

# The Future of Fuel Cells in Australia



An Interactive Qualifying Project  
completed in  
partial fulfilment of the bachelor of science degree at  
WORCESTER POLYTECHNIC INSTITUTE  
by

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# Abstract

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The Alternative Technology Association, a consumer advocacy group in Australia, requested a comprehensive review of the current status of fuel cell technologies in support of a policy recommendation regarding the possible application of fuel cell technology in a residential setting. We conducted interviews with key informants and a literature review to explore fuel cell technology in depth, as well as comparable alternative energies and how social, political, and environmental factors affect the further development and implementation of the technology. We implemented a strategic survey to assess the knowledge, opinions and concerns of the ATA membership about fuel cell technology. We then analysed these data to create a detailed recommendation to the ATA about the present and future applicability of fuel cell technology in Australia.

# Executive Summary

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Currently, Australia's per capita carbon dioxide emissions are among the highest in the world. There has been a continued effort in the country to move towards the use of sustainable technologies in order to reduce carbon emissions. One of the largest not-for-profit organisations promoting sustainable technology practices across Australia is the Alternative Technology Association (ATA). The ATA requested that our project group explore the future of fuel cell technology in Australia. We were asked to address specific objectives including researching the different types and applications of fuel cells, the cost of the technology, potential benefits of fuel cells along with advantages and disadvantages of comparable technologies, and lastly, to assess the potential role of fuel cells in Australia up to the year 2030. To accomplish our project goals and objectives and complete our report, we conducted in-depth research, surveyed the ATA membership, and interviewed numerous experts in the field, including two ATA staff members. The culmination of our project resulted in a policy recommendation for the Alternative Technology Association, which will prove useful as a basis to inform their members on both present and future fuel cell applicability.

A fuel cell is a device used to convert a specific type of fuel into electricity through a chemical reaction. The technology can be used for on- or off-grid power generation as well as many other applications. The majority of fuel cells are powered by hydrogen; however, many hydrocarbons can be used as energy carriers. This allows the utilisation of methane and natural gas as another means to fuel the device. There are various types of fuel cells that are best suited for certain applications. Our report specifically explores possible small-scale applications of fuel cells in sectors of home power generation, transportation, and portable electronic devices. Fuel cells used in these applications have potential to reduce overall carbon dioxide emissions.

A fuel cell is an energy converter, and if used in conjunction with sustainable technology to produce hydrogen, a fuel cell can provide continuous power with no carbon dioxide emissions. In Australia, there is currently widespread support for solar photovoltaic and solar hot water technology with various government incentives and policies implemented to promote the use of this sustainable technology. Although there are currently no incentives for fuel cell technologies in Australia, the incentives for solar power provide a valuable model for the promotion of widespread fuel cell usage throughout the country.

We discovered that fuel cells are already being produced by companies for applications in home power generation and transportation sectors. There are fuel cell vehicles presently in existence, but they are not yet commercially available or fully developed. Although there are barely any devices available for purchase by the general public, there is a company located in Australia, Ceramic Fuel Cell Limited, that is prepared to market their grid-connected home power generation fuel cells that run on natural gas. This is one of the first steps to initiate fuel cell use and to overcome the barriers to the development of the technology.

Despite the benefits of implementing fuel cell technology, we found that there are considerable obstacles that must be overcome before the market for the technology will expand. The high cost of the technology and the availability of more reasonably priced alternative products to reduce carbon emissions prevent consumers from considering purchasing a fuel cell. There are also no government policies or incentives in place in Australia, similar to those applying to solar PV, to encourage the purchase of fuel cells. Another barrier, more specific to the transportation sector, is a fuelling infrastructure. Our research revealed that hydrogen is the most promising future energy carrier, and if fuel cell vehicles are expected to use this fuel then the implementation of a hydrogen fuelling station infrastructure will be necessary. Once the production and interest in the technology increases and products are developed to demonstrate the benefits of the technology, the cost will drop and consumers will be more apt to purchase a fuel cell powered product.

As part of our report, we projected the future applications of fuel cell technology in Australia based on the information we gathered. Our group believes that near-future applications of fuel cells will begin with home power generation units that will run on natural gas. The next sector that we expect fuel cells to be implemented into will be transportation, accompanied by a suitable hydrogen-fuelling infrastructure to support fuel cell vehicles. We anticipate that portable electronic devices will be the last of the three areas where fuel cells will be implemented, once the technology is fully developed and practical for these applications. Alongside the development of the technology, we expect the hydrogen infrastructure and also hydrogen production, storage, and transportation methods to continue to develop and eventually allow fuel cells to be applicable many other areas. Our thorough research and investigation into fuel cell technology has culminated in a policy recommendation for the Alternative Technology Association. The policy outlines our

conjectures on the future application possibilities for fuel cells and when they are expected to reach a point of marketability.

