time and content limitations. In this case, in addition to being interesting and entertaining, exhibits should instil a visitor with the desire and determination to learn more upon departure (Neal 20).

2.5.4 Modern Exhibit Design

Exhibit designs today are based on an assortment of methodologies and presentation techniques. Primarily, there are aesthetic, evocative, and didactic exhibitions (Belcher 58). All of these design techniques can be used in a variety of combinations to present different modes of design including interactive, responsive, participatory and thematic designs (Belcher 65).

Science exhibits are generally considered to be didactic exhibitions, which are designed to educate and inform (Belcher 62). Aesthetic and evocative exhibitions are either emotive, or designed with the intention of arousing particular emotions (Belcher 59), and usually are not used in scientific exhibitions, which tend to be instructional and educational.

The didactic methodology applies a series of educational technology stages. Under the didactic scheme, the first step is to identify the exhibit objectives in measurable terms. After that, describing audience characteristics and careful assessment of the exhibition's message must be completed. With these things in mind, the next step is to design the arrangement of concepts for presentation; following this is actual testing of the design and modifications (Belcher 63). The flow of information and the display techniques being used should not attempt to coerce the visitors into one predetermined path, or try to force them to learn. Visitors are likely to find such designs annoying and perhaps bypass them altogether (Belcher 63).

Several design categories can be used in sequence to present the flow of information. One category, interactive exhibits, requires intellectual and physical participation from visitors, and sometimes varies presentation according to responses. An example of interactive exhibits might be a computer program or web site. Interactive exhibits are often used one-on-one and are not usually designed for group presentation (Belcher 65).

Similar to interactive exhibits are responsive exhibits, which respond to visitors automatically. Whether by motion detection or by pushing a button, they often trigger some special effect or response (Belcher 65). Another type of exhibit is the participatory exhibit, which usually has visitors engaged in an activity designed to promote understanding through physical involvement (Belcher 66).

Another category of exhibition, thematic exhibition, uses a story line to portray the concepts being presented. This method tends to provide information in a linear fashion (Belcher 66).

Whatever approach a designer wishes to take with an exhibit, there are a variety of presentation media available, including audio, video, graphics, animation, interactive computers, and theatre effects. No matter which ones are used or in what combinations, moderation should be used so visitors are not overwhelmed.

2.5.5 Web-Based Design

Relative to conventional exhibition design, designing a web-based exhibit provides some new challenges to be overcome, but many modern exhibition design techniques are still relevant and useful. For example, it is just as important for a web-based exhibit to provide non-linear interactivity in a way that is not overwhelming as it is for a traditional exhibit.

Web-based exhibits offer certain advantages over their traditional physical counterparts. These advantages are mainly the ease and speed with which web-based exhibits can be refined and modified; graphics, sounds, and themes can easily be adjusted when necessary. Another advantage of web-based exhibits is their cost effectiveness. Developing and maintaining a web-exhibit is far less expensive than actually constructing a physical exhibit in a gallery, especially if the display requires appreciable maintenance or revisions (Shneiderman).

Web-based exhibits allow for easy cross-referencing of concepts and source materials, which is very useful when there is a vast amount of information available. Presenting smaller fragments with links to other related information is perfect for allowing visitors to explore the areas that interest them in a non-linear fashion. However, it is important not to provide too many links and options, as this can lead to confusion about where they should go for the information they want (Shneiderman 556).

Sequencing, clustering, and emphasis on concepts and information are other high priorities in the design of web-based exhibits. It has been found that web users assume that information presented first or emphasised with large coloured fonts is the most important. Users also assume that information presented together may be thematically related. These factors should be carefully considered when designing a web page's layout (Shneiderman 576).

There are a few principles of design that apply equally to traditional mechanical museum interactive exhibits and web sites. As recommended by Gammon in Everything We Currently Know About Making Visitor-Friendly Mechanical Interactives, an internal document from the Science Museum, interface controls should be unambiguously designed so that they are not confused with non-functional portions of design, and vice versa. Reset mechanisms, if any, should be placed so they are not activated inadvertently, which may cause confusion. Additionally, non-linear computer based designs should be employed, as it is virtually impossible to assume that the user will follow a linear or fixed path unless there is no way to deviate from that order.

Users should also be provided with navigation support and an easy way to search for specific information. These features minimise confusion and allow users to head in the right direction when looking for something specific or to return quickly to a previously accessed area (Shneiderman 578).

2.5.6 Testing and Maintenance of Web-sites and Other Designs

Testing the effectiveness of web-based material is highly recommended by most software professionals and engineers, and can be accomplished in a variety of ways. For these tests, it is important that a representative sample of the audience is selected to ensure the reliability and accuracy of any feedback and data obtained. These tests can either be expert reviews, usability tests, or surveys (Shneiderman 124).

Another method to obtain feedback is through automated logging. Automated logging records the number of times a particular area has been accessed. This may expose patterns regarding what users are most interested in, which presentation techniques are most effective, and which areas need to be refined (Shneiderman 579).

Expert reviews are used to test a design's conformance to some set of heuristics or guidelines, to ensure consistency, and to inspect usability. Expert reviews are usually conducted on software programs that are large in magnitude (Shneiderman 127).

Usability tests, another method for evaluating designs, are often completed in laboratories with a tester observing a subject. It is difficult to obtain an accurate representation of an audience with usability tests due to time constraints and the normally low number of subjects, but they usually provide in-depth data and analysis of the design. These tests are usually conducted on large projects since they are so time and resource consuming (Shneiderman 132).

Surveys, as opposed to expert reviews and usability tests, are inexpensive and typically generate many responses. A survey typically becomes less biased as the number of respondents grows. This is because as the sample size increases, there is less chance of skewing the data to a particular group. To ensure all those responses are useful, a survey should have clear goals and focused questions to gather the relevant data (Shneiderman 132).

Administration of a survey can be done in a variety of ways in the form of a paper questionnaire, an online survey, or an online suggestion box. Online surveys save paper and distribution costs, and it has been found through many studies that people prefer quick forms on a screen to filling out a paper form. People are also more likely to fill out an online form if the questions are simple and few in number. Similarly, an online suggestion box offers people the chance to voice opinions; however, there is a certain bias due to self-selection, and response rates may be low (Shneiderman 134, 147).

2.5.7 Existing Fuel Cell Exhibits

Currently there are a number of web sites with information pertaining to fuel cells. There has been a marked increase in the number of these sites since last year when the public took a renewed interest in fuel cell companies as investment opportunities. Most of these web sites contain a wealth of information for the user; however, in general the information is not very accessible in that it is usually very technically oriented. The user seeking information is probably prepared to encounter this level of complexity. However the average user would likely have a great degree of difficulty understanding fuel cells. We have been unable to find any web sites that could be classified as sites that attempt to explain the concept of the fuel cell to a general audience satisfactorily. This lack of precedence makes the design process for a museum exhibit that much more challenging.

There are some museums that have been putting some portions of their gallery exhibits on-line. This is a relatively new medium for the traditional museum. In this way, museums can reach a much wider audience, but not without complications. The museum patron at a conventional exhibit has committed a good degree of time and trouble to actually travel to the museum; in this way, a certain level of interest is assured. In contrast, a visitor to an online exhibit could just be casually browsing. Because of this, museums need to tailor their online interactives to convey smaller bits of information that can be absorbed more quickly. The museums that already feature these interactives have had varying degrees of success. To the best of our knowledge, there are currently no museums that have any gallery exhibits devoted to fuel cells or any online-exhibits about fuel cells, although one is currently being developed by the California Science Center (http://www.casciencectr.org/). There is a greater degree of interest in California about alternative energy sources in general due to that state's more stringent environmental regulations, which may lead to more web sites on alternative energy in the future. Currently, however, there is no basis for comparison for a fuel cell exhibit, either physical or on-line.

2.5.8 School Audience at the Science Museum and the National Curriculum

Every year, nearly 20% of the visitors to the Science Museum in London are school groups. Because of this large audience from British schools, it has been necessary for the Science Museum to research the needs and wants of the schools. The information presented in this section is taken from results of over ten focus groups and three surveys conducted by the Science Museum (Gammon, Davies, Graham 1).

The National Curriculum in Great Britain has been established in order to provide all students throughout the country with a similar education. It is broken down into four different stages, or Key Stages, which are listed Figure 2.5.8. The first stage, or Key Stage One, is comprised mostly of children aged five to seven, but can include children who are younger. Children aged eight to eleven are in Key Stage Two, while those aged twelve to fourteen are in Key Stage Three. Key Stage Four includes children who are between the ages of fifteen and sixteen. A final group, which is not a key stage but represents a significant percentage of the school audience, is the tertiary level of education in Great Britain and is comprised of individuals mainly over the age of sixteen (Gammon, Davies, Graham 1).

Key Stage	% of Museum School Audience
Under 5's	2%
Key Stage One (5-7)	11%
Key Stage Two (8-11)	28%
Key Stage Three (12-14)	26%
Key Stage Four(15-16)	20%
Tertiary Level (16+)	14%

FIGURE 2.5.8 – KEY STAGES & BREAKDOWN OF MUSEUM SCHOOL AUDIENCE

There are some problems that schools face when planning and visiting the Science Museum. Schools in present-day Britain face a considerable amount of pressure on the amount of time and monetary resources that they spend so that they can give their students an optimum education. Additionally, many teachers do not have a lot of time to plan a museum trip and thus rely on the resources that are readily available to them at the museum, such as personnel or explainers. Because of this, it is especially important that the museum and its exhibits are exceptionally helpful to the needs of the teachers and students (Gammon, Davies, Graham 2-3).

There are other difficulties that teachers have which are inherent in science education. It is often difficult for teachers to educate their students on subjects that do not relate directly to them. This can be for a number of reasons, and the Science Museum found that this was a result of teachers never being taught a particular subject, material that had changed in recent years, subjects that had difficult underlying principles, and subjects that did not have a clear concentration. Some of the subjects that have presented teachers with a large amount of difficulty in teaching are material science, information technology, and genetics (Gammon, Davies, Graham 3-4).

There are several expectations that teachers have in their visit to the Science Museum. Teachers expect their visit to be exciting and educational for their students, but most of all they want it to be relevant to their curriculum. Many teachers have requested that content in the Science Museum have clear links to the material which they must teach from the National Curriculum. It is also expected that the museum provide material or exercises that cannot be seen or done in the classroom. Teachers also like to see "interactive and multi-sensory exhibits" as they are "both hands-on and mentally challenging" for the students (Gammon, Davies, Graham 5).

2.6 Surveys and Data Analysis

Surveys are often an important aspect of exhibit design, especially while testing an exhibit and gathering patron feedback. There are five main steps to designing a survey. The first stage is to define clearly the objectives of the survey and the population being studied. A method of data collection needs to be determined, and the questions used to extract this data need to be created. Along with the questions, a method for data analysis needs to be constructed. The last stage of survey design is to determine the sample needed from the target population (Kalton 6).

Surveys are a method of data collection usually characterised by structured questions, a data matrix, and a method for data analysis. The data matrix is simply a set of data comprised of answers from several people to a series of structured questions. Each attribute in the data matrix is the answer to a particular question for a specific case. For effective analysis of the data, all sections of a questionnaire need to be completed, or each attribute in the matrix needs a value. Without every attribute complete, analysis would be incomplete as it is largely based on case comparisons (de Vaus 3-5).

2.6.1 Defining Survey Objectives and Target Population

Defining objectives and a target population is the first and most important step in survey design. Both the objectives and the target population will eventually define the type of questions to be asked. Objectives may aim for different types of information such as opinions, knowledge, or demographics. Once survey objectives have been clearly defined, identifying the target population will be much easier. A portion of the target population that can be surveyed feasibly is called the survey population (Kalton 6).

2.6.2 Methods of Sample Selection

Who a survey is administered to can greatly affect the overall results. A sample is composed of the people who have responded to a survey, and who are members of the survey's target population. Several methods of sample selection exist including simple random sampling, stratified sampling, and multistage cluster sampling (Kalton).

Simple random sampling selects people from the target population to be surveyed with equal probability. By this method, each member of the population has an equal chance of being chosen. However, in order for this method to be effective, a large sample needs to be taken in order to accurately represent the population (de Vaus 64).

Another method, stratified sampling, divides up the target population into strata that depict the population. Then, a number of people that accurately represents population distribution among the strata are randomly selected with equal probability. This way, for example, a survey would get the correct proportion of upper class to lower class respondents (de Vaus 65).

A completely different technique, multistage cluster sampling, obtains a final sample by dividing a target population into sub-areas. These areas are repeatedly subdivided, with progressively smaller areas being sampled. This technique works best for geographical sampling, such as sampling of a city or state. However, it is possible to end up with a very unrepresentative sample by completely missing a specific portion of the target population (de Vaus 67).

2.6.3 Data Collection and Question Development

To obtain information from a defined target population, a method of data collection needs to be determined. This can be in the form of a standardised questionnaire because of its highly structured format that allows for a large number of respondents' data to be easily constructed into a data matrix, which is useful for data analysis (de Vaus 80).

Questions need to be tailored around the type of information desired to ensure that the final data matrix is useful and applicable. Thus, questions need to be carefully worded for easy understanding, and so that they are not offensive to the target population. Anticipation of every sort of data needed will ensure appropriate questions can be asked and nothing is missed (de Vaus 80).

Each question asked should attempt to gather certain focused content: behaviour, beliefs, attitudes, opinions, or demographic attributes. In order to obtain specific content or data, questions need to be simply worded and easy to understand. Leading, biased, or ambiguous questions are worthless in forming a practical data matrix (de Vaus 84-6).

Questions are often presented in either of two formats: open and closed. Open questions allow respondents to say what they want, while closed questions provide a limited number of options and force selections to a few choices. Using open or closed questions depends on content, respondent motivation, as well as questionnaire administration (de Vaus, 87).

There are a variety of types of closed questions including Likert-style formats or rating scales, semantic differential formats, checklists, rankings, and attitude choices. All of these closed formats rely on number scales for respondents to rate their viewpoints and opinions. The only difference between these formats is the style of presentation. The use of number scales converts well to a data matrix that can easily be analysed (de Vaus, 88).

2.6.4 Methods of Survey Administration

There are three main methods of survey administration: face-to-face, mail, and telephone. Each method has its strengths and weaknesses in response rates, sampling quality, answer quality, and practicality (de Vaus 106).

Face-to-face surveys traditionally have a higher response rate than mail or telephone surveys; however, they are often impractical due to geographical distances. Mail surveys require in most cases that a particular person, head of household for example, fill out the survey. This can lead to bias if the intended individual is not the one to fill it out. In order to have a representative sample there needs to be some degree of control over who completes the survey. One common difficulty that occurs is that it can be difficult to gain access to specific selected people for face-to-face interviews. Perhaps the greatest advantage of face-to-face interviews is that they allow for longer and more complex questions since the interviewer is available to personally communicate with the respondent. For open-ended questions, face-to-face interviewing is almost exclusively the manner of delivery, eliminating the need for extensive writing on the part of the respondent who may have difficulty putting ideas into writing (de Vaus 106-13).

2.6.5 Advantages and Disadvantages of Face-to-Face Surveys

Using face-to-face surveys allows both the surveyor and the respondent to share and explore the questions and answers involved in the procedure. The survey in this situation can permit misunderstandings on the part of both parties to be clarified, which could not happen in the scenario where, for example, a subject is asked to fill out a survey on his or her own. In addition to this, face-to-face surveying allows for immediate responses and the acquisition of information quickly. "Survey research based on the use of questionnaires, administered in face-to-face interviews, permits the collection of the most extensive data on each person questioned" (Brenner, Brown, and Canter 3). Also, many different types of information, such as gender, age, or political opinions can be collected in the same interview.

There are a few disadvantages to the face-to-face survey. This method can occasionally require many interviewers in order to conduct the number needed for the research. Also, the developer of a survey may have to spend considerable time and effort developing it so as to minimise the amount of confusion between the interviewer and the respondent. There is also a need on the part of the developer to utilise effective interviewing techniques and maintain good organisation throughout a survey. Both of these things can potentially cost a lot of money to the agency, which is sponsoring the survey research. Yet another disadvantage lies in the fact that contact during a survey interview is face-to-face and could create bias in responses. Intensive interviewing can cause a respondent to have memory lapses or feel sensitive to a particular topic and thus not respond truthfully to the interviewer. For example, a person who does not want to appear foolish may not answer a question the same way face-to-face as he or she would filling out a questionnaire independently. In the cases where a researcher feels that these disadvantages could be an issue, it may be necessary to employ other investigative tools in addition to the survey or research interview (Brenner, Brown, and Canter 4).

2.6.6 Methods of Data Analysis

According to de Vaus, there are three factors that influence the analysis of data: the number of variables, the level of measurement, and whether the technique is descriptive or inferential. The number of variables being examined or compared determines whether univariate, bivariate, or multivariate analysis is employed. Use of statistical analysis can help draw potential connections between variables, such as demographics and opinions (129).

The level of measurement can be nominal, ordinal, or interval. Nominal measurements have different categories that cannot be ranked or represented numerically. Ordinal measurements are separated into categories that can be ranked but not represented numerically. Interval measurements can be categorised, ranked, and represented numerically. Having a standardised questionnaire with interval measurements can create a numerical data matrix, perfect for multivariate analysis and identifying relationships and correlations (de Vaus 130-1).

All of these forms of statistics can be further categorised as either descriptive or inferential. Descriptive statistics are those that describe a population sample, create averages, and generalise the results of the sample to the entire population. Inferential statistics are used to describe patterns, make statistical predictions, and estimate certain trends in an entire population from a sample (de Vaus 134-5).

Analysing data can be performed with univariate, bivariate, or multivariate analysis methods. With these different methods a particular type of analysis appropriate to the data and objectives can be selected, such as frequency distribution to determine sample spread, or multiple correlation to determine trends in the sample (de Vaus 134).

2.6.7 Reporting the Results

Reporting the results of a survey typically includes a description of the research objectives along with any details of the sample, response rate, and the method of data collection used. Additionally, any methods that were used to validate the analysis of the data should be included. Finally, the conclusions based on the data and research should be presented, backed-up with tables and graphs that present the data in a clear and concise manner (Breakwell 88).

3. Design Process

The National Museum of Science and Industry is planning a major new gallery whose focus will be on energy in all of its forms and how it affects our lives. The museum requested that we provide a web-based prototype exhibit on fuel cell technology as well as preliminary suggestions for an actual physical exhibit to be built in the gallery. The steps that we took to complete these tasks, along with results gained along the way, are presented in this chapter.

The first task that we undertook was to research of all the information that we anticipated would be needed to complete this project. The literature review serves to summarise in a concise manner the most pertinent information that we found. Some of the key areas investigated were fuel cells, museums, modern exhibition design, as well as surveying and interviewing.

After our background research we began using the didactic methodology in our design process. The first step of this methodology is identifying objectives, which we completed through research and correspondence with the Science Museum. The second step of this methodology is describing the audience. Information provided by the Science Museum on the target audience of the energy gallery was valuable; however, our preliminary research showed the benefits of further analysis of the audience. Accordingly, we designed and administered an interest survey to determine museum visitor's levels of interest in a variety of topics relating to energy and fuel cells. Trends in this data revealed differences between various age and gender groups, leading us to tailor our content and layout to target the Energy Gallery's audience by illustrating the key areas we needed to address. Particular attention was paid to the data obtained from patrons surveyed who were within our target audience range.

After identifying audience interests, we moved to the third step of the didactic methodology: assessing messages and content. Our data confirmed our hypothesis that public knowledge on fuel cells is extremely limited; therefore, our final list of messages consisted of mostly the benefits of fuel cells with some technical information. All of our content was drafted to communicate these messages with the added objective of referring museum patrons to objects in the Science Museum's collections.

With our messages and content we began arranging concepts for presentation, which is the fourth step of the didactic methodology. We drafted and evaluated several concepts for a prototype exhibit before settling on an interactive and thematic design. During the development and implementation process, we considered a variety of audience characteristics and museum design guidelines. These factors played key roles in the decision making process of what information would be included and how it was presented.

Equipped with the necessary content as well as information on how to construct an effective exhibit, we created a prototype and tested it on the museum staff and patrons. This testing allowed us to observe reactions to the prototype. Through these test sessions followed by brief interviews, the prototype was revised before submitting the final version to the museum.

Additionally, a selection of physical design suggestions for the final Energy Gallery was compiled using several different sources, including our own ideas and our analysis of museum patrons' interests revealed by our interest survey. Additionally, we considered the existing Energy Gallery plans and pending designs. Our entire design process, as well as results, is detailed below to describe and justify each of these steps taken to complete our project.

3.1 Background Research

The first step of our project, background research, was broken down into four key areas: fuel cells, museums and exhibit design, survey design and data analysis, and research interviewing. We chose to divide our efforts into these sections after determining that this was the range of information that we would need to know in order to successfully design an exhibit on fuel cells. Initially we researched fuel cells because we clearly needed to have an in-depth understanding of the technology. More importantly, we needed to know how to effectively communicate this understanding, so we also researched museum and exhibition design. A portion of the design research covered web design, since our exhibit would be making extensive use of computers and the web. We also knew that we would need to gather information to evaluate our exhibit, which led us to research surveying techniques as well as interview techniques to ensure that we could prepare an effective survey or interview, successfully administer it, and properly analyse the results.

We selected surveying and interviewing as our data collection methods after a brief comparison of various techniques including usability testing and expert reviews. After much research, we reinforced our original idea that surveys and interviews would be the most effective methods of data collection for us. Other techniques required impractical laboratory facilities or unavailable expert consultation. Some other concerns we had included time constraints and consistency issues, since effective methods for exhibit evaluation were already in place at the Science Museum. Our interviewing and surveying research helped us design and administer our surveys and preliminary interviews.

Most of the information found in our background research came from books and authoritative World Wide Web sites. These sources were carefully selected, and where possible information considered authoritative within the industry was given priority. This research was essential, as it provides the necessary background information needed for the construction of an effective prototype exhibit and successful completion of the project.

3.2 Preliminary Interviews and Visits

While still in the United States, we decided that it would be beneficial to conduct some preliminary interviews and visits in order to put our background research into perspective. We wanted to hear from actual fuel cell researchers and to witness concrete examples of museum and exhibition techniques that have been put into practice.

Our most important preliminary interview was with Professor Ravindra Datta, head of the WPI Chemical Engineering Department and an authority on fuel cell technology. Through this interview we gained clarification on how fuel cells actually operate as well as insight on what he saw for the future for fuel cell technology. This important information, not easily found through traditional research, proved to be very helpful in making our exhibit more accessible so that the average museum patron could understand its message. Professor Datta was also gracious enough to give us a tour of the WPI laboratory where fuel cell research was taking place as well as give us the opportunity to speak with the resident graduate students. For summarised notes from the interview with Professor Datta, see Appendix B.

To gain a better perspective on some of our background research, we visited the Boston Science Museum. The purpose of this visit was to make observations on exhibition techniques in practice and to relate these observations to the information gleaned on exhibition design. While there, we visited all of their exhibits while paying special attention to those that were interactive and computer based. We noticed that the exhibits that received the highest amount of participation from patrons had hands-on and interactive elements. During our visit we also observed some surveys being conducted in the museum. One in particular that was interesting to us consisted of a member of the museum staff sitting at a table and conducting his survey. This method of surveying appeared unsuccessful; through our observations we found that his response rate was minimal. This can be attributed to the fact that the staff member was not actively engaging the museum patrons. This observation, combined with information provided to us by the NMSI, influenced our interest survey techniques for the better; we subsequently adopted a more aggressive technique for our survey administration.