Our recommendations include promoting the use and development of fuel cells for the purposes of transportation and energy storage, as well as supporting the development of technology to promote the sustainable production of hydrogen. We recommend that the ATA be prepared for home generation fuel cell systems to be fully commercialised within the next 10 years, and for fuel cell cars to reach the market within the next 10-15 years. Portable micro-fuel cells are not expected to reach the consumer market within a reasonable forecast period. We hope that by following these recommendations, the ATA will be able to make informed and productive decisions in advising its members and the community about fuel cells.

# Acknowledgements

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# Authorship

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Eric Dickinson, Erik Klinkhamer, Gawain Thomas, and Rachel Winsten each completed extensive research, and found reliable sources to complete this report. All participants contributed to the writing and editing of the report. Each group member attended interviews and tours to aid in the completion of the project. The authors of this report worked as a group to complete the project, and the work was distributed as evenly as possible between the participants.

# Nomenclature

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**ATA** – Alternative Technology Association

**BAU** – Business as usual

**Capex** – Capital expenditure

**CCS** – Carbon Capturing and Storage

**CO<sub>2</sub>** – Carbon Dioxide

**FiT** – Feed-in tariff

**GHG** – Greenhouse gas

**H<sub>2</sub>**– Hydrogen

**kW** – Kilowatt

**kWh** – Kilowatt hour

**LRET** – Large Scale renewable energy target

**MW** – Megawatt

**MWh** – Megawatt hour

**Opex** – Operational expenditure

**RET** – Renewable energy target

**Solar PV** – Solar photovoltaic

**WPI** -- Worcester Polytechnic Institute



# Chapter 1: Introduction

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Over the past ten years, the global interest in sustainability and alternative energy has increased tremendously. This can be attributed to a number of factors, which include increasing awareness of climate change, diminishing supplies of fossil fuels and a steadily increasing global population. As interest in this matter increases, so does the demand for information on alternative or 'green' technologies, including solar panels, wind turbines, and geothermal heat pumps. This demand has turned a formerly obscure area of research into a rapidly growing job sector that generates an estimated US\$100 million annually (REN21, 2009).

Australia has been leading a large portion of the world's research and development in renewable technology. However, the current implementation of such technologies in Australia is astonishingly scarce – studies have concluded that Australia's greenhouse gas emissions per capita are the highest in the world and less than 4% of Australia's electricity in 2005 was generated by renewable means. Survey results have shown that the Australian populous is largely in support of increased use of renewable energy sources. However, a plentiful supply of coal and a strong coal industry as well as the government's large financial support for fossil fuels has made the cost of these new technologies comparably high. Thus, the renewable technology industry in Australia is largely export-based (Aye, 2005).

In spite of the cost, there are efforts on many fronts to increase awareness and promote the use of renewable technologies in Australia. There are a number of organisations around the country whose focus is on informing Australians about new alternative technology, as well as providing them with access to the technology itself. One of the more prominent organisations is the Alternative Technology Association, commonly referred to as the ATA.

The ATA was created in 1980 with the purpose of spreading information about sustainable practices and technologies. The 2009-2010 ATA annual report states that the "ATA has over 11,000 members and subscribers and thirteen volunteer branches in Australia and New Zealand" (Alternative Technology Association, 2010). 'Going green' is a modern term used internationally to describe the transition of adding sustainable practices to one's lifestyle. The hard work of the ATA and the support from their members helps Australia

make progress in becoming a sustainable and environmentally friendly country. For more detailed information on the ATA and their programs, please see Appendix A.

The ATA is constantly involved in new projects and in promoting the use of innovative technologies. Presently, the ATA is interested in the possibilities for the future applications of fuel cells in Australia. As part of our collaboration with ATA, we will be investigating fuel cells and providing a full analysis on the feasibility of fuel cell implementation to the ATA.

Compared to non-sustainable present day energy technology, fuel cells have the potential to be more environmentally friendly as well as being more efficient. The ATA wishes to generate interest and educate their members and the Australian general public about fuel cells as an alternative sustainable energy technology. Information regarding the types, applications, and costs of fuel cells is not readily available. This is due to the fact that the technology is still being developed, and in turn, any products available to the general public are very expensive. The ATA does not presently have an evidence-based policy pertaining to fuel cell technologies. Specific information regarding the residential applicability of fuel cells, for example, will be helpful to residents interested in a new sustainable energy technology.

Because fuel cell technology has the potential to become a crucial part of the world's energy system and may become a large part of the ATA's energy sustainability plan, our team set up multiple goals and objectives to ensure a successful project. The main goal of this project was to compile as much information as possible on the different types of fuel cells, their applications in today's world, and their individual cost to implement. We researched how interested people are in incorporating this new technology into their daily lives. This information will allow the ATA to offer guidance to people who have questions on integrating the new technology into their everyday activities. Our second goal was to equip the ATA with new policy recommendations on fuel cell technology. Aside from general fuel cell research, we evaluated other available energy sources in order to compare their respective cost and social impact. By doing this, we were able to determine the feasibility of further advancement and implementation of fuel cells as a household application. With help from the ATA, their members, and key informants, this project determined the most suitable plan of action regarding fuel cells, and discovered the potential role that fuel cells may play in the future of Australia's energy market.