After arriving in London and acclimating ourselves with the Science Museum, we met with several staff who were very helpful with guidance and suggestions. Valuable suggestions came from our Science Museum liaison Claire Bonham-Carter, Sarah Hunt, a researcher in visitor evaluation, and Katie Streten, the Science Museum's web-administrator. Additionally, we were provided with comments from other museum staff during our initial presentation and throughout the design process. Sarah Hunt provided us with details on Science Museum procedures and policies covering survey design, administration to the public, and data analysis. She also provided us with internal reports and forms to see what sort of analysis and writing the Science Museum typically produces. Katie Streten spoke to us about web policies and restrictions including design, layout, and bandwidth issues. Initially, our liaison Claire Bonham-Carter helped us get acclimated with the museum environment, and throughout the whole project she provided us with feedback and suggestions which helped shape our project. The information we received from these three key sources greatly helped clarify how we would achieve our goals.

3.3 Identifying Objectives

To develop our web-based prototype, we utilised the didactic methodology, which applies a series of educational technology stages described in our literature review, including identifying objectives, describing the audience, assessing messages and content, and arranging concepts for presentation.

The first step, identifying objectives, was completed through our research and correspondence with the Science Museum. Our criteria for objectives were that they should be in measurable terms whenever possible and parallel the objectives of the Energy Gallery. The main objective of our exhibit is to teach all people about fuel cells in a way that is interesting and relevant, especially for children ages 7 through 14, which is the target age group for the Energy Gallery. Another objective we had for our prototype was for it to be interactive, allowing visitors to explore the areas that they wished, such as environmental issues. Interactivity became an objective at the request of the Science Museum, and is justified by the benefits of enhancing the recollection of concepts and the potential for increased interest and excitement (Belcher 65). We initially planned on providing media relevant to the topic currently being viewed, with links to other related areas. The success of these objectives was measured through a feedback survey, which is discussed in a later section.

3.4 Describing the Audience

The second part of the didactic methodology calls for the description of audience characteristics. Describing audience characteristics was accomplished through our initial museum visitor interest survey. Demographic information was integral to our survey to ensure that we obtained interest levels from a sample representative of every gender and age range, although we didn't need extensive demographic information for profiling purposes.

Demographic information was also important in identifying responses from our target audience. Since our target audience is the same as that of the Energy Gallery, children in educational Key Stages Two and Three (ages 7-14), we needed to be able to distinguish them from other age groups to make sure that the exhibit would retain the intended focus. However, information on everyone's interests was collected to ensure that families accompanying children would still be presented with interesting and relevant information.

3.4.1 Interest Survey

Surveys were used in conjunction with interviewing techniques in order to gain insight into museum visitors' interests. Our interest survey was administered to obtain visitors' levels of interest in a variety of energy related topics. For this survey we chose to use a structured and standardised survey to remain consistent with the Science Museum's usual approach, and because authoritative scholars such as Shneiderman argue that it offers better results, increased reliability, and less bias than other data collection techniques (132). We chose to use a structured survey with oral administration, as opposed to an interview with follow-up questions and other methods, with the difference being that close-ended structured questions are less time consuming and less obtrusive than open-ended and follow-up lines of questioning.

We initially planned to conduct our interest survey during our first week in London by approaching and directly requesting museum visitors to fill out a short form to discover what they found most interesting about fuel cell technology. However, at the suggestion of Sarah Hunt, our methods changed into informal question sessions with us filling out the survey for the patrons. We made an effort to actively engage the patrons to both achieve a higher response rate and to assure that we would receive the demographic variation in respondents that we were looking for.

Before administration of our survey, we pre-tested our survey design and interviewing skills on five members of museum staff, followed by five museum patrons. This pre-testing allowed us to work out any problems with word choice and question effectiveness. After we learned that the new energy gallery was aimed primarily, but not exclusively, at children ages 7 through 14, we decided to conduct some additional surveys with patrons in that age group. This extra collection was done immediately after the discovery.

The museum typically requires the surveying of approximately thirty patrons with an equal number of patrons from each demographic group (composed of 5 age ranges and

2 genders). In our case we surveyed for approximately two days, obtaining over 70 surveys with a 90% response rate. We felt that this number of responses would give us a sufficient data pool to generalise the interests of the museum audience as well as enough data to find trends in interests as a function of age and gender. Given our limitation of seven weeks to complete our goals, a longer and more extensive survey would have detracted too much time from the design and development of our prototype. Figure 3.4.1 depicts the demographic distribution of the interest survey respondents.

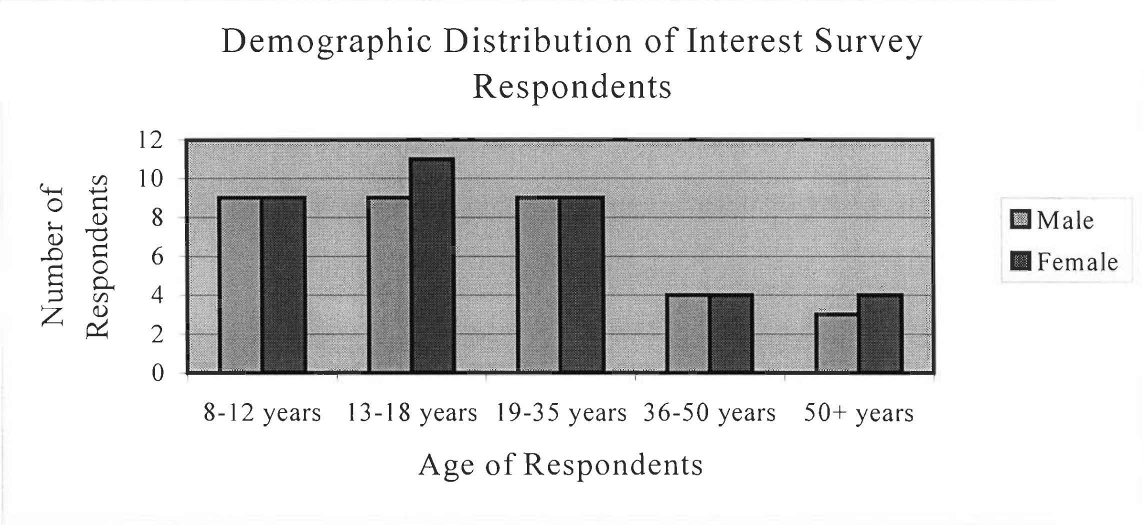


FIGURE 3.4.1 DEMOGRAPHIC DISTRIBUTION OF INTEREST SURVEY RESPONDENTS

Equal representation of various demographics was important since the museum has a complex audience, and we did not wish to exclude anyone's interests. The Science Museum's current practice is to attempt to appeal to both genders of every age, and not exclusively to the largest visitor demographic. Therefore it was unnecessary to sample visitors based on their demographic information and the overall museum visitor profile. However, we still collected limited demographic information consisting of age and gender. This demographic information was used to ensure that we had a well-distributed sample that adequately represented the interests of the Energy Gallery's target audience (children ages 7 through 14) as well as their families.

The survey consisted of four open-ended questions and two Likert-scaled questions. The survey began with two open-ended questions which did not merit long responses and whose purpose was to get the respondents thinking about energy in general. Immediately following those questions we decided to use Likert-scales to determine visitors' interest levels for various topics. According to most experts, Likert-scales offer a simple and consistent method of information gathering and use close-ended questions that allow easy compilation of data (Reagan). By ranking their interests with these scales, we could determine what museum visitors would like to see most in a fuel cell exhibit. Topics covered included the environment, transportation, personal electronics, the space program, and large-scale power generation. Appendix C contains the specific questions we asked. After the two Likert-scale questions, we asked the patrons if they were familiar with fuel cells, and if they were, to describe one for us. This question was used to determine knowledge levels of fuel cells and to see approximately what percentage of the museum audience knew what a fuel cell was. The second part of the question was to make the distinction between people who actually knew what fuel cells are, and those who only thought they knew. Our last question was included at the suggestion of the Museum; it asked where the respondent had heard about fuel cells.

To analyse the data we plotted the results of all of the questions in the interest survey, standardised and non-standardised, by age and by gender. Graphs were used to visualise the data so that trends could easily be observed. Identifying trends in interests would tell us who was interested in what, so that we could design an exhibit that attempted to cover everyone's interests.

We found that museum visitors as a whole were interested in every application of fuel cells that we listed in our survey; however, by analysing the data by demographic groups, we found some concrete trends. The two demographic groups of particular interest to us were those of Key Stages Two and Three -- children between 8-12 and 13-18 years old. By analysing our interest survey data with respect to these groups, we found that these groups were most interested in personal electronics, and they showed by far the least amount of interest in home power. In addition, they were more interested in transport than they were in the space program. This plotted data is contained in Appendix F section 3. We used this data when we designed our exhibit to structure the sections of our exhibit. Specifically, we used this information to dictate the order of the sub-sections in the *Fuel Cells and You* portion; personal electronics was the first topic, followed by transportation, then the space program and home power. Our reasoning behind including home power at all was to appeal to our audience outside of Key Stages Two and Three, as our survey results show that as the age of the group being surveyed increased, so did their interest in home power. We hoped that by covering this broad range of topics we had included information that would appeal to all different audiences. The complete analysis of our interest survey, along with charts of the data collected, can be found in Appendix F.

3.5 Assessing Messages and Content

Careful assessment of the exhibit's message is the third step of the didactic methodology and of our design process. A list of content and messages that needed to be conveyed was obtained by reviewing our background research. Because the Energy Gallery targets a younger and family-oriented audience, concepts and principles were given a higher priority than advanced technical information, but in the end both were included to varying degrees.

There are a few general messages our exhibit attempts to convey. These messages are simply the benefits and disadvantages of fuel cells: that they are clean, efficient, renewable, and in everyone's best interests, but also they are not yet widely available and refinement of their fuel might possibly be expensive. Our content was designed to convey these messages with specific information on how fuel cells work, how they could benefit all of us, and the advantages that they have over current methods of power generation such as combustion of fossil fuels. Our group assessed the exhibit's content and ability to communicate those messages through analysis of the prototype through the feedback survey, which will be described in Section 3.8.1.

3.6 Arranging Content for Presentation

Step four of the didactic methodology, arranging content for presentation, was closely integrated with the design of our concept and our existing list of messages. In order to arrange our content we went through an intense brainstorming and discussion session to design a layout and outline of our web-exhibit. Eventually we came up with a theme, discussed in the next section, which helped to conveniently arrange our content in what would hopefully be an exciting and relevant manner.

A key stage of redesign and revision was anticipated following the results of our feedback survey, due to the improbability of predicting responses and having complete initial user satisfaction. Revision mainly consisted of the repetition of steps three and four of the didactic methodology, creating a process in which we carefully revised our web-based prototype through feedback analysis and continual revisions, until our objectives were accomplished and all parties were satisfied. More detailed information on our feedback survey is contained in Section 3.8.1.

The design of the web exhibit includes a main page with links, as well as a navigation bar. We wanted our exhibit design to have a look and feel consistent with existing on-line displays the museum might already have. However, we did not allow this to limit our design, and given museum approval, we extended our design to one that we feel would be a more appropriate format.

3.6.1 The Concept and Design

Our final concept and layout went through many designs before any development occurred, and many revisions afterwards. For example, we planned on having our site remain consistent with the museum's existing web site, which we did, but not as rigorously as we initially planned. We also planned on having a navigation bar that would provide links to various content pages and our feedback survey.

The purpose of a navigation bar is to provide quick access to specific areas of the exhibit, without users having to go back to the main page or an index. Additionally, our plan initially was to provide a link to a "kids-corner" on the navigation bar, where images and content would be geared towards children. However, we felt that if our thematic concept successfully communicates to all audiences, especially children, an exclusive kids-corner would not be needed.

Our thematic concept originated in part from our background research, which revealed four main types of exhibition: interactive, responsive, participatory and thematic designs (Belcher 65). Responsive designs use elements that simply respond to an action, such as a motion sensor starting a video display. Participatory designs require participation in an event, such as the re-enactment of a battle. Thematic designs use a story to convey information, while interactive designs require interaction to teach abstract concepts. Because we are designing a web-based exhibit and users will be constrained by the limitations of computers, using responsive and participatory designs is impossible, although our design does contain responsive elements, such as animated buttons. Since a combination of approaches is often recommended, we decided to employ interactive and thematic design techniques.

The information to be conveyed in our site has been written in layers, or levels of depth. All text, diagrams, and pictures that appear on the first page of a subsection are considered to be at the "top" or "first" level of our exhibit. The top level of the exhibit is the first thing a patron would see in each subsection. This level has been designed with relatively straightforward information so that a child, or possibly an adult who did not wish to read a large amount of text, could easily get valuable content from the exhibit. A second level has been provided for the visitor who wishes to learn more about what he or she has been learning about on the top level. This information is different from the top level in that the terminology and complexity is greater here. We believed that implementing this type of content structure within our site would be the best method of allowing visitors to learn as much or as little as they wished. This structure also allowed us to cater to children who may not understand the more complex information of the second level.

3.6.2 The Theme and Characters

The Energy Gallery will be focused on children from Key Stages Two and Three (ages 7-14) and their families. Similarly, we plan on making our exhibit on fuel cells accessible as best as possible to these groups. The only criteria for design selection were appeal to children and families and being an effective vehicle for communicating concepts. In order to attract children within Key Stages Two and Three we chose a cartoon theme to communicate the information on fuel cells. We felt that this would use the thematic exhibit design in an effective way since cartoons are generally targeted towards children. Originally, we intended to create a different approach to a theme by associating William Grove (the inventor of fuel cells), space exploration, and fuel cells in an introductory animation. However, we felt that this would not appeal to our desired audience or allow for easy communication of our messages, and thus did not meet our selection criteria.

Our cartoon concept was divided into four representations of different aspects of energy technology, embodied by four characters: *Captain Fuel Cell*, *Old Fossil*, *Nature*, and *The Smiths*. *Captain Fuel Cell* was created to represent fuel cell technologies and their advantages to the world. He has a youthful and clean-cut appearance that symbolises the clean and efficient method that fuel cells use to produce energy as well as his new arrival into the conventional energy production arena. *Old Fossil* is the villain element of our cartoon, and is representative of all sources of energy that are considered to be non-renewable. His appearance is very dirty as though he has been surrounded by smoke for long periods of time, and he looks very old. This is symbolic of the fact that non-renewables have been around for many years and are generally a destructive method of generating energy, producing greenhouse gases. Our third character, *Nature*, represents the interests of the environment. Her appearance is very green and is symbolic of a conventional "clean" environment of trees, rolling hills, and grass. The final character, *The Smith Family*, is actually a composition of four different individuals. *The Smith Family* is comprised of a father and mother, along with a young boy and girl. The children in the virtual family are barely older than children in Key Stages Two and Three, so that young children visitors will be able to associate more with these older stereotypes than a younger version of the same characters. Originally, this element of our cartoon included only a small boy, but we decided that this would not appeal to our whole audience. The concept of having an entire family was employed so that most children could identify with either the boy or girl, and adults could relate to either the male or female parent. All family members have their own interests, corresponding to their age and the findings of our interest survey, so that we could relate certain applications of fuel cells to them and our audience.

3.6.3 Exhibit Layout

The exhibit is divided into four main sections, with a main page that tells the user how to explore the site and then use the interactive portion. An introductory animation that features all of the cartoon characters is included at the beginning in order to draw museum visitors into exploring the site and also for introducing the characters and fuel cells in a very basic way. The four main sections are titled as follows: *Meet the Characters*, *Fuel Cells and You, Fuel Cells and Nature*, and *Fuel Cell Challenge*.

Meet the Characters allows the user to click on any of the four different cartoon representations in order to find out what each character represents. *Captain Fuel Cell*'s section is the most extensive of the four, as it provides a brief explanation of the advantages of fuel cells and displays an animation of the chemical reactions inside a fuel cell. One difficulty in designing this particular subsection was including all relevant information on a single page. We decided to resolve this by including an arrow to link the first section to a second section that displays the remainder of the information that could not be displayed on the first page. We also added a link so that the users can "learn more" if they so choose. We felt that this option gave the users the choice of learning as much or as little as they wished. This section was intended to familiarise the users with all the characters as well as educate the users about how fuel cells work. Throughout the site, details become more scientifically sophisticated as the user proceeds into the second section of content, and here advanced specifics on fuel cells can be obtained in the same manner.

The *Fuel Cells and You* section lists four different applications of fuel cells and a brief explanation of each. This is also where the different applications are linked with the interests of the cartoon family. For example, in the space program subsection, the little girl who wants to be an astronaut is present and makes a small comment about fuel cells in space. We considered having the characters explain how fuel cells are used in each application, but we felt that this would go against our survey findings that show that a very small percentage of the population know what fuel cells are, and we did not want to insult users' intelligence by having a child explain fuel cell specifics to them. We also added "Click to Learn More" links in each subsection, again so users could learn more if they wanted. This section also provides, whenever possible, references to any fuel cells which are "on gallery" outside of the fuel cell exhibit. In this section, the users should have learned how fuel cells can impact their lives for the better, but also received reinforcement that fuel cells are not yet commercially available to them.

The *Fuel Cells and Nature* section is intended to show users how using fuel cells can help reduce the pollution problems currently affecting the environment. We chose to include this section primarily because our interest survey showed trends that the audience in general was interested in the environment and how it is impacted from the use of different energy sources. We also decided that this section was important to include since it takes nature and fuel cells and relates them to the user. The purpose of this section was to illustrate and emphasise the positive effect fuel cells could have on the environment.

The final section of our exhibit, *Fuel Cell Challenge*, is an interactive quiz game designed to reinforce concepts presented in the exhibit and to encourage users to find the answers that they do not know. The goal of the game is to save the environment, while enabling people to maintain their lifestyles. This can only be accomplished through knowledge, as knowledge is power; thus the quiz game. The quiz consists of multiple-choice questions, in order of increasing difficulty, which covers a majority of the material in the exhibit. The easier questions feature information found in the first section of content, and the more difficult questions cover the second section of more advanced content. If the answer to a question is not known or when an incorrect answer is given, *Captain Fuel Cell*, as the host of the quiz game, provides a hint. The users have as many opportunities to answer a question, as they need to get it correct. Limiting the number of times the users can respond might make them feel ignorant or defeated if they lose in the traditional way and have to restart. When a correct answer is given, a short statement is provided which reinforces to the user the answer and concept behind the question. The quiz features sound effects and a progress bar to indicate a progress level to the user. Ten questions allows the quiz to have some depth, while ensuring that it can be completed in a few minutes. Once all ten questions have been answered correctly, a reward animation is played which tells the user that nature has been saved and then reinforces some key messages from the exhibit. Appendix H contains the site map, and Appendix I contains screen shots of every page in the site.

3.7 Exhibit Implementation

As previously described, the primary objective of our prototype is to educate the museum-going public on fuel cells. Our prototype employs visual aids and interactivity to make the exhibit educational, as well as entertaining and enjoyable. In our design we employed the concept of interaction, one of our objectives, by avoiding linear web designs, and by encouraging exploration into areas of interest as they appear. A linear web design was avoided because it would attempt to coerce the visitors into one predetermined path. Visitors are likely to find such designs annoying and perhaps bypass them altogether (Belcher 63).

At the Science Museum's recommendation, we implemented the web-based prototype with Macromedia Flash and Director. Both Flash and Director allow for easy creation of animations and interactive media presentations, and the means to display them on the web. We also made use of Adobe GoLive, Adobe PhotoShop, and Macromedia Fireworks. Learning these software packages and going through tutorials was a time consuming but important process. Mastering these packages was important to effectively implement all of our design decisions. GoLive is a web-site authoring tool, which helps to simplify coding complex HTML. PhotoShop is a comprehensive graphics editor, and was used in the creation of our images. Fireworks was used primarily for creating the buttons and text effects. All of these programs have virtually unlimited capabilities in the design of media; their only limits are the designers' imagination and the amount of work they are willing to put into it. We made sure that these software tools were available for our use in London. Careful investigation was made into alternative software packages, and through our own experience, we determined that these were the most appropriate tools.

Before any designs were brainstormed or any of these multimedia and web authoring packages were used, we carefully considered any potential technological restrictions. Since this exhibit is targeted for use via the World Wide Web, there are specific technological considerations that needed to be addressed; the main areas of concern are download time and display issues across different browser and computer platforms.

Download time is an extremely important factor in any World Wide Web site. Whether or not a page loads quickly enough can be the deciding factor in whether a user continues to browse a site or not. For this reason, we carefully considered download time in every facet of the prototype. Of particular concern was the size in bytes of the introduction animation and the interactive. Fortunately, the Macromedia products that we used employ extensive compression schemes that minimised file size allowing for maximum design flexibility. For every static graphic that we produced, we used a feature of our software to determine how long it would take for a user to download over a variety of different modem speeds to give us an accurate picture of how long the user would need to wait for a page to load. Using these tools, we did everything possible to minimise download time for the user.

Display issues are another major concern for the World Wide Web. The first complexity is that different visitors use different computer platforms, and each platform has different Web browsers unique to that platform. The common platforms are both Macintosh and PC while the most common browsers are Netscape and Internet Explorer. Inherently PCs and Macintosh display information in slightly different manners; the Gamma values are different between the two as the amount of pixels per area. These appear to be small issues, but in reality they make a difference. For instance, because of the way the Macintosh draws its information on screen, text on a web page appears smaller than the same text displayed on a PC. Between browser platforms there are unique alignment and spacing issues as well as tags that are specific to each. To be proactive we obtained statistics from the Science Museum's web server that helped identify the most used computer and browser. We designed the site with a target platform, but tested it across as many different platforms as possible. In the end we produced a site that should look just as good on any platform as it does on another.

Finally, since we are anticipating that our prototype will eventually be used on gallery, we designed the site with the idea in mind that it will someday be adapted to a touch screen display. In designing the site navigation, there were no text links made, just buttons, all of which are large enough for fingers on a touch screen. Another consideration was optimum resolution. Katie Streten, the Science Museum's web co-ordinator, agreed that our target resolution should be 800x600. To maximise the useable screen area, we have our site open a new window from its "parent" window in the main Energy Gallery page without the buttons and toolbars that are usually displayed in the browser. By eliminating these, we have much more space to work with. An added benefit of this is that since the whole screen area at 800x600 resolution is being used, it can be more easily adapted to gallery use where it will occupy a full screen probably not run on a web browser. By carefully planning and anticipating potential problem areas, we feel that our site is very flexible for diverse web use as well as for gallery adaptation.

In gathering images for the site, we found that copyright permissions would be needed to use certain images. Initially we planned on requesting permission to use this media as it was needed. However, the Science Museum's own picture library has many appropriate images that we have access to where copyright was not an issue. There were still, however, some instances in which we had to contact companies to obtain copyright permission for fuel cell and fuel cell related images. These companies included International Fuel Cells, DaimlerChrysler, ONSI Corporation, Energy Related Devices, and General Electric.

3.8 Analysis of Prototype and Revision Process

Initial analysis of our prototype was completed through review sessions with Science Museum staff followed by informal discussion-like interviews. This was the first testing done, so that any issues could be resolved and revised before gallery testing and visitor feedback. The testing area allowed for visitors to be observed while they tested the exhibit. A survey was administered following the observation and testing.

3.8.1 Observations and the Feedback Survey

Once the prototype was available for testing, observations on visitor behaviour were made by a project team member followed by an open-ended survey to collect feedback on our web-based exhibit. Both open-ended questions and observation were used to remain consistent with the Science Museum's current testing procedures. Such feedback was valuable to determine the effectiveness of our design in communicating the highly technical information on fuel cells. As with our initial interest survey, we selected a wide range of testers from our audience, so as to obtain a sample representative from demographic groups. The responses of every person who used the prototype were used in our analysis, serving to make our results clearer and more comprehensive.

We conceived before coming to London that the survey would be computer-based and accessible at any time during the patron's interaction with the prototype. Our rationale behind making the survey computer-based was to remain consistent with the web-based design of the prototype. An advantage of this would be that the prototype would be fresh in the users' mind, and because they would still be sitting down, they would be statistically more likely to fill out an online survey as opposed to a physical one (Shneiderman 134). However, this was changed to remain consistent with existing Science Museum procedures. The changes consisted of having the user under observation while using the exhibit, directly followed by an oral interview during which administrators filled out a brief form. Initially, we planned on having the survey take up no more than one screen to increase the likelihood that its length would not discourage the user. Similarly, the revised interview survey was only one page and required only a few minutes of the user's time. It has been documented that shorter surveys yield a greater response rate (Shneiderman 134).

The observations were made on user reactions, comments, and course of action while using the prototype exhibit. As with all observations, our observations were subject to bias from both observer and user, and were evaluated qualitatively with this in mind. The observation form and feedback survey can be found in Appendix D.

Immediately following the stage of testing and observation, the feedback survey was administered by a member of the project team who queried users on their reactions to the prototype's content and presentation. The initial draft of the survey used a series of Likert-scaled questions. The questions queried users on satisfaction, whether they felt they learned anything, appropriateness of images and graphics, and the overall design. Additionally, a comment box with a short introduction was available for visitors to add their own opinions. The revised version of this survey contained similar questions edited for oral presentation in an open-ended style. The availability of a commentary portion allowed us to collect a wide-range of viewpoints not covered by our survey questions.

3.8.2 Testing and Revisions

A period of pre-testing was reserved for Science Museum staff. Initial testing included a period of observation and informal discussion with six staff members. All the staff enjoyed the site's theme and images; however, some staff thought an increased text size would be helpful along with some changes in navigation buttons. A large majority of this feedback was positive, so we took the effort to address the few concerns pointed out. An increase in text size was eventually determined to be unnecessary as the reading trouble was attributed to a small screen set at an unusually high resolution. After the resolution was corrected, this problem went away. Improvements were made in both navigation buttons and written directions by rewording text and implementing animations where they were previously lacking.

After the period of pre-testing, the process of obtaining visitor feedback began. With our observations and interviews from visitors, we looked for information on how well our design effectively communicated and accomplished the objectives of the exhibit. Feedback from Key Stages Two and Three testers were of special importance, and were given precedence over users of other demographics. Twenty-two out of forty interviewed users were located in the 8-12 and 13-18 age groups, the age groups that correspond to our target audience. Overall, a 90% response rate was obtained from visitors approached with the prospect of testing a new exhibit.

During observation, a majority of the users appeared to react positively to the introductory animation. Navigation through the exhibit went smoothly for most of the visitors. Users seemed to understand the buttons and links, and often went through the areas by the order in which we laid them out. The average visitor spent approximately 15 minutes traversing the site, not including time spent on the interactive.

Our feedback data indicates that the messages that the users received closely corresponded to our intended messages: the importance of fuel cells as efficient and renewable sources of energy while being environmentally friendly. Additionally, some visitors reported unintended, but beneficial, messages such as a feeling of hope that things can change and improve, individual families can make a difference, and that it doesn't take an entire population to do something like help the environment. We felt that this was a good indication that we had accomplished our goal to effectively communicate the beneficial aspects of fuel cells.

Results of the survey were used in revision of our prototype by addressing specific problem areas identified for optimising presentation. One problem area that we found was that 46 percent of the visitors we tested did not fully understand the exhibit content. Further analysis showed that this was due to both the technicalities of the information and unfamiliarity with the English language. Though some revisions have been made from these results, translation into a foreign language has not been completed and some information cannot be made less technical than it currently is. For example, every component of a fuel cell has technical terminology associated with it, including the anode and electrolyte. When discussing the anode and describing what it does, we could mention things like negative charge and ions and so forth. But each of these technical words also requires an explanation, especially to a seven year-old. It seems that we can do either one of three things in our technical descriptions – describe what an anode does, describe what an anode does and mention negative charge and ions, or describe both what anodes do and what negative charges and ions are. We took the middle option and mentioned the extra scientific terms to remain as technically accurate as possible, but did not fully describe to decrease the overall amount of highly technical text.

Even so, one user commented that the text on the screen was too dense. As a result, every area of content was revised and condensed; unfortunately, some areas remained relatively "text heavy". Thinning these areas beyond what was already done was not possible unless the information was to be divided into different pages, which is something we wanted to avoid. By dividing the content into more pages, the site would become more convoluted and harder to navigate.

Additionally, one user commented that the text size was too small. In exploring this, we determined that this would not be an issue on the target user's personal computer. We reasoned that this comment resulted from the combination of the small size of the laptop screen combined with the high resolution that it was set at during testing. After changing the resolution and using a different monitor, we received no comments on text being too small to read.

However, overall the exhibit received a very positive response. On a scale of one-to-ten, the average response on the overall rating of the exhibit was approximately 7.5. When visitors were asked what they liked most about the exhibit, the most common responses were the cartoon theme, the interactive, and the introductory animation, in that order. When the visitors were asked what they liked least, 39 percent of the population replied that they liked all of it. The largest complaint, that the exhibit was "text heavy," came from only 14 percent of the visitors.

A complete and detailed analysis of the observations and surveys is contained in Appendix G.

3.9 Physical Exhibit Recommendations

After going through the entire development and implementation of our web-exhibit, we formulated a few preliminary ideas for an actual physical exhibit on fuel cells and presented them to the Science Museum in addition to our web-based prototype.

Suggestions were developed throughout the phases of our project. Some were conceived of while still in the United States, while some were made by walking through an exhibit and thinking of an idea that would work well, and others from the findings of our surveys and interviews. All suggestions were further developed into a presentable form before our final presentation and recommendations.

Considering the interactive nature of the exhibit, we propose that it would be helpful to obtain a working fuel cell that responds in some manner to the presence of a user, whether by press of a button or motion sensor. We suggest a combination of display methods for increased effectiveness. One interesting option we propose for this exhibit would be a working fuel cell car, which could be obtained from one of the current manufacturers such as DaimlerChrysler. This option appears impractical when examining the lack of available floor space in the Energy Gallery plans. Even though space is limited, a car could potentially be suspended from the ceiling or placed in another part of the gallery with an explanation of how it is powered and its performance statistics.

Another key element of the exhibit should be a computer-based feedback terminal. Terminals such as these have been implemented at the Boston Science Museum, and provide a non-obtrusive method of finding what museum patrons are learning, what they like, and what they dislike. This terminal should be video-based, so that the user can be seen and heard by the evaluating staff. Such an addition to the exhibit will allow the Science Museum to update the exhibit from useful suggestions to accommodate the museum patron.

Through our interest survey we found a strong indication that, despite their lack of knowledge about fuel cells, patrons were interested in how energy is used in many different applications. For this reason, our team has decided upon a few different ideas which incorporate this concept into a physical exhibit. Our first suggestion could directly show the application of fuel cells to the museum visitors by having the fuel cell exhibit, and possibly other exhibits surrounding it, be powered by a stationary fuel cell power unit, which could be obtained from General Electric. If possible, this power unit could be modified by making the housing constructed out of clear materials to illustrate its inner workings. In conjunction with having the exhibit powered by a fuel cell, an LED display could be provided which could estimate the amount of fossil fuels that have been conserved by using this method in the museum. Specific information on the conservation of fossil fuels would have to be further researched by exhibit developers before such an idea could be implemented.

In addition to presenting the applications of fuel cells it is also important that the visitor understand fuel cell history and operation, since applications are not the entire picture. For this reason we have recommended the inclusion of both a history board with pictures of key individuals in the development of fuel cells, such as William Grove and Francis Bacon, as well as an animation which shows the operation of a fuel cell in a way which is easily understood. Such an animation can be found within our exhibit in the *Fuel Cell Operation* section and could be adapted to a computer display.

3.10 Deliverables

At the end of our seven weeks in London, we delivered a functioning web-based prototype exhibit on fuel cells that had been improved based on evaluation by visitors. We also submitted an outline of our best recommendations on how an eventual exhibit on fuel cells could be constructed. This exhibit, should it be constructed, could make up a crucial and attractive element of the newly constructed energy gallery.

4. Summary and Recommendations

Our team's computer-based prototype exhibit on fuel cells is the product of several different research techniques and methods. During our time in London, we conducted two separate surveys – an interest survey to gauge visitor interest levels in different applications of energy, and a feedback survey and observation session from which we were able to determine and correct the noticeable deficiencies in our exhibit. According to the data we collected from our surveys, this exhibit has in fact been tailored successfully to the interests of museum visitors.

The interest survey that we conducted indicated many different interests within the museum audience. It became apparent to our team in analysing the results of this survey that most people in general had very little knowledge of what fuel cells are. This data indicated to our team that there was a great need in the Science Museum for an exhibit on fuel cells that described this technical concept to a non-technical and young audience.

Our feedback survey and observation was designed to be an indicator of how museum visitors felt we could improve upon our exhibit design and content. The main concern of our team was to make our site content understandable, while at the same time keeping visitors interested enough to go through most of the site. Our data indicated that visitors had some difficulty understanding the technical content, but they received most of the intended messages. The feedback surveys also revealed that museum visitors enjoyed the cartoon element regardless of age, and many commented that it helped to draw them into the exhibit and its content.

During the course of this project, our team has observed many different exhibit designs at the Science Museums in London, England and Boston, Massachusetts. One observation that we have made is that we have encountered very few exhibits, if any, which have employed a technique similar to ours -- using an animated theme to communicate an understanding of a particular subject. Since our observations and feedback analysis have indicated that our thematic approach to teaching fuel cells has been effective within the museum audience, it may be of interest that the Science Museum research and explore the possibility of creating more exhibits of this type.

Our team has made several suggestions for a physical exhibit on fuel cells, the details of which can be found in Chapter 3.9. Briefly these suggestions include a history board that details the achievements of Grove and Bacon, as well as an animated diagram of a basic fuel cell. Additionally we have suggested that a stationary power unit be obtained to power the exhibit, housed possibly in a clear case to show its inner workings. We have also recommended that the museum include an LED display with the exhibit to show fossil fuel conservation resulting from the use of the stationary power unit in the fuel cell exhibit.

A final recommendation is that our exhibit, should it be placed on the web, also be adapted to a touch screen and placed on gallery. Our design has incorporated large icons for navigation for this reason, making the graphical and layout transition very simple. Since the exhibit was designed for the web, it may have too much text for an exhibit on gallery. We recommend that the content be scaled down to a maximum of 60 words per page for an on gallery version. The placement of our exhibit on gallery will be left entirely to the discretion of the Science Museum, and such placement would allow more than just Internet users to view our exhibit.

To conclude, based on our research during the course of this project, following these recommendations would make interesting and educational additions to a physical exhibit on fuel cells. This technology has the potential of reshaping the way we use energy, and it is important that as many individuals as possible learn this information. Our exhibit is an innovative and unique implementation on fuel cells to fulfil this need. To the best of our knowledge, our web exhibit is the first to feature thematic concepts with animated characters, and is on the forefront of the exhibition of fuel cells.

5. Bibliography

Belcher, Michael. Exhibitions in Museums. Washington: Smithsonian Institution Press, 1991.

Blomen, Leo and Mugerwa, Michael, ed. Fuel Cell Systems. New York Plenum Press, 1993

Breakthrough Technologies Institute. http://www.fuelcells.org/ Accessed: January 23, 2000

Breakwell, Glynis M. Interviewing: Problems in Practice. Exeter: British Psychological Society,
1990

Brenner, Brown, and Canter. The Research Interview: Uses and Approaches. London: AP, 1985

Daimler Chrysler. http://www.daimlerchrysler.de/ Accessed: January 27, 2000

De Vaus, D.A. Surveys in Social Research. London: UCL Press, 1996.

Electro-Chem-Technic. http://www.i-way.co.uk/~ectechnic/home.html/ Accessed: January 23, 2000

Fry, Martin R. Environmental Impacts of Electricity Generation: Fuel Cells. IEEE Proceedings-A140.1 (1993): 40-46.

Gammon, Ben. Everything We Currently Know About Asking Visitor-Friendly Mechanical Interactives. London: Science Museum, 1999.

Gammon, Ben and Theano Moussouri. Text and Labels: Do Visitors Read Them. London: Science Museum, 1995.

Gammon, Davies and Graham. School Groups in Museums. London: Science Museum, April
1999

Hirschenhofer, John. Fuel Cell Status: 1996. IEEE AES Systems Magazine (1997): 23-28.

Hockaday, Robert. Micro Fuel Cells For Portable Electronics http://www.energyrelatedevices/ppts/lucerne_640/tsld001.htm Accessed: January 27, 2000

Kalton, Graham. Introduction to Survey Sampling. Beverly Hills: Sage Publications, 1983.

Lewis, Ralph H. Manual for Museums. Washington: National Park Service, 1976.

Los Alamos National Laboratory. http://www.education.lanl.gov/resources/fuelcells/ Accessed: January 23, 2000

National Fuel Cell Research Center. http://www.nfcrc.uci.edu/ Accessed: January 23, 2000

National Museum of Science and Industry. http://www.nmsi.ac.uk/ Accessed: January 23, 2000

Neal, Arminta. HELP! for the Small Museum. Boulder, Colorado: Pruett Publishing, 1973.

Rahman, Salfur, and Kwa-sur Tam. A Feasibility Study of Photovoltaic-fuel Cell Hybrid Energy System. IEEE Transations of Energy Conversion 3.1 (1988): 50-55.

Scientific American. Taking on the Energizer Bunny http://www.sciam.com/1998/0498issue/0498techbus2.html Accessed: January 27, 2000

Shneiderman, Ben. Designing the User Interface: Strategies for Effective Human-Computer Interaction – 3rd ed. Reading, Massachusetts: Addison-Wesley, 1998.

United Technologies Corporation. http://www.internationalfuelcells.com/ Accessed: January 27, 2000

Appendix A - The National Museum of Science & Industry

Mission Statement

"The Museum exists to promote the public's understanding of the history and contemporary practice of science, medicine, technology and industry."

Background Information

In the nineteenth-century Prince Albert organised The Great Exhibition of 1851 to promote scientific achievements. The Exhibition was a success, and the profits were used to establish the South Kensington Museum in 1857. In 1909 the Science Museum was formally separated from the Victoria & Albert Museum.

The Science Museum, along with the National Railway Museum in York and the National Museum of Photography, Film & Television in Bradford, comprise the institution known as the National Museum of Science & Industry. The museum is governed by a Board of Trustees, appointed by the Prime Minister, and funded by grant-in-aid from the Department of Culture, Media and Sport.

The National Museum of Science & Industry possesses the world's largest and most significant collection that illustrates the history and contemporary practice of science, technology, medicine and industry. The Science Museum covers seven floors and has more than 40 individual galleries. These galleries display over 15,000 objects from the Museum's collections. (http://www.nmsi.ac.uk/)

Appendix B – Summarised Notes from Interview with Professor Datta

This appendix includes information gained from Professor Ravindra Datta, head of the Chemical Engineering Department at Worcester Polytechnic Institute, Worcester, Massachusetts. The information is paraphrased from the original notes from the interview.

Timothy Dresser and Andrew Jeas at Worcester Polytechnic Institute conducted this interview on February 9, 2000.

What types of fuel cell research being done here at WPI?
There is a Fuel Cell lab located in Olin Hall. Their research relates to proton exchange membrane fuel cells. This research focuses on improving small PEM fuel cells, $5cm^2$ to $25cm^2$ (2 to 10 watts). Any results at this level can be then scaled up to larger PEM fuel cell uses.

What are some of the other areas in which research is ongoing with fuel cells?
Usually it is not feasible to carry a tank of liquid or compressed hydrogen. Current research is progressing in the area of converting conventional fuels such as gasoline or ethanol to a hydrogen rich gas, for use in present fuel cells. Additionally research is progressing in finding ways to store hydrogen in metal hydrides.

Where do you see fuel cells in 10 to 25 years?
Fuel cells will replace batteries in many applications. Some of the areas will include in homes, cars, and cellular telephones. The use of platinum in fuel cells, one of the most expensive components, will be diminished over time as less expensive replacements are found. Another expensive component of fuel cells, specific to PEM fuel cells, is the proton exchange membrane. Professor Datta predicts that the cost of the membrane will decrease over time.

What are some interesting statistics relating to fuel cells?
Low output voltage from a single cell, high current ($250mA/cm^2 – 1A/cm^2$)
Typical efficiency of a Fuel Cell 35% to 50%
Max efficiency of an Internal Combustion engine 20%
Current density of fuel cells much higher than that of batteries

Can you recommend any sources for information about fuel cells?
"Fuel Cell Systems" (Plenum Press) is an authoritative source on all types of fuel cells.

To your knowledge, have there been any other projects at WPI concerning fuel cells?
Currently an Interactive Qualifying Project team is researching usage of fuel cells in homes. Professor Datta is co-advising this IQP. The two undergraduate students on this project are Bryan Leblanc and Peter Olszak.

Appendix C - Interest Survey Questions

Hello my name is _______, I'm working with The Science Museum testing out ideas for exhibits in the new Energy Gallery. There are no right or wrong answers; we're only interested in your opinion, which can help us develop new exhibits. Would you mind sparing a few minutes answering some quick questions? If something is unclear please interrupt with any questions.

1. **Could you please name some sources of Energy that you are familiar with?**

2. **Are you familiar with alternative or green energy sources? Could you please list some?**

3. **I'm going to list several topics relating to energy and I'd like you to tell me how interested you are in each topic.**

	Not Interested	Somewhat Interested	Interested	Very Interested
Personal Electronics (mobile phone, portable computer, etc.)				
Transport (automobiles, trains)				
Space Program				
Energy in Your Home				
Environmental Impacts of Energy				

Now I'm going to list several properties of energy sources; please tell me how interested you are in each.

	Not Important	Somewhat Important	Important	Very Important
Costs (and economic impact)				
Longer life (operation time)				
Efficient use of non-renewables				
Emission-free, environmentally friendly				

4. **Are you familiar with the term "fuel cell"?** NO YES
   Could you describe a fuel cell for me?

5. **From what source(s) have you heard about fuel cells?**

Age Group: 8-12_____ 13-18_____ 19-35_____ 36-50_____ 50+_____
Gender: Male______ Female______.

Appendix D – Observation Sheet and Feedback Survey Questions

Hello my name is ______ and I work for the Science Museum. We are testing an exhibit for a new gallery that we are developing. Would you and your child(ren) be interested in spending a few minutes helping us test them out? {if yes take into testing area}. This is only a prototype of the final exhibit so there is still a lot we need to improve but we want to see what people think of it. Just pretend that you came across it in the gallery...

Specific points to look out for:	Describe step by step what happens as if you were dictating it out loud to someone.
How do users react to the intro animation?	....
What do the users say to each other and to you?	....
In what order do the users go through the exhibit?	....
Do the users understand the buttons and links?	....
Do the users appear to read the exhibit content?	....
How long do the top level pages hold the users attention? Which ones do they skip?	....
Do the users select to learn more info? How long does the second level pages hold their attention?	....
Do they users read the interactive intro and instructions? Did they understand them? Did they read the hints and read the "correct" question screens?	....
Additional Observations:	

Follow up questions:

1. What do you think this exhibit was trying to show you? {Prompt with, "What do you think we are trying to say to you about fuel cells?" if they are stuck.}

2. Did you find the information that was in the exhibit interesting? {if yes, what}

3. Were there any terms or phrases in the exhibit that you didn't understand? {was there any text that was too long}

4. Was there any text that was hard to read? {disappeared too quickly, colour issues, etc}

5. What did you think of the diagram that showed how fuel cells worked? {Was it clear?}

6. What did you think about the game? {Follow up, "Were there too many questions?"}

7. What did you like most about the exhibit? {What did you like about it?}

8. What did you least like about the exhibit? {How could we improve it?}

9. On a scale of 1 to 10 where 1 is not interested at all and 10 is very interested, how interested would you be in using this exhibit in an exhibition?

10. Do you have any other comments about the exhibit?

Age group:

8-12 13-18 19-35 36-50 >50

M / F Date:

Appendix E - Project Timeline

Timeline

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Interest Survey							
Exhibit Design							
Develop the Exhibit							
Prototype on Display							
Feedback Survey							
Final Exhibit							

Appendix F – Summary and Evaluation of the Interest Survey

This appendix summarises our findings from our interest survey which was conducted from March 29, 2000 through March 30,2000. A total of 71 surveys were conducted with a 90% response rate. All surveys were conducted face-to-face between a patron and a member of the project team.

All of the participants in this survey were from Launch Pad, the Challenge of Materials Gallery, or the Space Gallery. The survey was broken down into age group and gender, and it was the intention of the team to collect data from our target audience of Key Stages Two and Three as well as families. The breakdown of our survey audience was as follows: 18 (8-12 years), 20 (13-18 years), 18 (19-35 years), 8 (36-50 years), and 7 (50+ years) with 34 of our audience being male and 37 being female.

The graphs to follow are a graphical representation of the data that we collected. When possible we have attempted to analyse trends within our data sets. All raw data has been compiled into charts, and has been provided at the end of this appendix.

F.1 Question 1

Can you please name some sources of energy that you are familiar with?

Question 1 and 2 functioned to get an idea of how comfortable and familiar the general public is about the term energy and different energy sources. Additionally, this served the purpose of getting the patron thinking about energy so they would be better prepared to answer the questions to come.

Figure F.1a shows the breakdown of responses given by percentage of occurrence. It can be noted by this graph that fossil fuels were the most popular response by our survey audience, with solar power not far behind. The fossil fuel response was a compilation of any response that was considered to be a fossil fuel. For example, if a participant responded with “coal”, then that was graphed under the category of a fossil fuel.

It is worthy to mention that survey participants occasionally had some confusion as to what the particular kind of energy the survey was referring to, which can been seen in our raw data, and somewhat in Figure F-1a. The single largest response here was “kinetic” energy with some of the lesser responses being “friction”, “caffeine”, and “sugar”. We were aware of this, but since this happened infrequently and because the intention of the survey was primarily to get participants thinking about energy we didn’t consider it to be a problem.

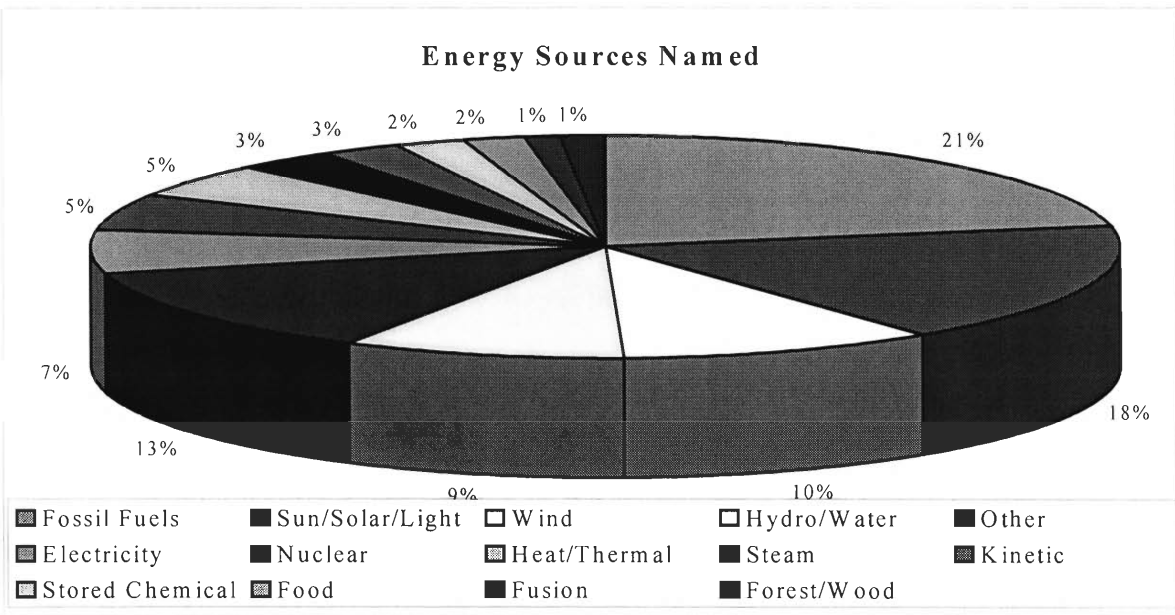


FIGURE F-1A – ENERGY SOURCES NAMED BY PERCENTAGE

One interesting observation that we made during the analysis of our data was that survey participants from different age groups gave a significantly different number of energy sources. In Figure F-1b, it can be observed that females between the age of 13 and 18 had the highest average number of responses for this question. This is only speculative, and it is possible that it could change if the survey pool was increased.

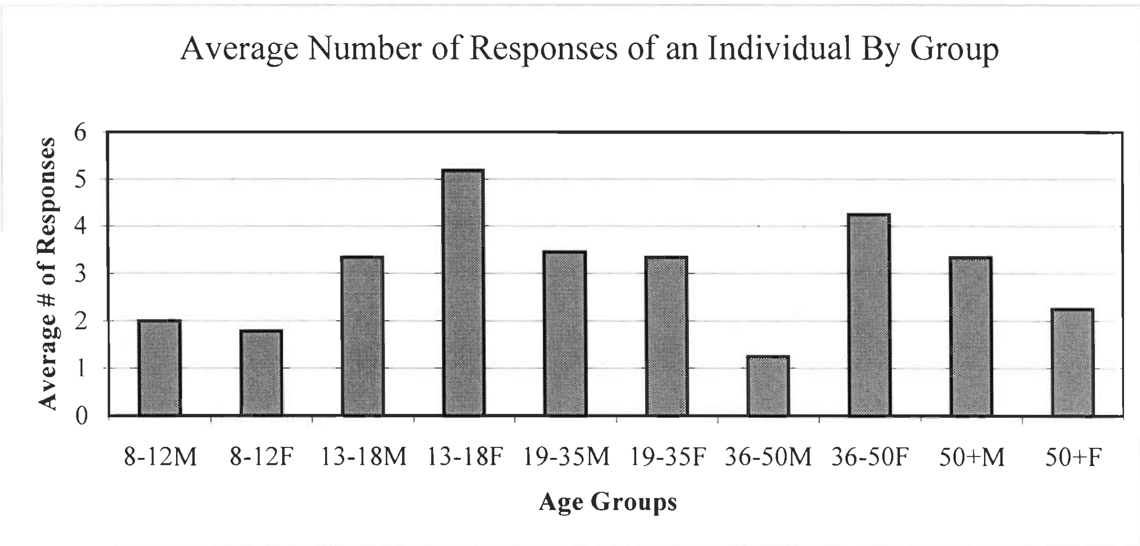


FIGURE F-1B – AVERAGE NUMBER OF RESPONSES BY GENDER AND AGE

F.2 Question 2

Question: Are you familiar with Alternative or Green Energy Sources? Could you please list some?

As mentioned previously, this question was intended to get the survey participants thinking about energy. Figure F-2a shows the percentage of those people who responded either "yes" or "no". In general, we found that the majority of those surveyed said that they knew what an alternative or green energy source was. Of those respondents who said "yes", we found that the most popular responses given were solar, wind, and hydroelectric. In less than 10% of the case, those who said "yes" on the first part of the question, gave a response which was not an alternative energy source. There could have been a number of explanations for this, and it could have been that the survey participant did not know what alternative or green energy meant. Figure F-2b lists the different responses for question two.

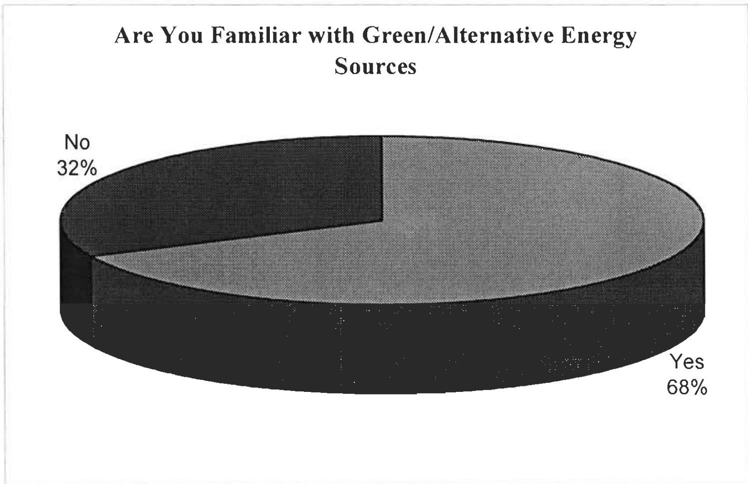


FIGURE F-2A – FAMILIARITY WITH GREEN/ALTERNATIVE ENERGY SOURCES

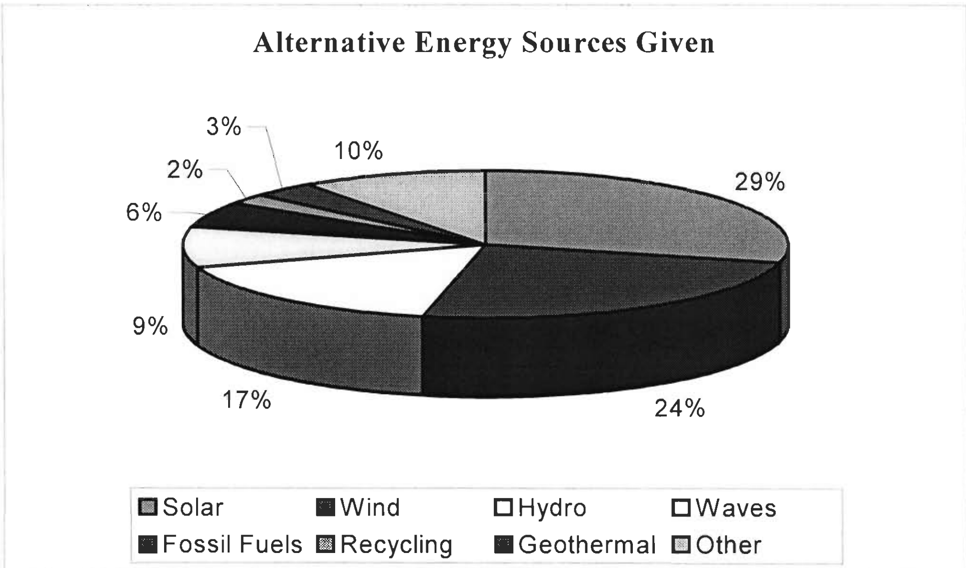


FIGURE F-2B – BREAKDOWN OF ALTERNATIVE ENERGY SOURCES GIVEN BY PERCENTAGE

F.3 Question 3

Question: I'm going to list several topics relating to energy and I'd like you to tell me how interested you are in each topic.

Question 3 and 4 had the purpose of gauging the interest level of the museum public in different areas of energy. These categories in question 3 included personal electronics, transport, the space program, home power, and environmental impacts of energy. For each of these categories, the respondent was asked to rate his or her interest by giving a number on the scale of 1 to 4; "1" indicating "not interested" and "4" indicating "very interested". The values of each response was weighted in the results, so that a response of "very interested" would have a greater influence on our graph as opposed to a response of "not interested". Figures F-3a – F-3e show a breakdown by age and gender, with values of interest level being on a scale from 0.0 to 1.00. Interpretation of these numbers is as follows – a score of 0.0 would indicate that all responses within that particular group was "not interested" whereas a score of 1.00 would indicate that all the responses in that group were "very interested".

Upon observation of these results, it can be noted that there was a wide range of responses, which seemed to vary by gender and age only on certain topics, such as transport, space, and home power. Perhaps the greatest and most obvious trend in interest level was in the category of home power, where individuals in the age range of 8-18 seemed to have very little interest, but as age increased the interest level increased with it as well. These results were consistent over both the male and female participants.

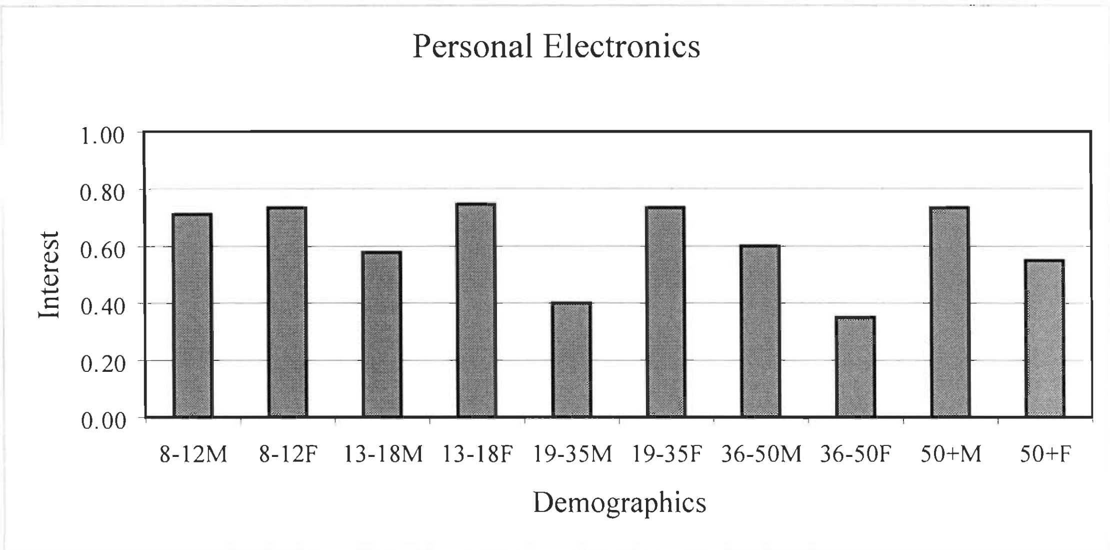


FIGURE F-3A – INTEREST LEVEL IN ENERGY APPLICATIONS INVOLVING PERSONAL ELECTRONICS

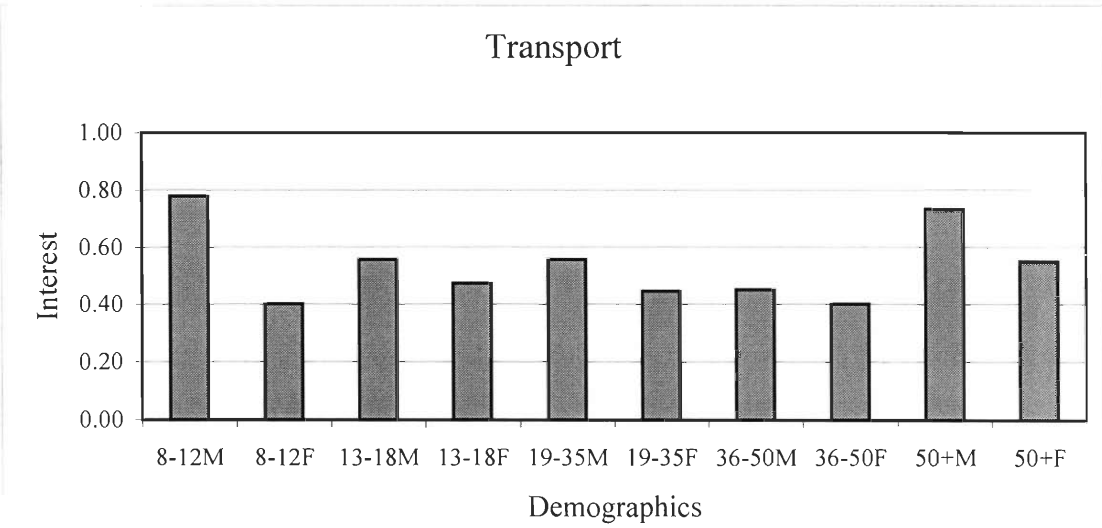


FIGURE F-3B – INTEREST LEVEL IN ENERGY APPLICATIONS INVOLVING TRANSPORTATION

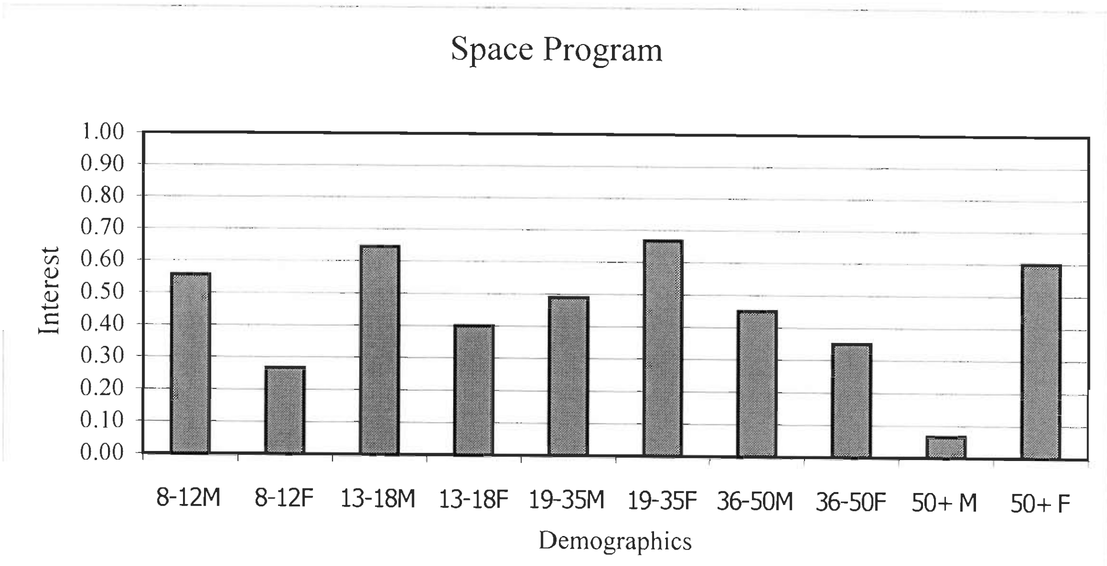


FIGURE F-3C – INTEREST IN ENERGY APPLICATIONS INVOLVING THE SPACE PROGRAM

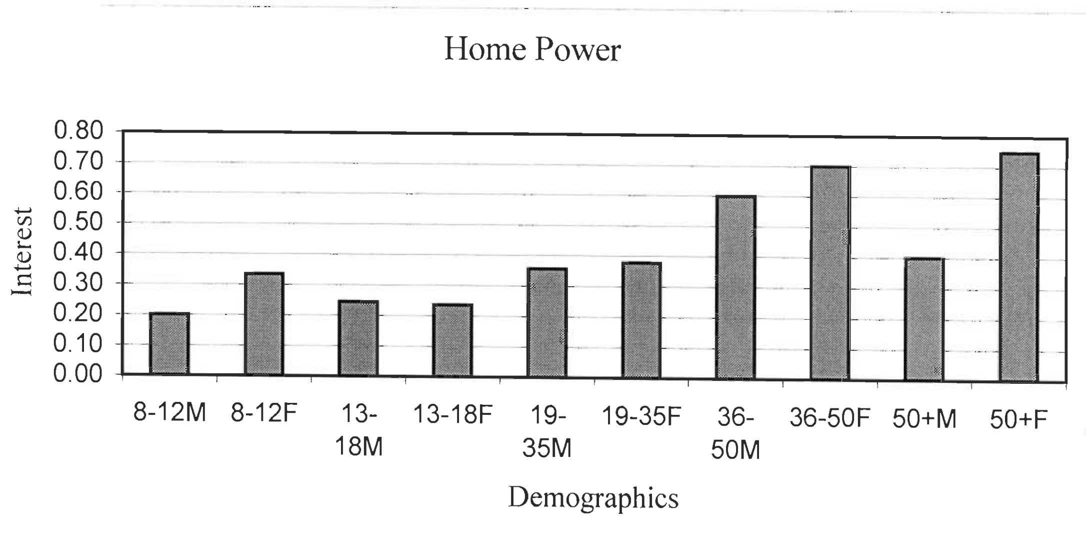


FIGURE F-3D – INTEREST LEVELS IN ENERGY APPLICATIONS INVOLVING HOME POWER

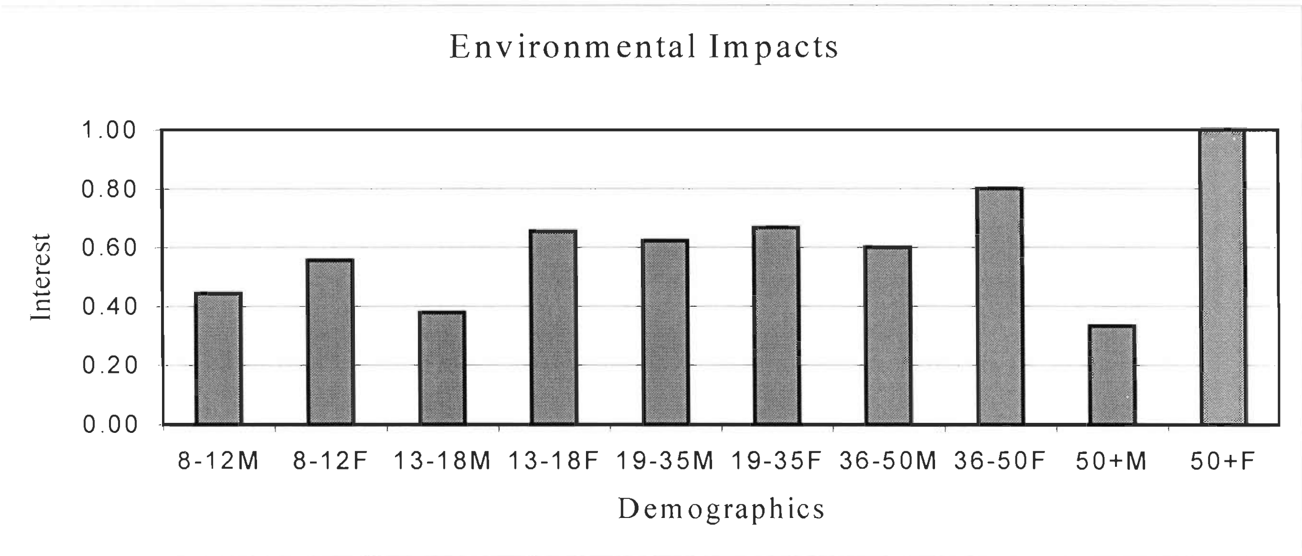


FIGURE F-3E – INTEREST LEVELS IN ENERGY INVOLVING THE ENVIRONMENT

The “Environmental Impacts of Energy” and “Personal Electronics” section seemed to not have a correlation between different groups. On average, most of the survey participants seemed to be “interested” in these categories, with slightly less interest in the 8-12 age range for environmental impacts. “Personal Electronics” seemed to have a less consistent response between genders, with those in the age range of 19-50 having significantly different levels of interest across males and females. It is possible that this could be corrected by an increase in the sample size, since the results for males and females in this age range were not consistent. Based on these results we determined that the environment is subject that appeals to all age groups

“Space Program” had high levels of interest for young males aged 8-18, who responded on average as being “interested”. Young females in the same age group, on the other hand, expressed only low amounts of interest. The highest amount of consistent interest across gender here was in the age range of 19-35, where both groups expressed an average response of "interested".

"Transport" had a similar level of lukewarm interest across age ranges and gender, with males between the age of 8-12, and 50+ being the only inconsistent groups who showed much higher levels of interest than the rest of the groups. In general, males in all age categories claimed a higher level of interest in transport than females did in the respective age groups.

The following is a general summarisation of each demographic group for this question:

- **8-12 year olds** are most interested in *personal electronics* and least interested in *home power*, with males additionally showing strong interest in *transportation* and females showing interest the *environment*

- **13-18 year olds** are most interested in *personal electronics* and least interested in *home power*, with males additionally showing interest in the *space program* and females showing interest in the *environment*

- **19-35 year olds** are most interested in the *environment* and least interested in *home power*, with males additionally showing interest in *transportation* and females showing interest in both *personal electronics* and the *space program.*

- **36-50 year olds** are most interested in *home power* and the *environment* and least interested in *transport* and the *space program*, with males showing additional interest in *personal electronics.*

- **50+ year olds** are most interested in *transportation,* with males additionally interested in *personal electronics* and females showing interest in the *environment*. (there was not a common least interest for this group)

F.4 Question 4

Question: Now I'm going to list several properties of energy sources; please tell me how interested you are in each.

This question dealt with four different properties of energy, and was asked in the same fashion as question three. The four categories included costs, operation time, efficient use of non-renewable energy sources, and emission-free qualities of energy sources. Like before, the responses were weighted and then graphed. Figure F-4a – F-4d shows the survey results for this question.

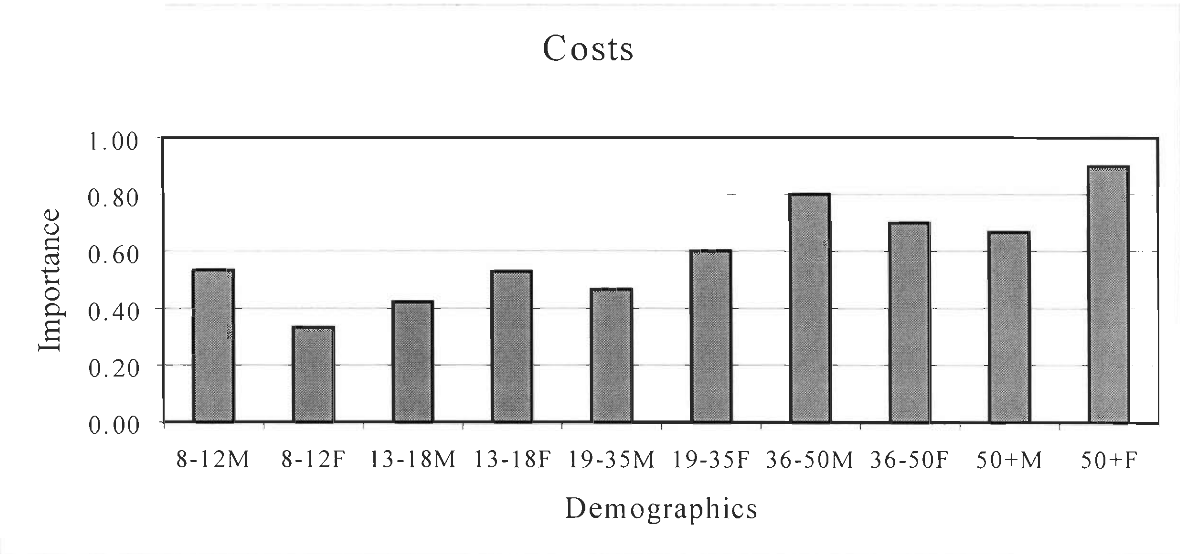


FIGURE F-4A – INTEREST LEVEL IN COST OF ENERGY

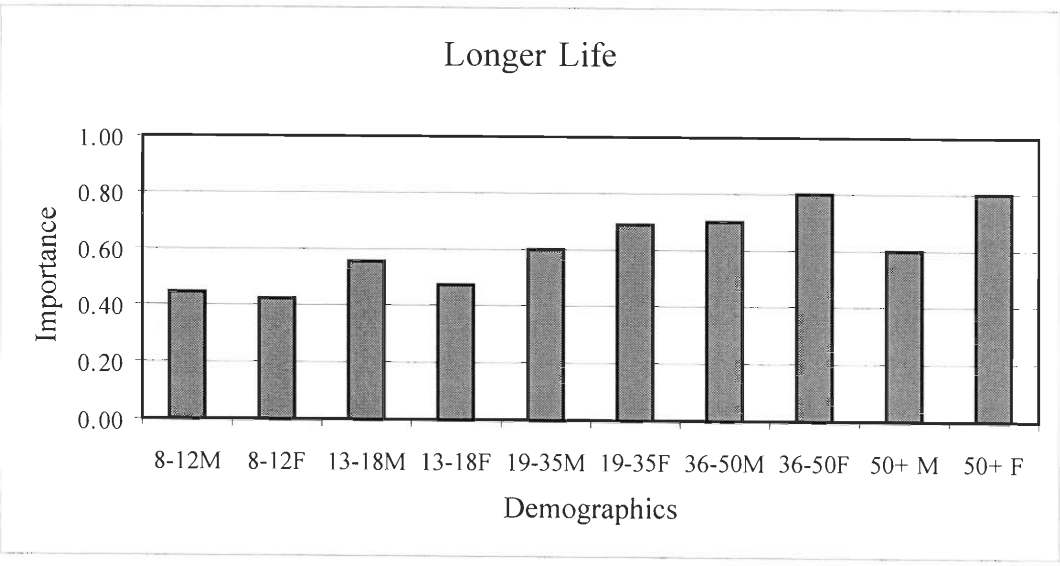


FIGURE F-4B – INTEREST LEVEL IN OPERATION TIME OF AN ENERGY SOURCE

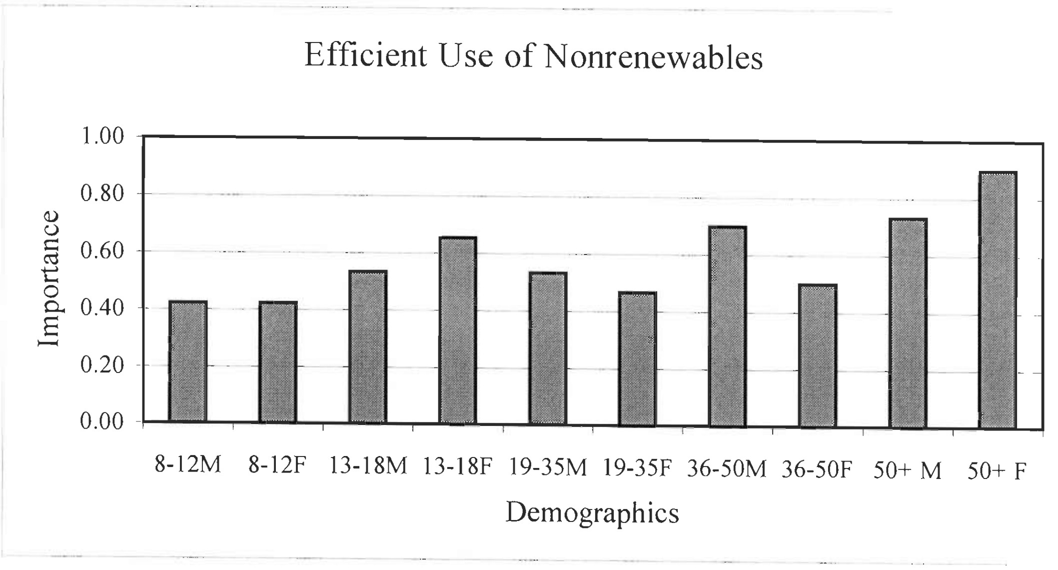


FIGURE F-4C – INTEREST LEVEL IN THE EFFICIENT USE OF NON-RENEWABLE ENERGY

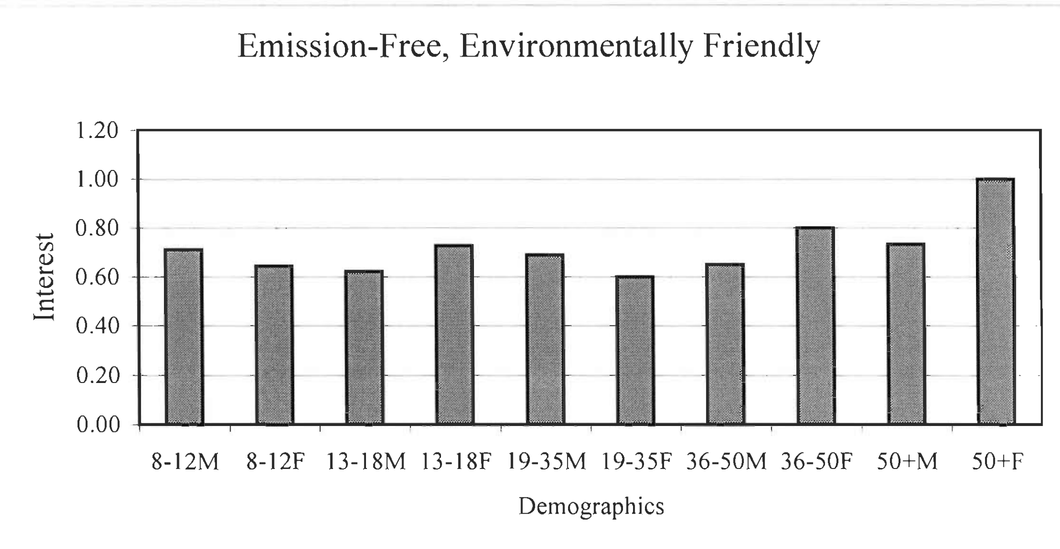


FIGURE F-4D – INTEREST LEVEL IN EMISSION-FREE ENERGY

"Cost", "Longer Operation Time", and "Efficient Use of Non-renewables" all showed a trend where children showed the least amount of interest, but that interest level went up as age increased. In all four categories, there does not seem to be any particular distinction between genders. "Emission-free Energy" seems to be an interest among all age groups, with only the females aged 50+ standing out with a considerably higher interest than any or group. In general, though, this particular category seems to have no correlation between the topic and age or gender.

F.5 Question 5

Question 5: Are you familiar with the term "fuel cell"? Could you describe a fuel cell for me?

We included question 5 and 6 to confirm our hypothesis that most people in general do not know what a fuel cell is. This turned out to be correct, as 66% of those people that we surveyed claimed they did not know what a fuel cell was. Of the remaining 34% who said "yes", we found that very few could actually describe a fuel cell. Only 6 people, out of the 71 surveyed, could give a satisfactory description of a fuel cell. Examples of the descriptions which we accepted as valid were "like a battery", "they're electrochemical", and "hydrogen-based for cars". Figure F-5a shows the response for the first part of question five.

One interesting observation which we made was that a significantly higher number of males than females responded that they were familiar with fuel cells. This can be seen in Figure F-5b, which breaks down the responses into age groups and gender and shows the percent of respondents out of each who said "yes". Additionally, Figure F-5c shows the percent of correct descriptions given out of those who claimed they were familiar with fuel cells.

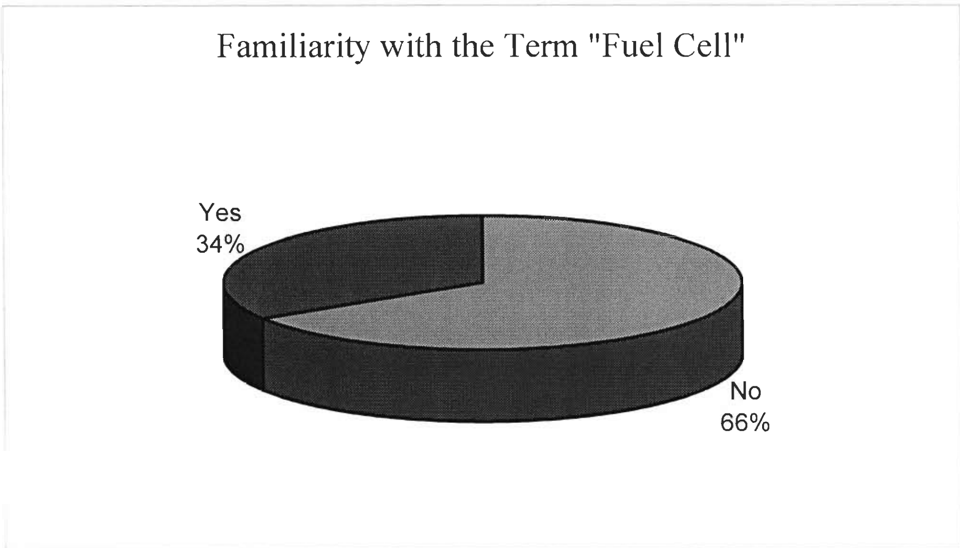


FIGURE F-5A – PERCENTAGE WHO CLAIMED FAMILIARITY WITH "FUEL CELL"

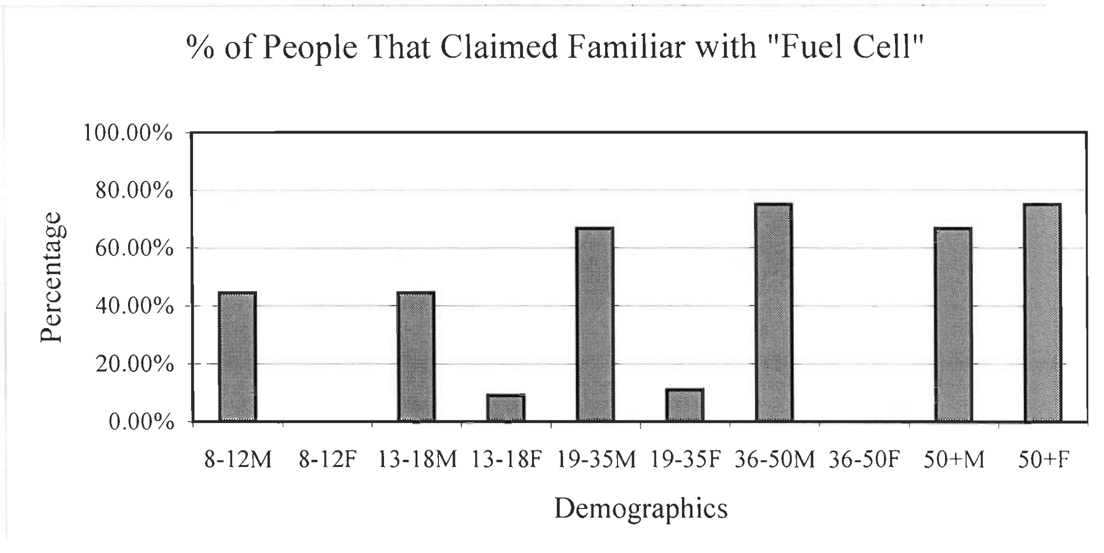


FIGURE F-5B –PERCENTAGES OF THOSE WHO CLAIMED FAMILIAR WITH "FUEL CELL"

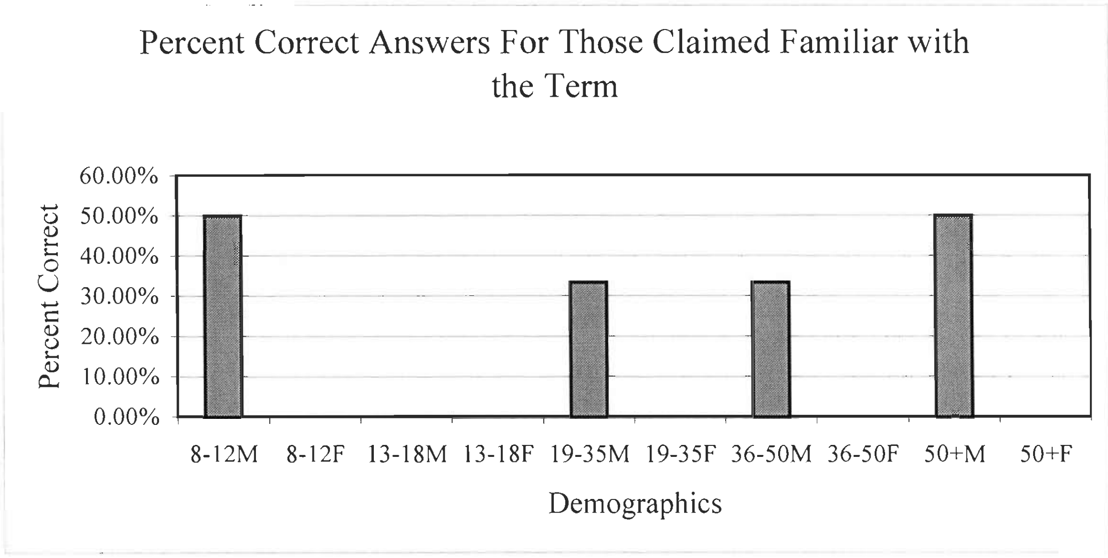


FIGURE F-5C – PERCENT OF THOSE ACTUALLY FAMILIAR WITH THE TERM "FUEL CELLS"

F.6 Question 6

Question: From what source(s) have you heard about fuel cells?

We included question 6 in our survey as a curiosity to find out where our survey respondents felt they had heard about fuel cells. Out of all responses, television, magazines, and school were the most popular answers. We found that most of respondents that could not describe a fuel cell could not list any sources. Further more, we observed that when they were asked this question, they appeared unsure of their answer. Figure F-6 shows the responses given by the survey participants for question six.

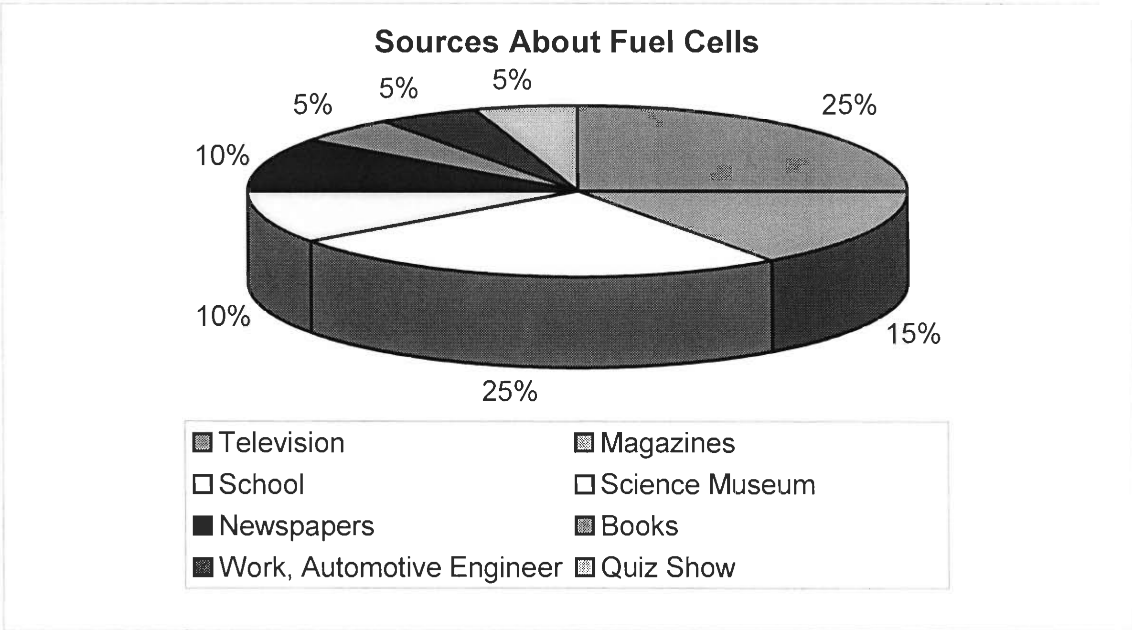


FIGURE F-6 – SOURCES WHERE RESPONDENTS HAVE HEARD ABOUT FUEL CELLS

Appendix G – Results of Observation and Feedback Survey

The administration of our feedback survey took place between April 19th to April 21st, 2000, just outside of the *Space* and *Challenge of Materials* galleries. Forty visitors tested the exhibit and provided feedback, from a total of 44 visitors that were approached with the opportunity to test a new exhibit, resulting in a 90% response rate. Of the 40 visitors surveyed, 22 were in the 8-12 and 13-18 age ranges, which are our target age groups - Key Stages Two and Three.

The demographic breakdown of our audience shows that the majority of visitors surveyed were members of Key Stages Two and Three, but a wider audience was also surveyed. This is because the web audience is broader than the gallery audience, so it was important to obtain a wide sampling. The demographic information of the feedback survey respondents is shown in Figure G.0.

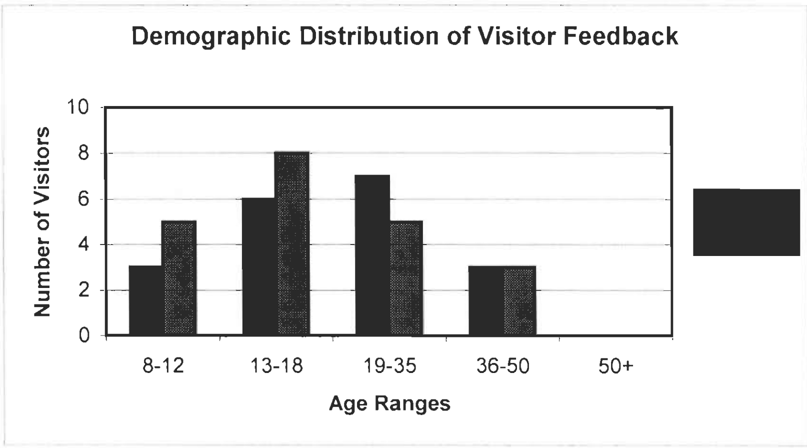


FIGURE G.0 – DEMOGRAPHIC DISTRIBUTION OF VISITOR FEEDBACK SURVEY

G.1 Question 1

Question: What do you think this exhibit was trying to show you?

The purpose of this question was to determine whether we had effectively communicated our intended messages to the users. We found that the messages that the users received closely corresponded to our intended messages: the importance of fuel cells as efficient and renewable sources of energy while being environmentally friendly. Additionally, some visitors reported unintended, but beneficial, messages such as a feeling of hope that things can change and improve, individual families can make a difference, and that it doesn't take an entire population to do something like help the environment.

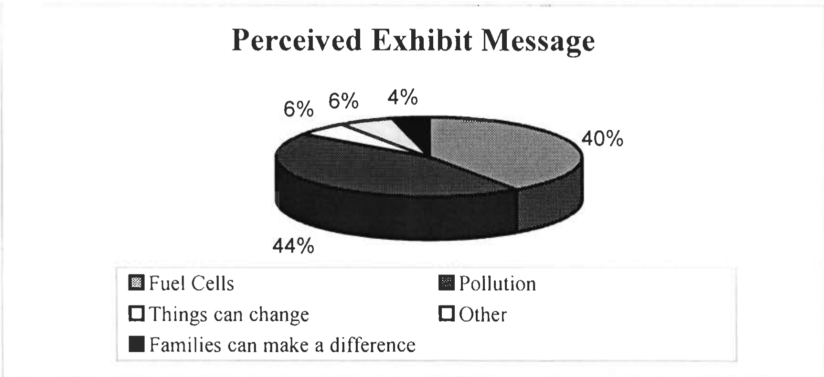


FIGURE G.1 – PERCENTAGE OF RESPONSES ON PERCEIVED EXHIBIT MESSAGE

G.2 Question 2

Question: Did you find the information that was in the exhibit interesting?

One of our objectives was not only to communicate information on fuel cells, but to do so in an interesting and relevant manner. The purpose of this question was to determine whether users thought the exhibit and its content were interesting.

A large majority of the people, approximately 89 percent, thought that the information in the exhibit was interesting, especially all of the advantages that fuel cells possess. Graphical representation of this data can be seen in Figures G.2a and G.2b.

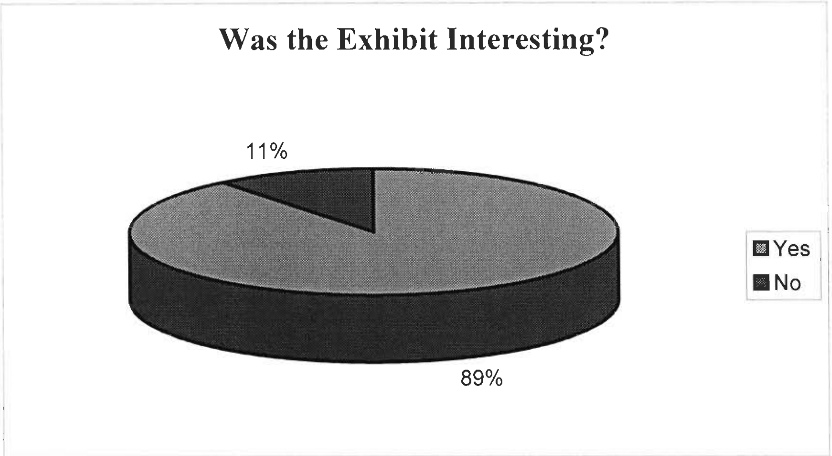


FIGURE G.2A – THE PERCENTAGE OF VISITORS THAT FOUND THE INFORMATION INTERESTING

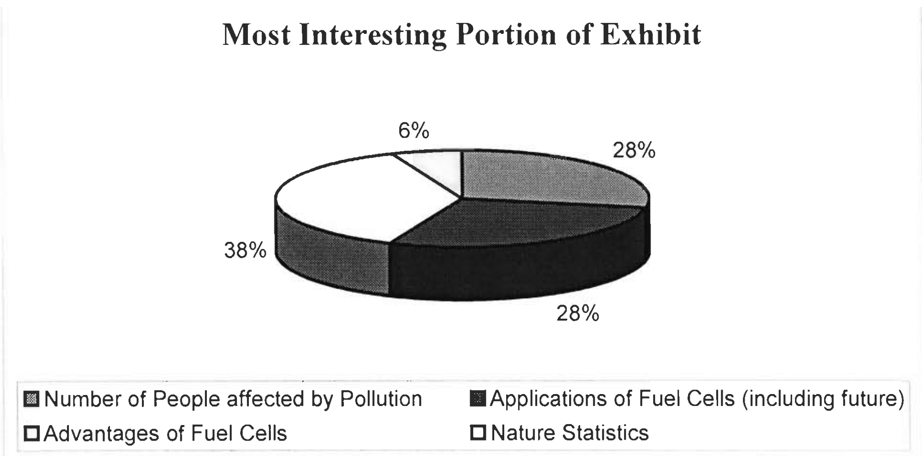


FIGURE G.2B – THE MOST INTERESTING PORTIONS OF THE EXHIBIT

G.3 Question 3

Question: Were there any terms or phrases in the exhibit that you didn't understand?

This question also delves into the area of effective communication, and attempts to determine wh

results of the data collected.

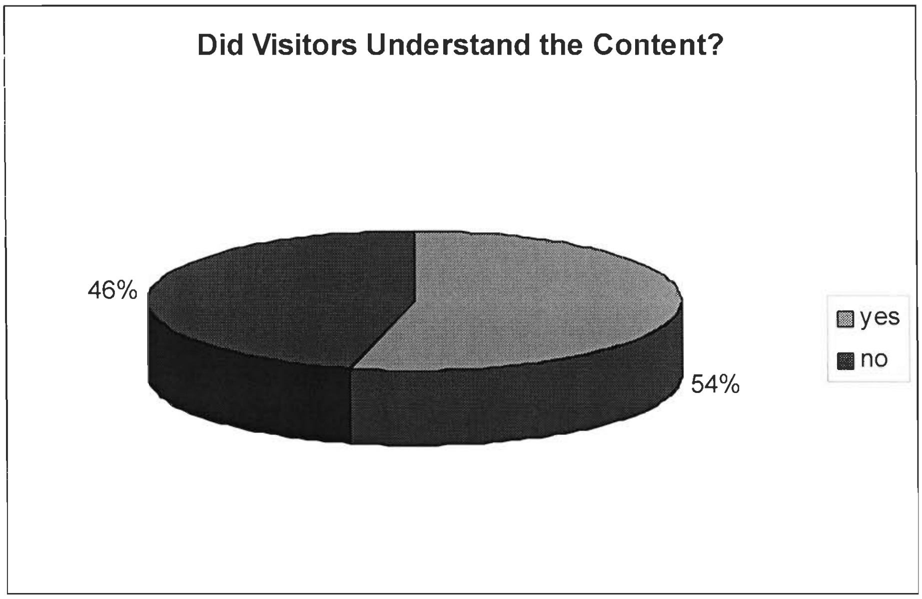


FIGURE G.3A – PERCENTAGE OF VISITORS WHO UNDERSTOOD THE CONTENT

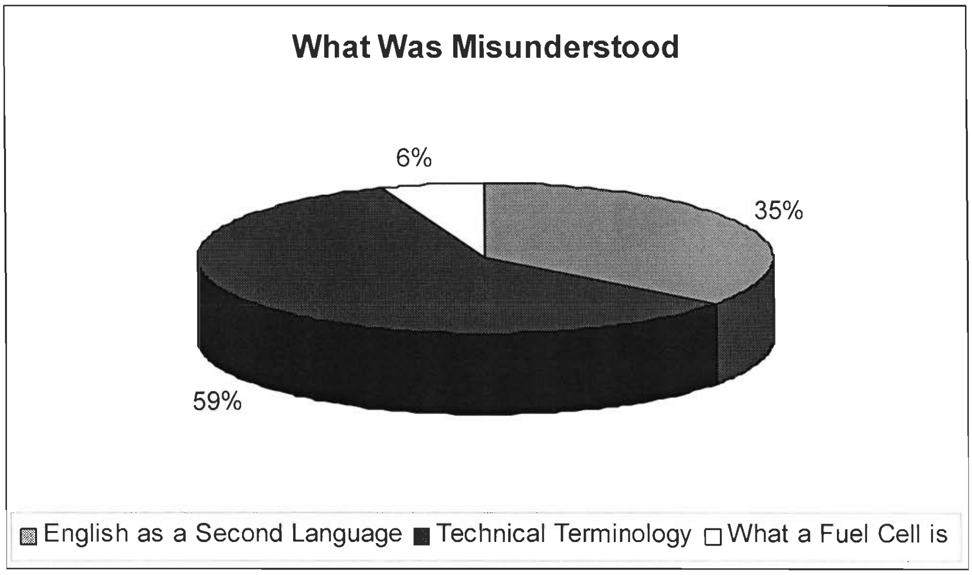


FIGURE G.3B – THE AREA OF CONTENT THAT WAS MISUNDERSTOOD

The data indicates that 46 percent of the people did not fully understand our exhibit, which suggests that we should revise certain areas. However, further analysis shows that most misunderstandings were the result of the technical information and unfamiliarity with the English language. It is noteworthy to recall that the more technical information is found primarily in the second level of content, which is not essential to understanding the message we are attempting to convey. Through our analysis of question one we can conclude that our messages were successfully communicated, which is the most important aspect of the project.

G.4 Question 4

Question: Was there any text that was difficult to read?

Invariably the response to this question was no. None of the testing groups reported any problems with text being hard to read; however, some comments and suggestions were recorded.

One user suggested that the text could be spread out more, as they thought it was too dense in certain areas. Additionally, some users suggested that we increase the font size of our text. A third individual reported that the text was too bland and didn't stand out enough; the use of other colours could be tested to overcome this problem. However, white and black remain the highest contrasting colours and no other users commented that this was a problem.

G.5 Question 5

Question: What did you think of the diagram that showed how fuel cells worked?

This question's purpose is to determine not only how well the diagram communicated the operation of fuel cells, but also if it is aesthetically pleasing.

The most frequent response was that it was "okay", clear, and helpful in understanding fuel cell operation. Approximately one-third of the visitors who were tested did not even encounter the diagram by quickly bypassing all second level content. A graphical representation of the data follows:

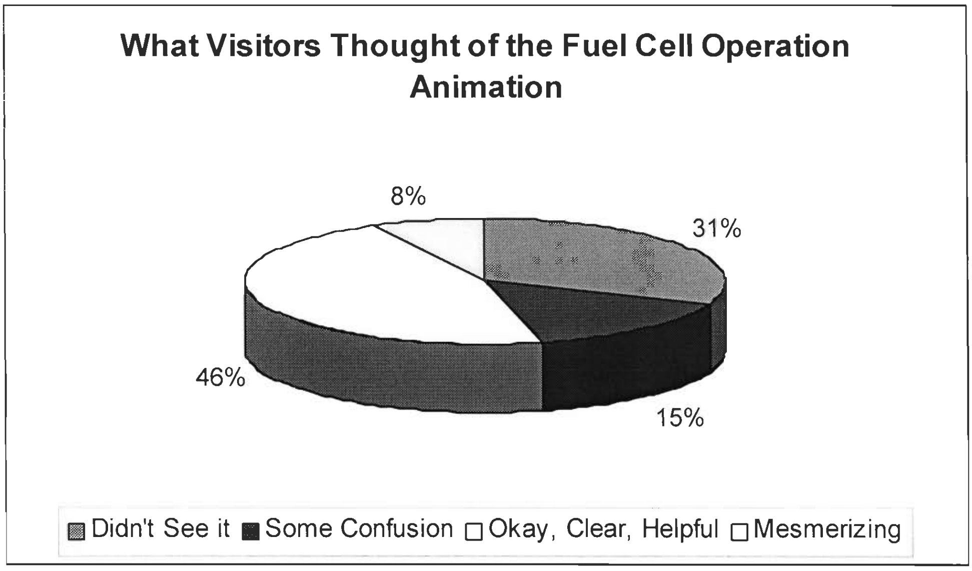


FIGURE G.5 – VISITOR OPINION ON THE FUEL CELL DIAGRAM ANIMATION

G.6 Question 6

Question: What did you think of the game?

The purpose of this question was to determine the effectiveness and value of the interactive portion of our exhibit. Over one third of the respondents expressed some variety of satisfaction with the interactive game, and only 10% of the respondents either did not see it or failed to spend time completing it. Many additional comments were also made, mostly praising various portions of the interactive and some saying there was too much content or too many questions. Graphical representation of the data can be seen in Figure G.6.

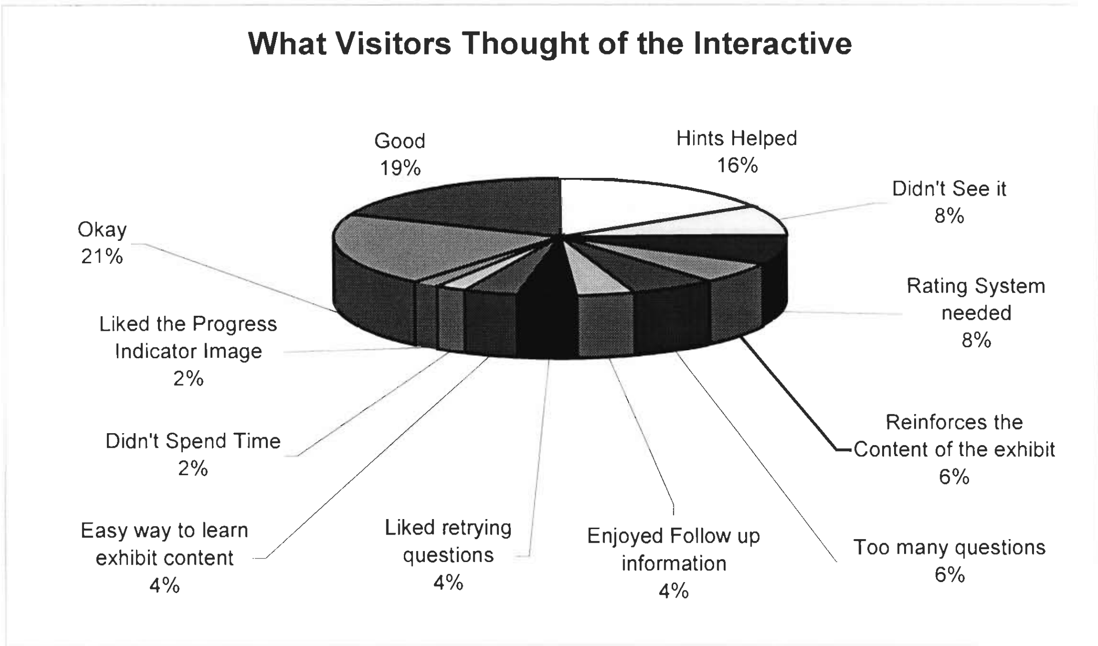


FIGURE G.6 – VISITORS THOUGHTS ON THE INTERACTIVE

G.7 Question 7

Question: What did you like most about the exhibit?

This question helped us identify different areas that the users liked. This information is useful in that it can help us to avoid making changes to a well-liked area, which could possibly have adverse affects. These results are shown below in Figure G.7.

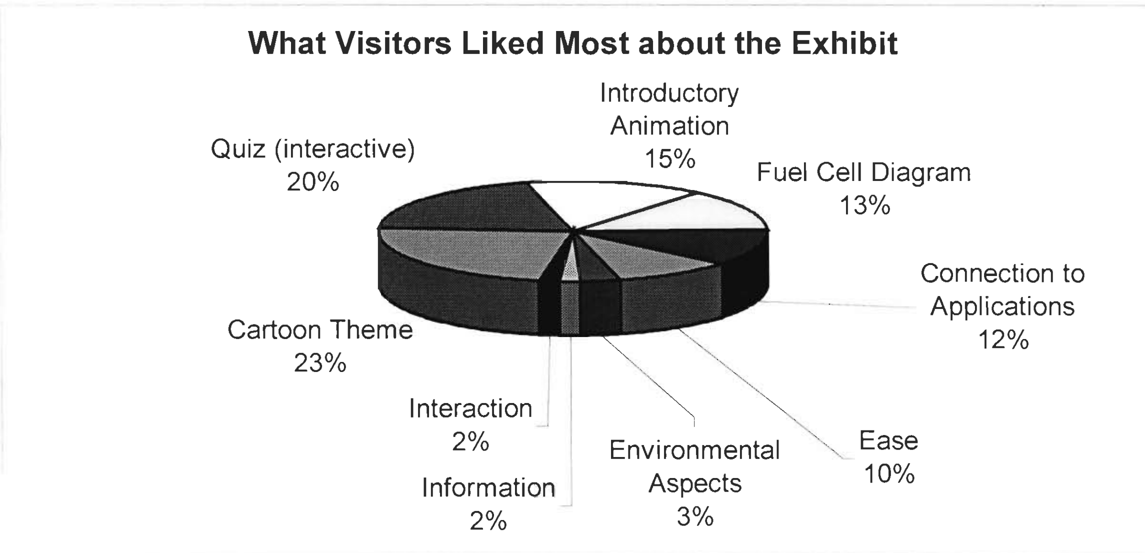


FIGURE G.7 – WHAT VISITORS LIKED THE MOST ABOUT THE EXHIBIT

G.8 Question 8

Question: What did you least like about the exhibit?

In a similar manner as the previous question, the purpose of this question was to determine which areas needed the most revision. The most frequent response received was that the site was text heavy. Other frequent complaints include slow animations, consumption of time, and confusion. Graphical representation of this data can be found below in Figure G.8.

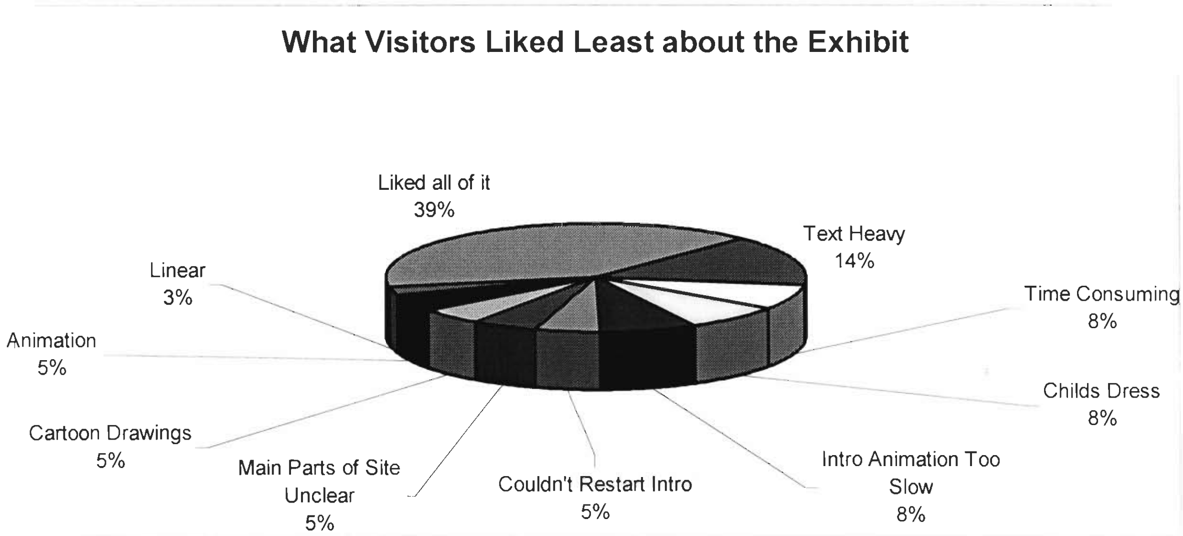


FIGURE G.8 – WHAT VISITORS LIKED LEAST ABOUT THE EXHIBIT

G.9 Question 9

Question: On a scale of 1 to 10 how interested would you be in using this exhibit in an exhibition?

This final question of the feedback survey tries to determine an overall interest level by various demographic groups. This is done to see if we can effectively communicate to our prime audience (young children in the educational Key Stages Two and Three) by catching their attention and their interest. Figure G.9 details average levels of interest by various demographics:

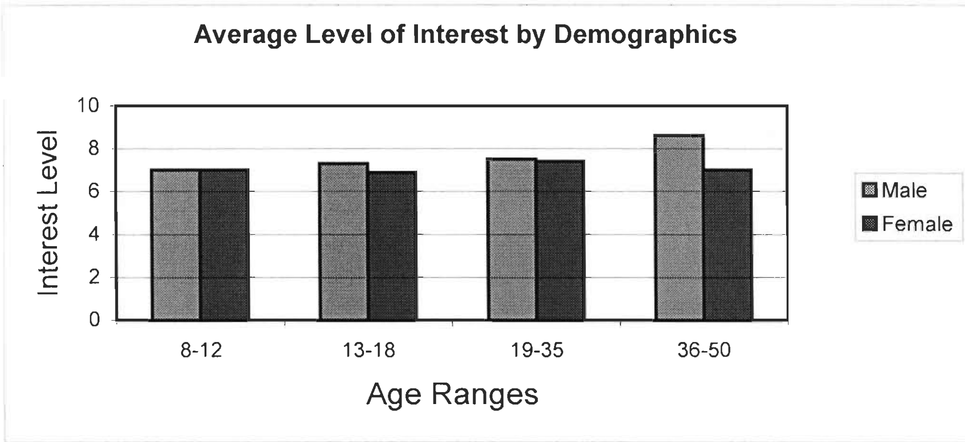
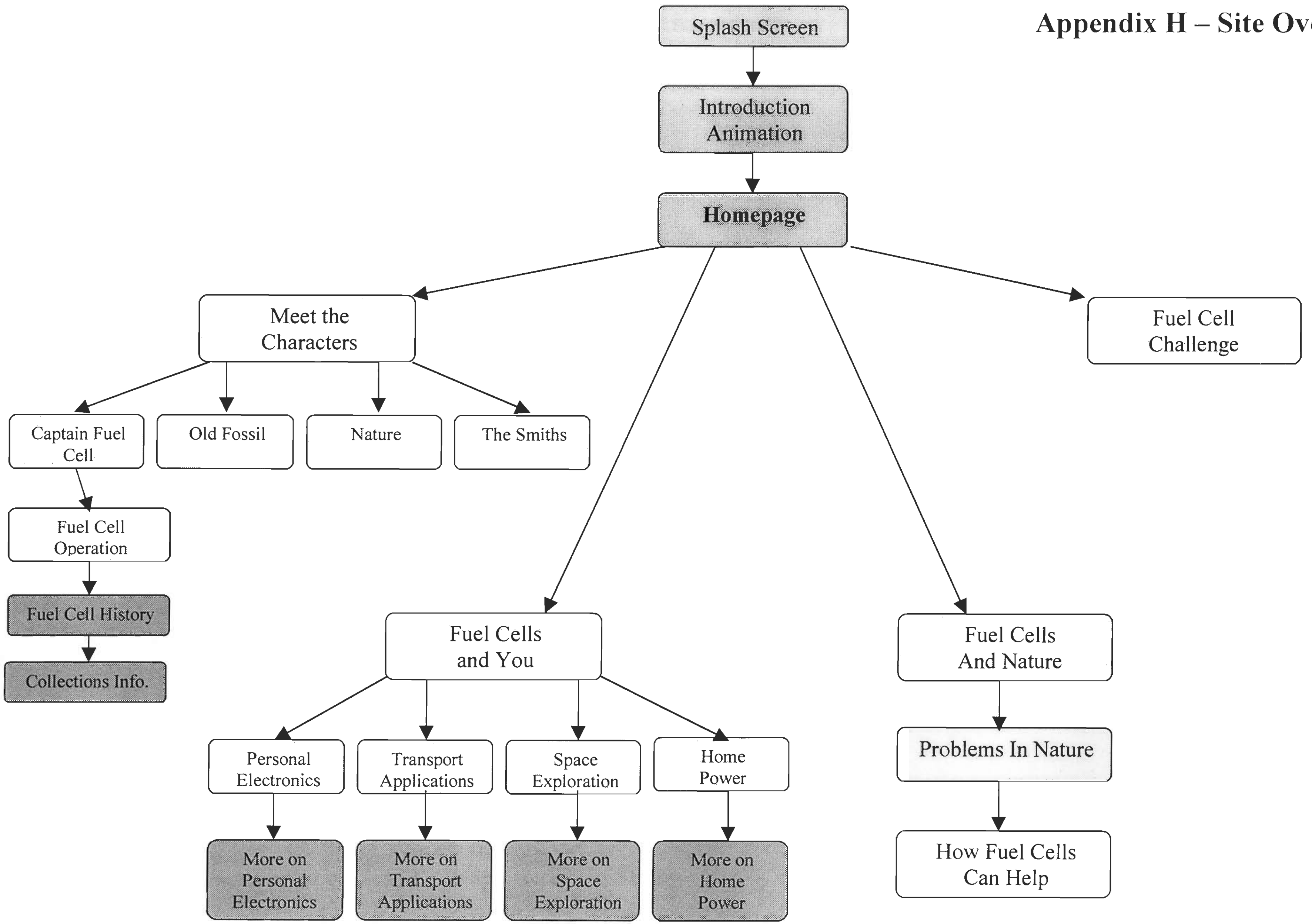


FIGURE G.9 – INTEREST LEVEL IN EXHIBIT BY DEMOGRAPHICS

Appendix H – Site Overview



Appendix I – Screenshots

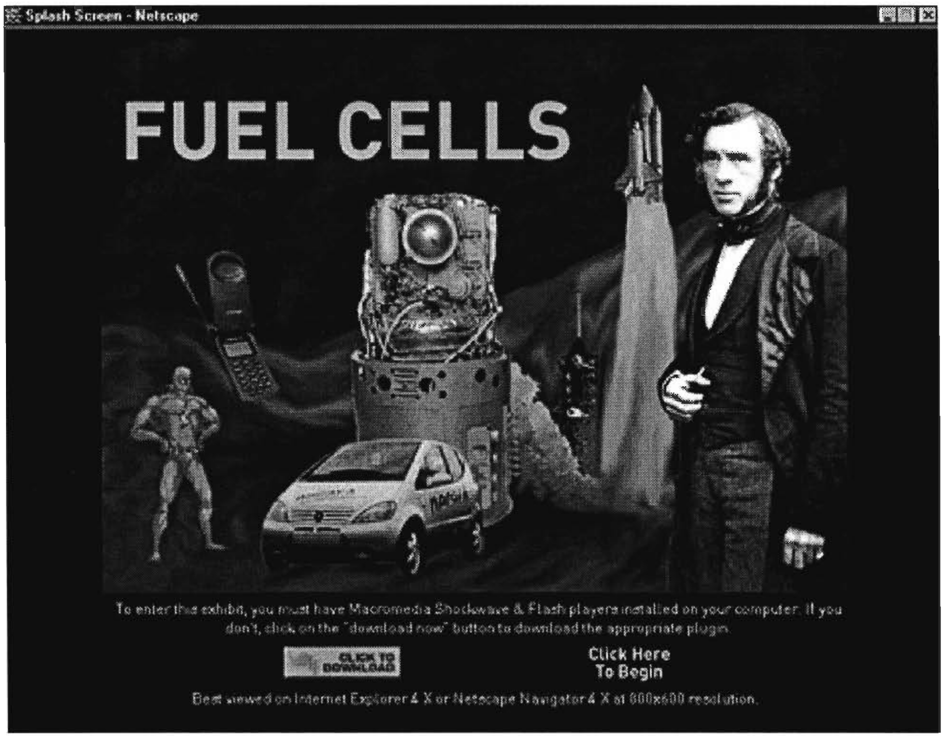


FIGURE I.1 – SPLASH SCREEN

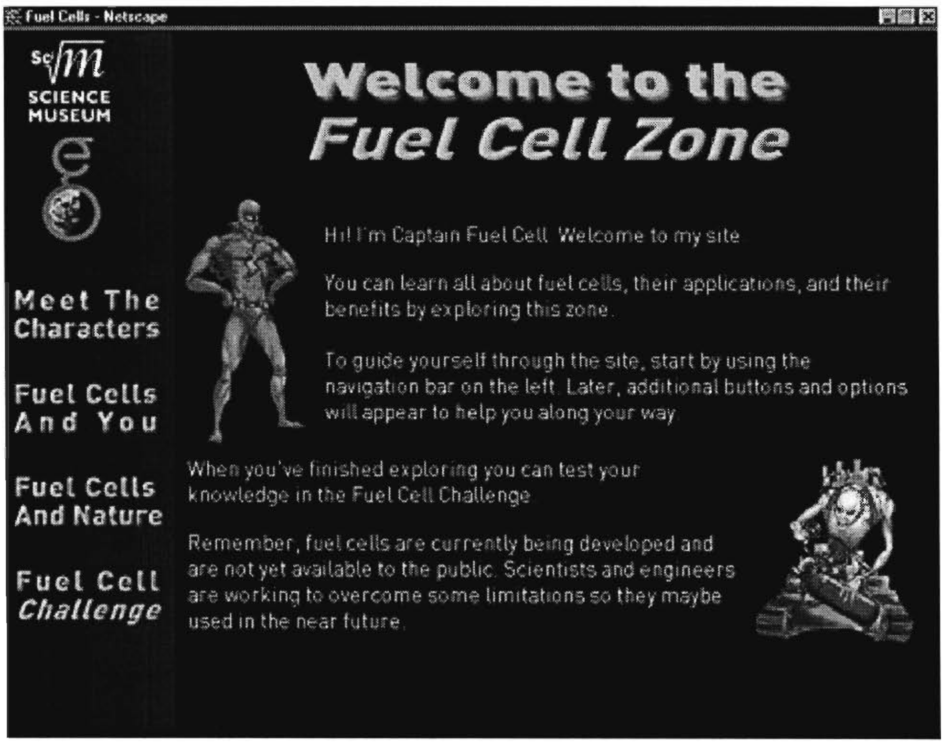


FIGURE I.2 – HOME PAGE

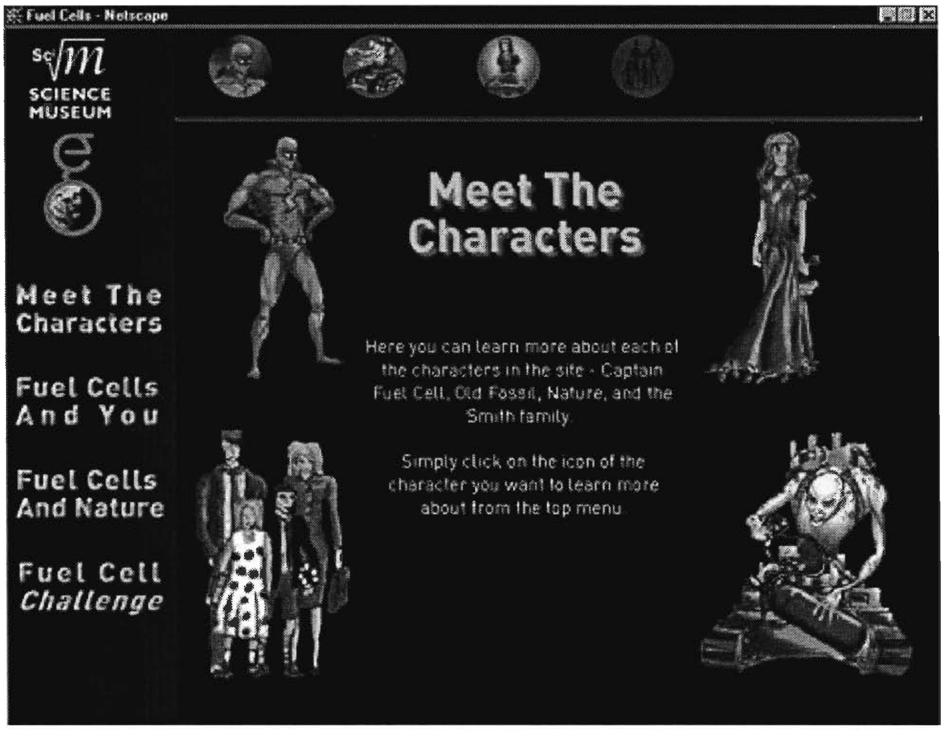


FIGURE I.3 – MEET THE CHARACTERS

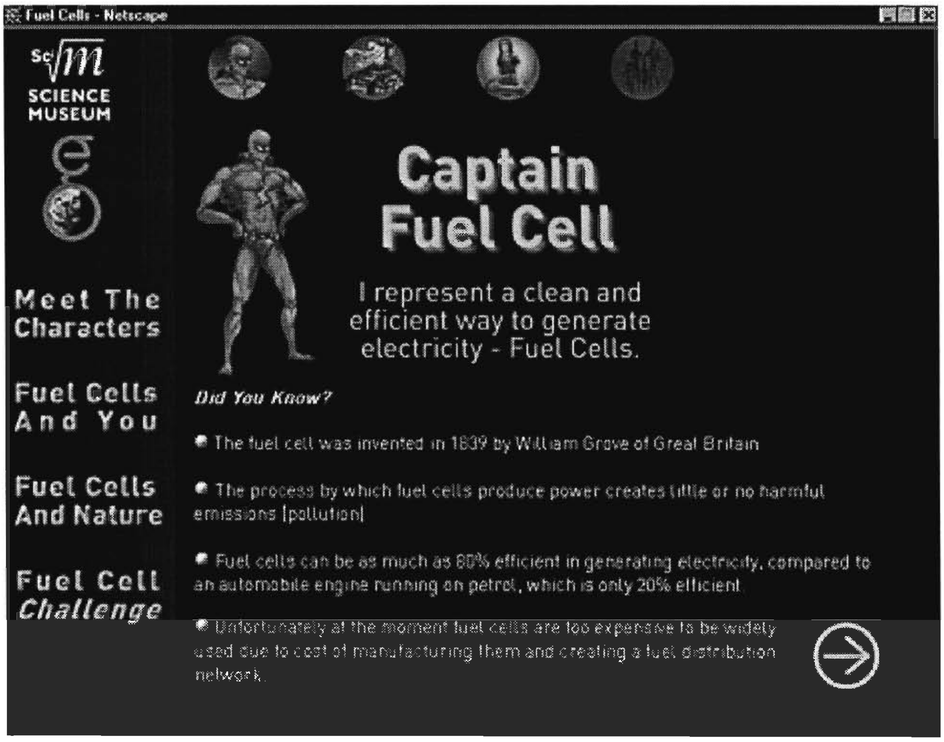


FIGURE I.4 – MEET THE CHARACTERS → CAPTAIN FUEL CELL

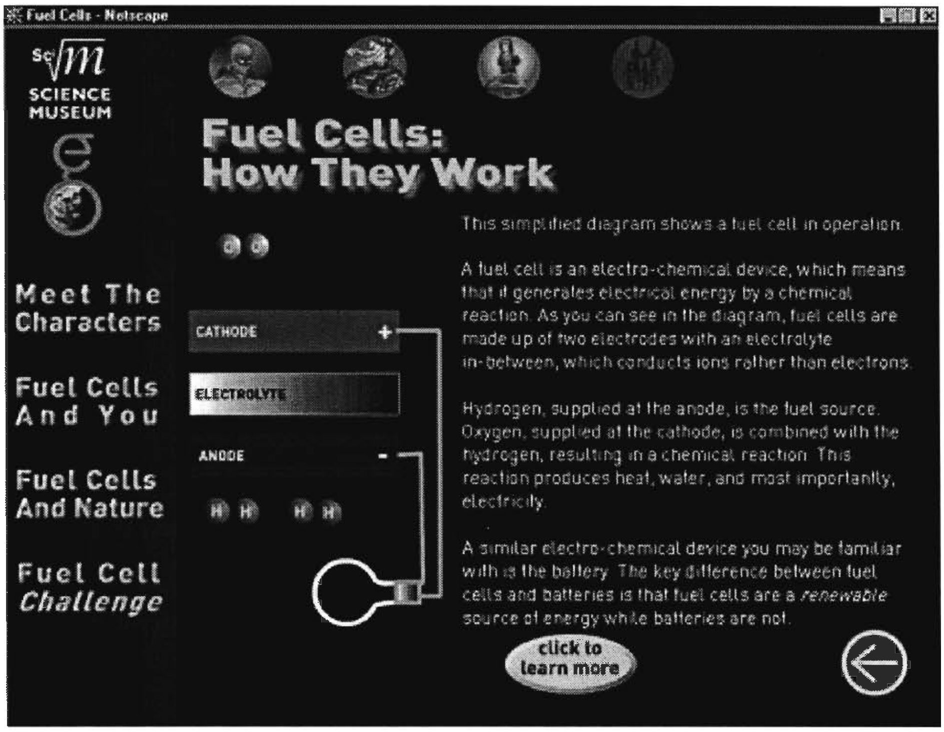


FIGURE I.5 – MEET THE CHARACTERS → CAPTAIN FUEL CELL → FUEL CELL OPERATION

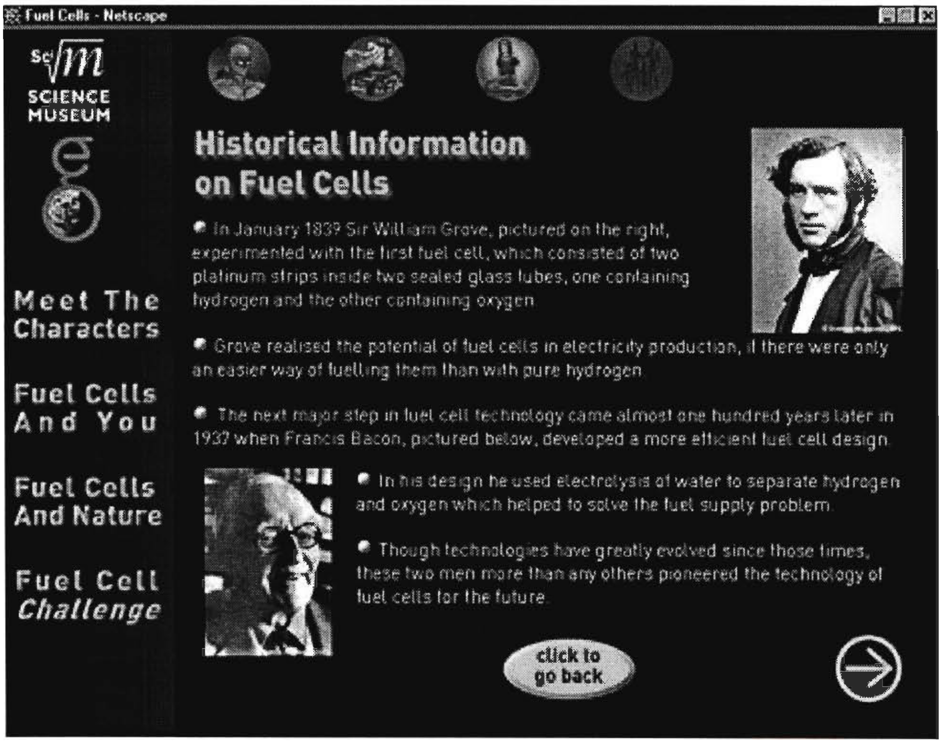


FIGURE I.6 – MEET THE CHARACTERS → CAPTAIN FUEL CELL → HISTORICAL INFORMATION

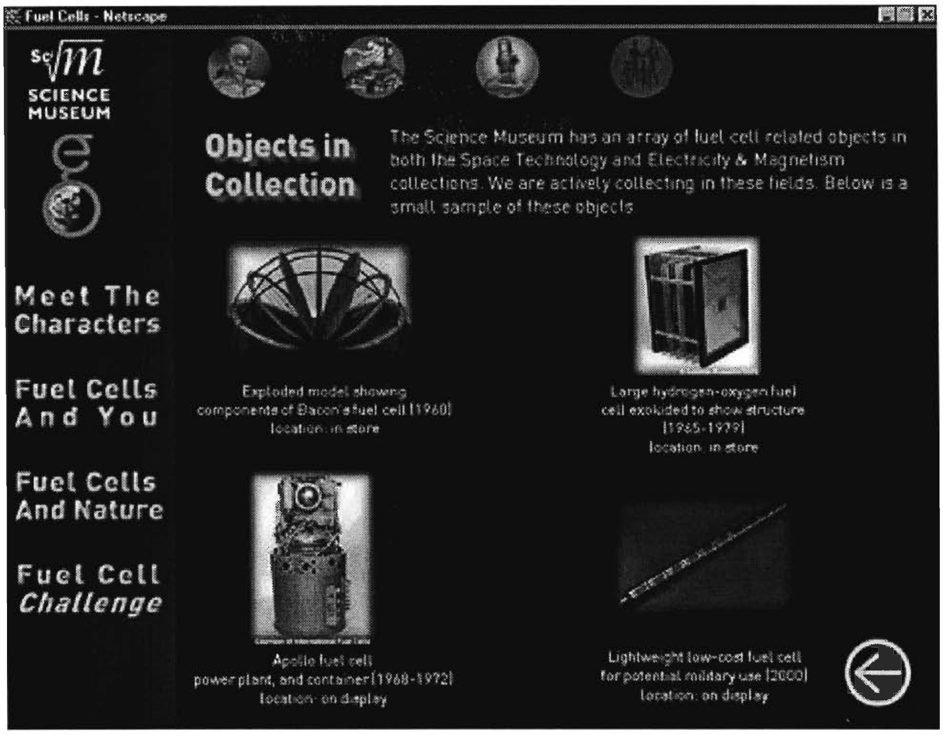


FIGURE I.7 – MEET THE CHARACTERS → CAPTAIN FUEL CELL → COLLECTIONS INFORMATION

FIGURE I.8 – MEET THE CHARACTERS → OLD FOSSIL

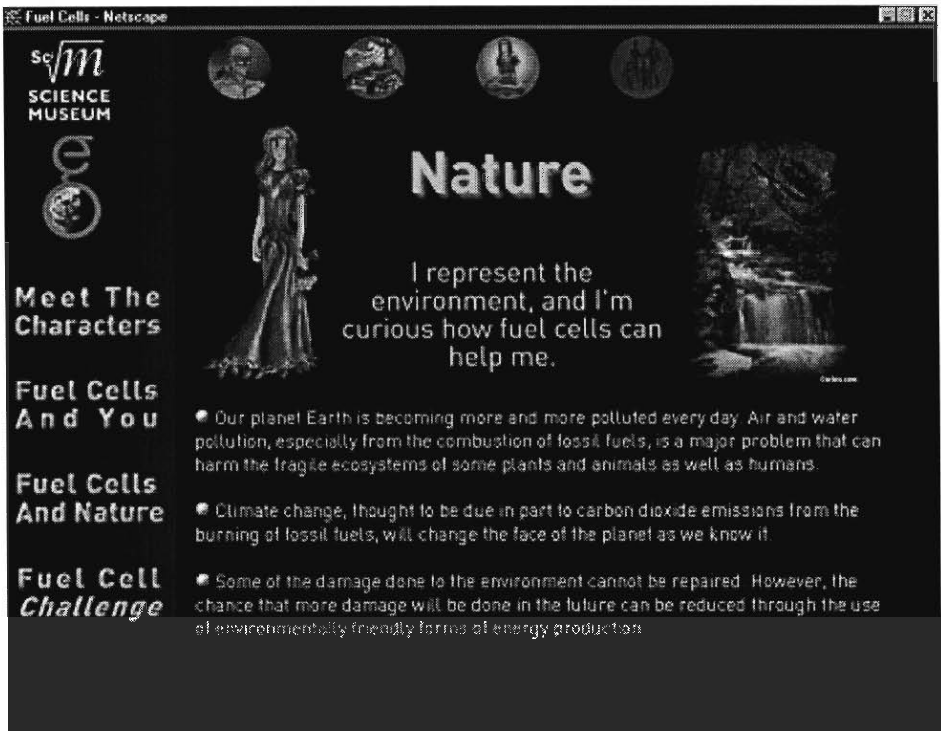


FIGURE I.9 – MEET THE CHARACTERS → NATURE

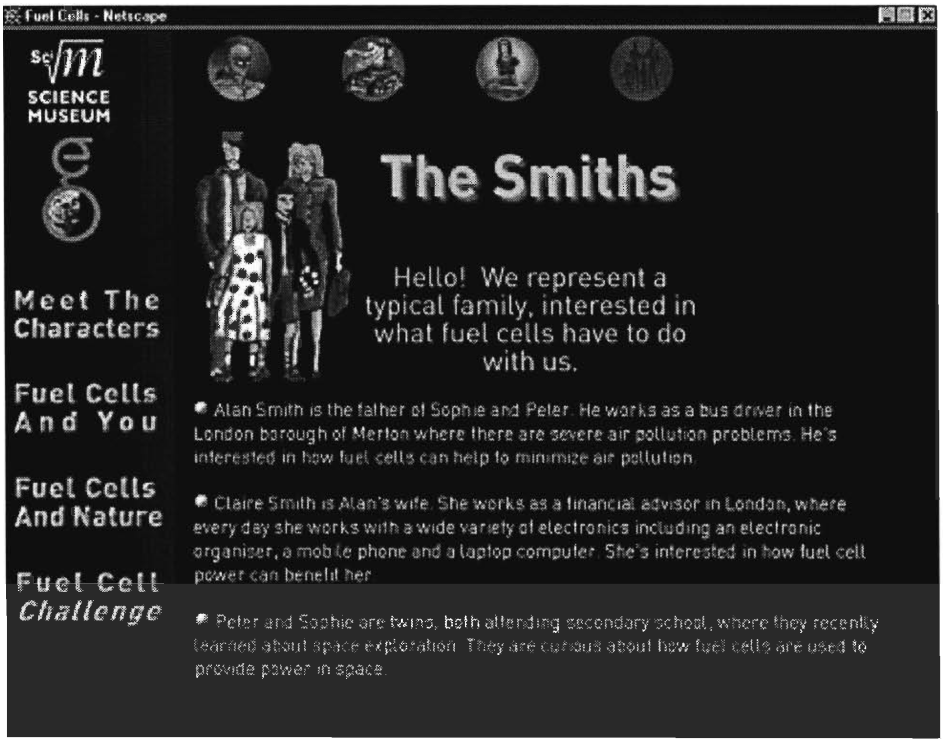


FIGURE I.10 – MEET THE CHARACTERS → THE SMITHS

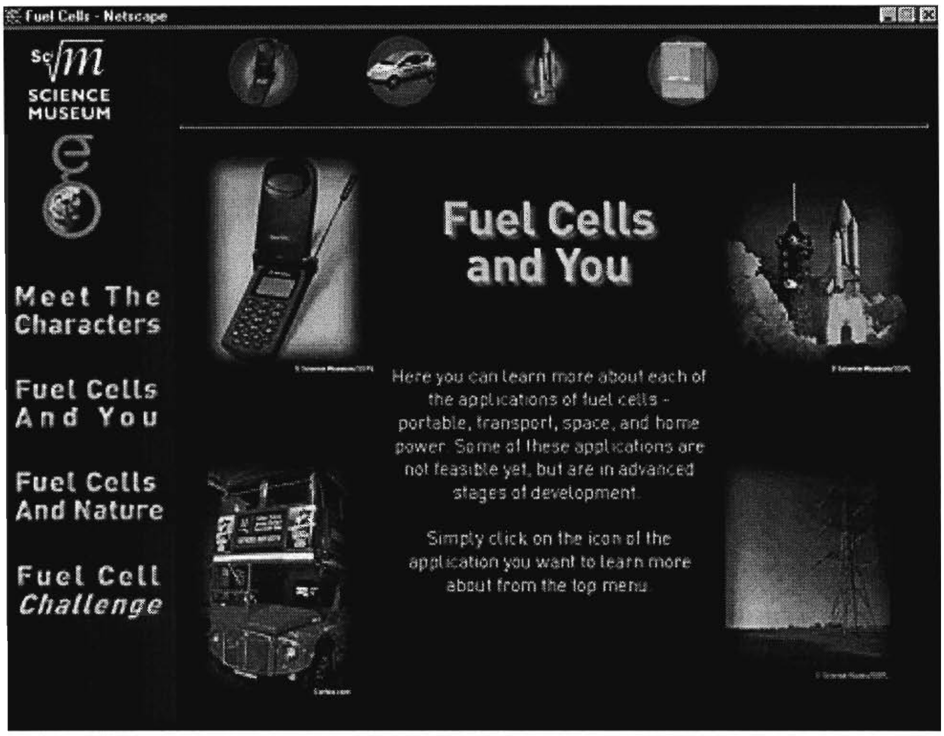


FIGURE I.11 – FUEL CELLS AND YOU

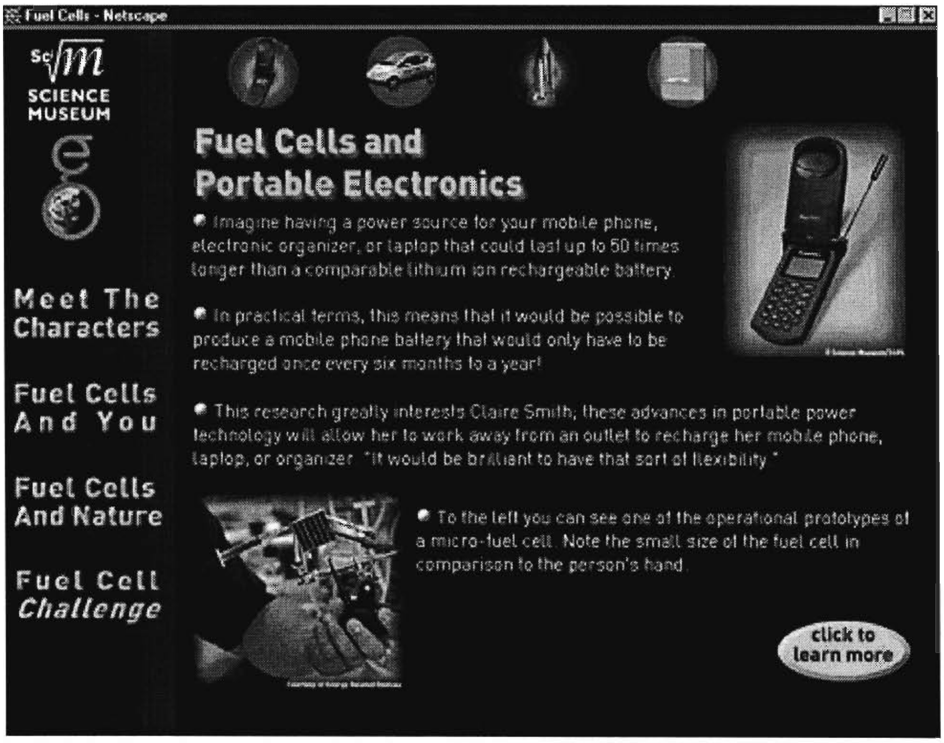


FIGURE I.12 – FUEL CELLS AND YOU → PORTABLE ELECTRONICS

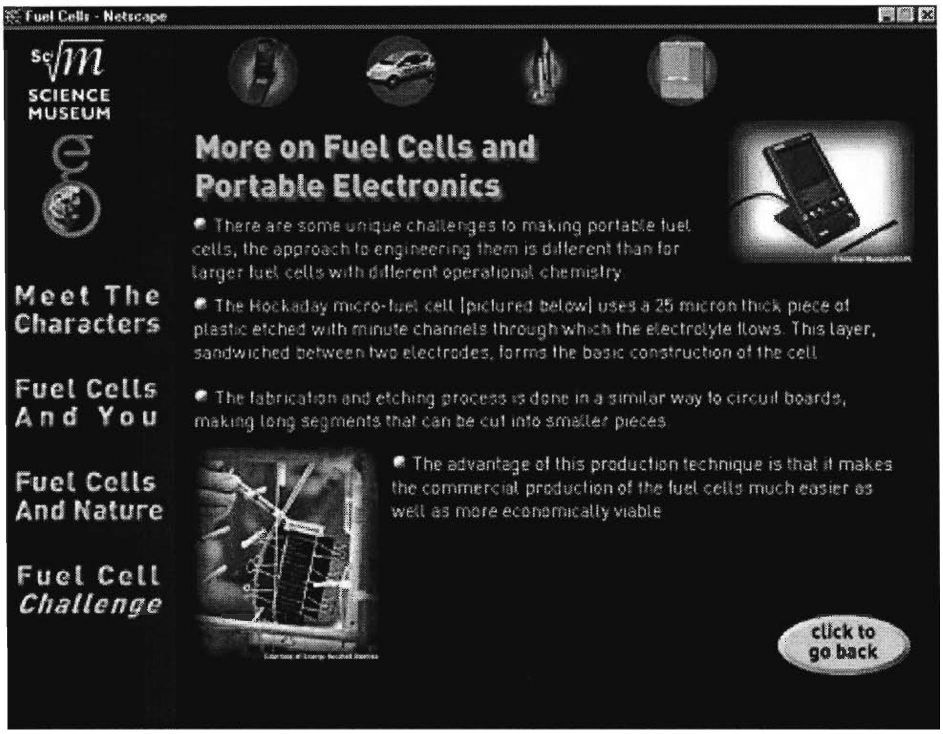


FIGURE I.13 – FUEL CELLS AND YOU → PORTABLE ELECTRONICS → MORE

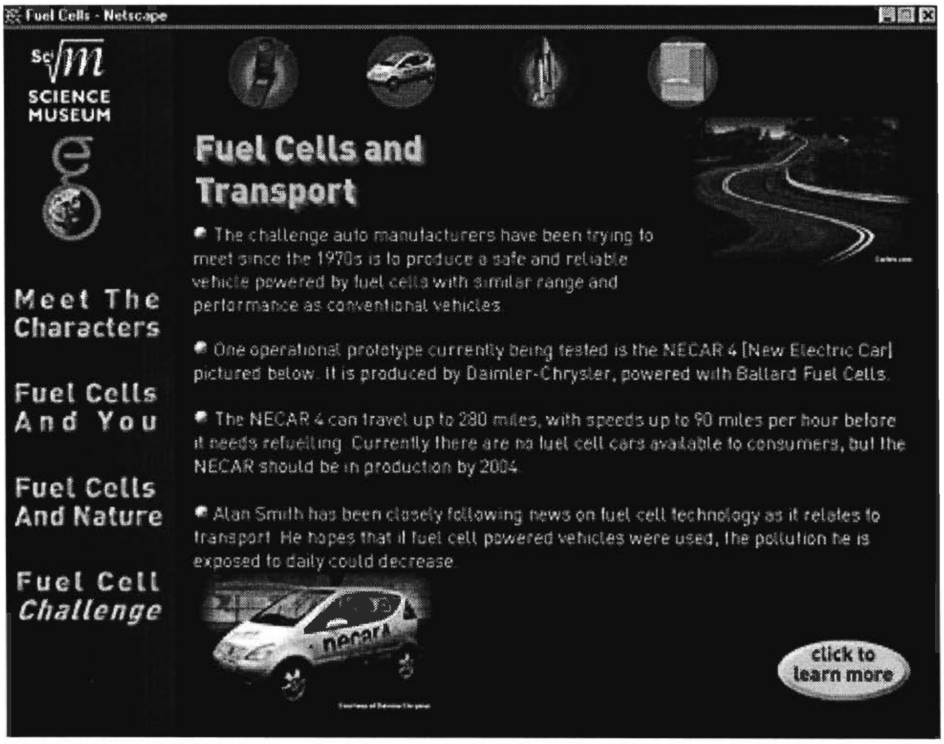


FIGURE I.14 – FUEL CELLS AND YOU → TRANSPORT

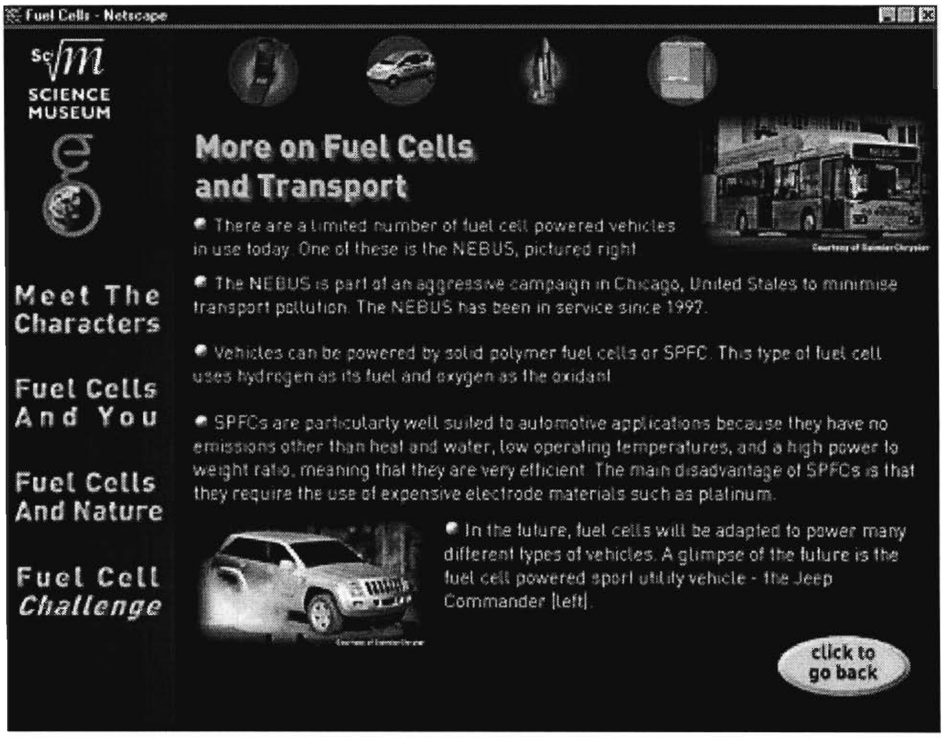


FIGURE I.15 – FUEL CELLS AND YOU → TRANSPORT → MORE

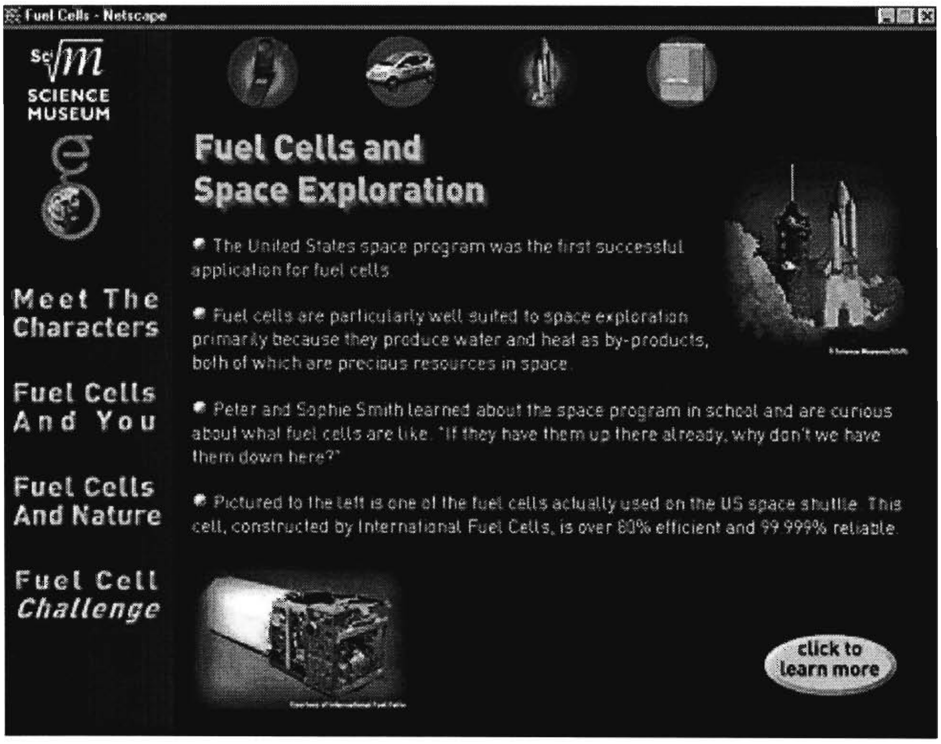


FIGURE I.16 – FUEL CELLS AND YOU → SPACE

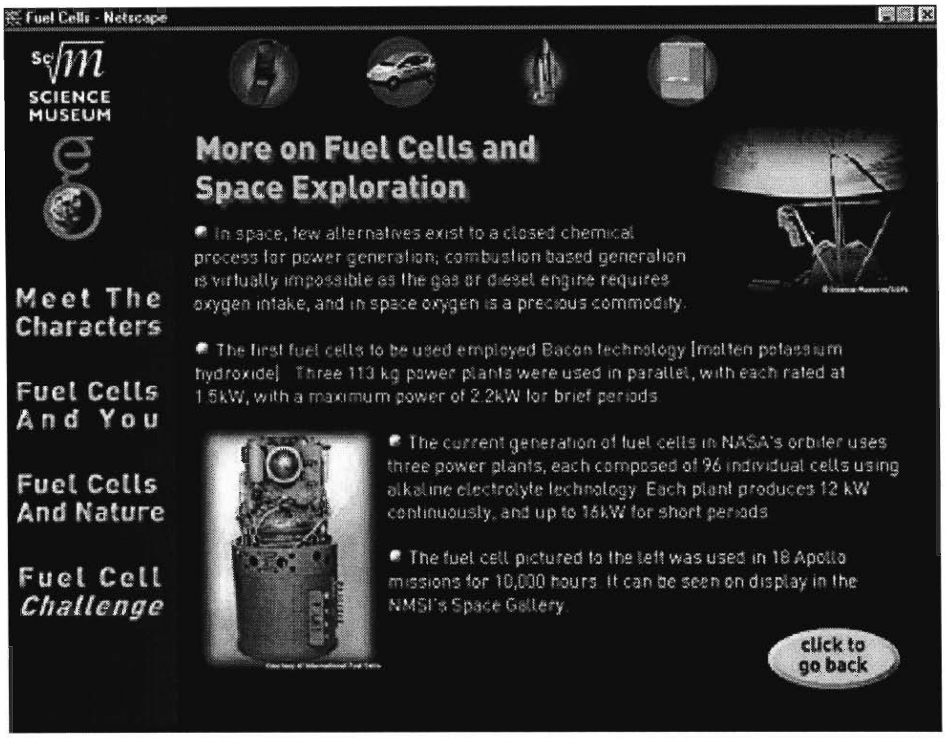


FIGURE I.17 – FUEL CELLS AND YOU → SPACE → MORE

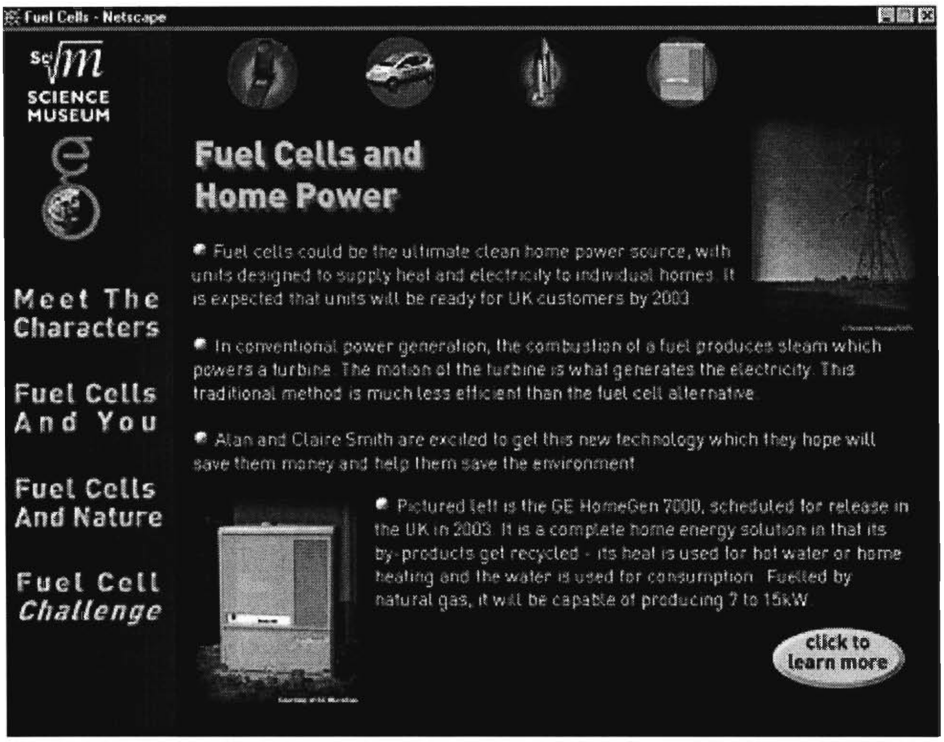


FIGURE I.18 – FUEL CELLS AND YOU → HOME

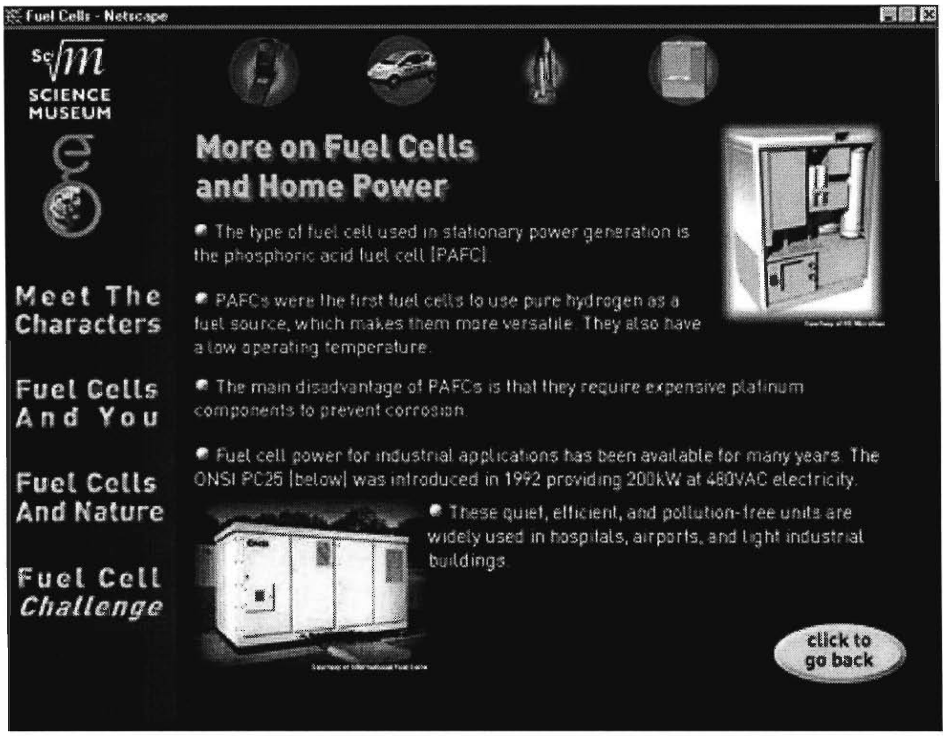


FIGURE I.19 – FUEL CELLS AND YOU → HOME → MORE

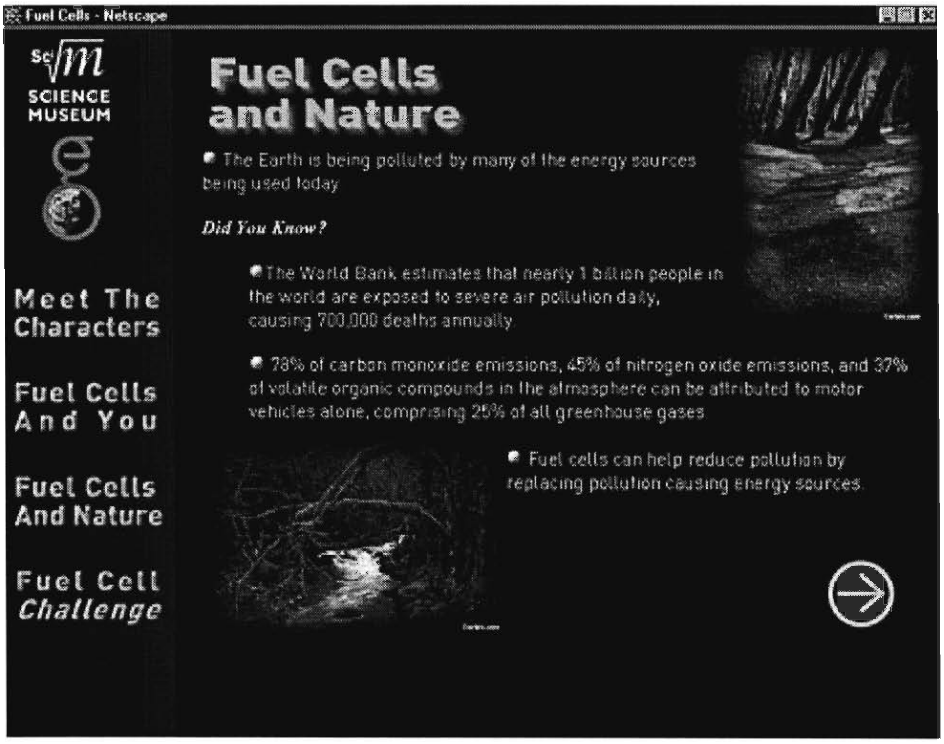


FIGURE I.20 – FUEL CELLS AND NATURE

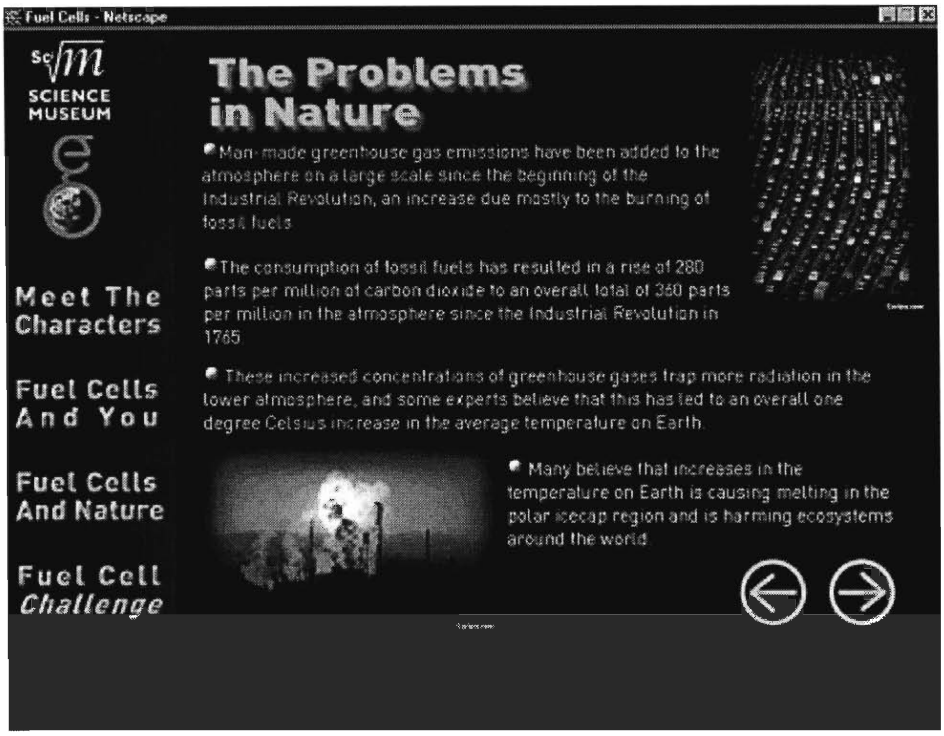


FIGURE I.21 – FUEL CELLS AND NATURE → THE PROBLEMS IN NATURE

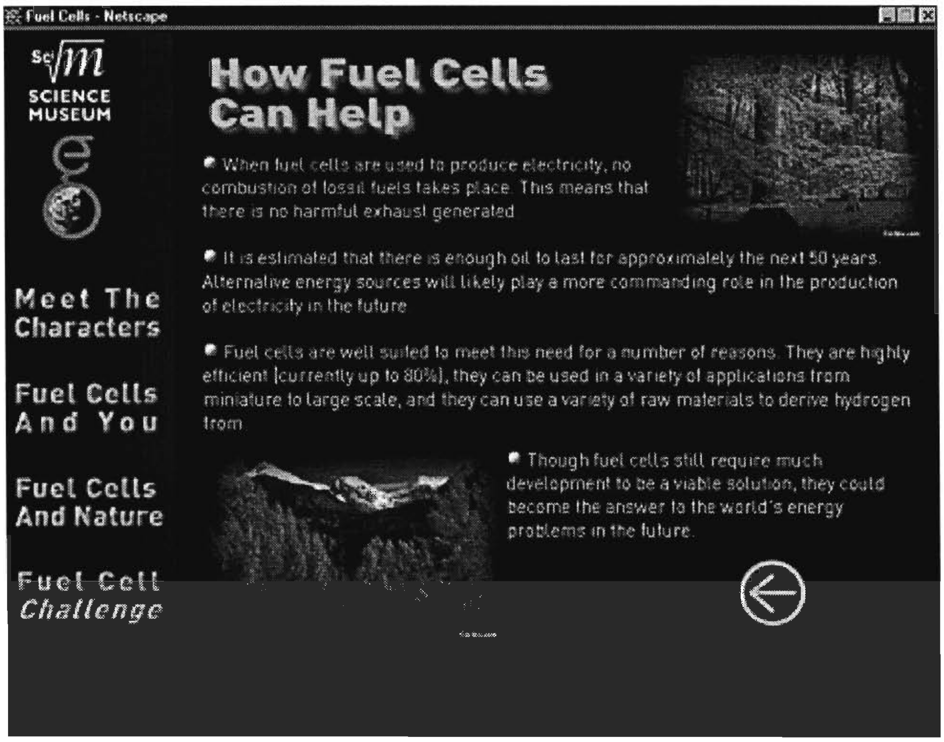


FIGURE I.22 – FUEL CELLS AND NATURE → HOW FUEL CELLS CAN HELP

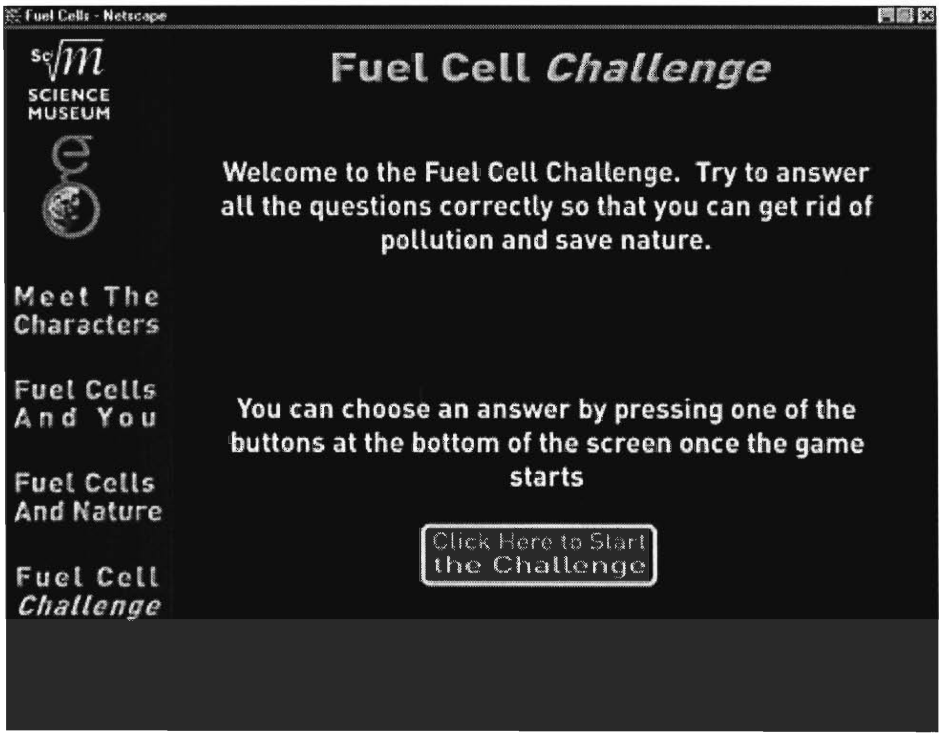


FIGURE I.23 – INTERACTIVE, INTRODUCTION

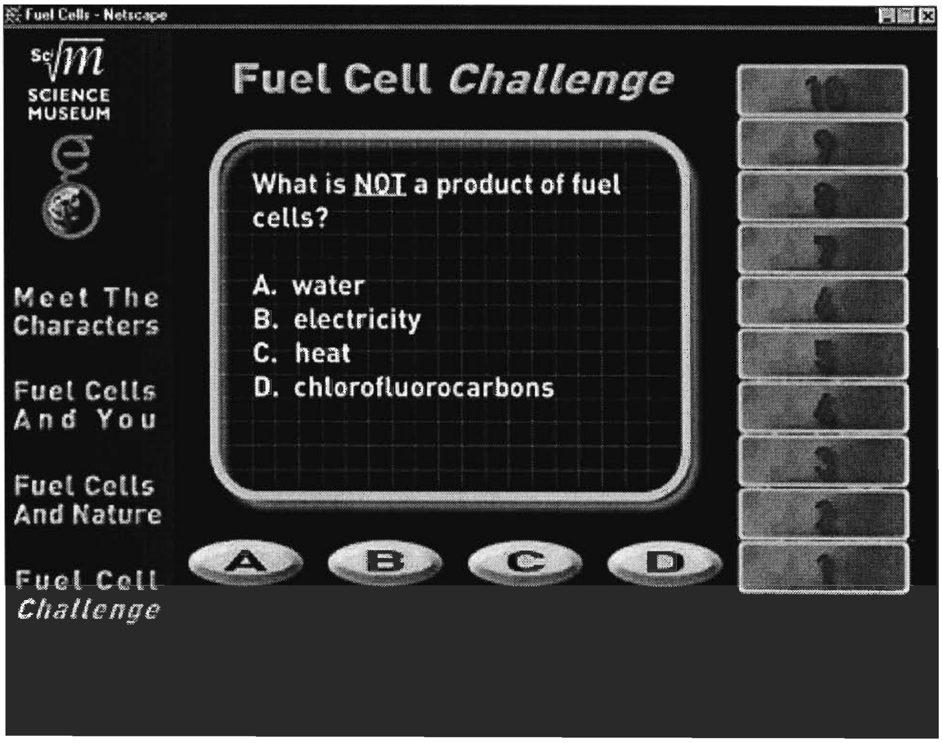


FIGURE I.24 – INTERACTIVE, MAIN SCREEN