# Chapter 2: Methodology

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This chapter describes how we gathered and analysed data pertinent to our project in order to complete our objectives. Our objectives were accomplished by conducting a survey of the ATA membership, interviewing technical experts and ATA staff members, and reviewing relevant case studies and literature that were available to us in Melbourne. Once sufficient information was accumulated, we performed qualitative and statistical analysis to complete our project goals.

## 2.1 Project Goals

The first goal of our project was to create a detailed report on the applicability and potential of fuel cells in Australia for the present day and in the future. We also developed policy recommendations for the Alternative Technology Association. In collaboration with the ATA, we completed the following objectives:

1. Researched into the types of fuel cell technologies and their applicability for households, personal transport and small scale applications
2. Analysed the costs of fuel cell technologies, including projected cost curves of fuel cells and a discussion of external cost factors
3. Summarised the benefits and drawbacks of fuel cell technologies, and compared them with other alternative energy technologies
4. Assessed the potential role of fuel cell technologies in the context of energy and climate policy in Australia in 2030

Our methodology chapter will show how we accomplished these objectives, and incorporated our findings into a final report and policy recommendation for ATA.

## 2.2 Methods to Complete Objectives

We gathered data from technical experts, ATA members, ATA staff and experts on fuel cells and other sustainable technologies. Based on the information gathered from our informant interviews, we continued to research current case studies and literature related to fuel cell technologies, policies, and economics. To understand the social elements of the project, we sent out a survey to ATA members asking them about their current opinions and experience with new sustainable technology. This continued research helped us to address all four of the objectives listed above.

### 2.2.3 ATA Member Survey

In our project, it was critically important to understand the public's views and pre-existing knowledge on sustainable technology as well as on fuel cells. We ascertained this knowledge by creating a survey specifically for ATA members. The ATA members were used as a sample of individuals predisposed to sustainable technology, with an unknown level of knowledge and opinion on fuel cell technology. The database of ATA members contained approximately 5,000 members, all of whom received an invitation to participate in the survey. After leaving the survey open for two weeks, we received approximately 15%, or about 650 responses.

The questions that we posed in our survey were designed to provide specific information. The first section of the survey was designed to analyse basic information about the individual participants. These questions primarily included their age and place of residence. We then asked questions regarding their familiarity and opinions on sustainable technology, specifically what technologies they currently use and their priorities when purchasing new technologies. Our last section was designed to gauge their level of direct interest in fuel cell technology. These questions asked how much more they were willing to pay for various fuel cell products. The products were categorised as transportation devices, home power generators, and portable products such as laptops and cell phones. The survey was created electronically using Zoomerang (<http://www.zoomerang.com/>) and responses were solicited by sending a direct link via email to the ATA's entire membership.

Once this survey was closed, we were able to analyse our data thoroughly. This allowed us to draw conclusions about the participants' level of interest in fuel cells compared to other sustainable technology. Additionally, we were able to analyse comments left by the participants. Regardless of the participants' level of knowledge about fuel cells, this survey gave us a great deal of information that was crucial in making our policy recommendation.

#### *Sensitivity Analysis*

Upon request by an ATA staff member, a second copy of our survey was sent out to a different sample of individuals. The survey was redistributed to an email list by a contact at Ceramic Fuel Cells Limited. Because we had little control over the selection of individuals that received the survey link, we were not confident about the composition of the sample and we collectively decided not to include the results of the second survey in our primary

analysis. However, as part of our sensitivity analysis, we did analyse the data of the second survey and provide comparisons to the original survey when applicable.

As noted above, the second survey sample was an email list made up of many individuals interested in Ceramic Fuel Cell Limited. This included fuel cell and sustainable technology enthusiasts, shareholders, staff members and many other individuals who have registered for CFCL's email bulletin. The sample was about 3,000 members large. Within two weeks of opening the survey, we received about 12% feedback (about 400 responses).

## **2.3 Technical Background Research**

When conducting an analysis of a product or technology, it is important to understand the background and history of the technology. In this case, it was not only important to understand the history and background of fuel cell technology, but also to have some familiarity with other technologies that may compete with fuel cells. This technology includes not only other sustainable energy conversion technology, but other non-sustainable energy sources as well.

In order to gain a basic understanding of fuel cells and sustainable technology, we began to look at the literature available to us. This literature was found at Gordon Library at Worcester Polytechnic Institute. Additionally, we were able to utilise many scholarly journals through Worcester Polytechnic Institute's database subscriptions. This information was used to gain an understanding of the technology, and its benefits and requirements. We then began to research more specific details on each individual technology, including details that related to the technology behind each specific type of fuel cell. Further we were able to use previous reports and documentation completed by other universities and researchers to gain opinions on the current state of fuel cell technology.

Our second method of research involved interviewing technical experts. We contacted Robin Goodhand, principle scientist at AECOM. Mr Goodhand gave us critical information on hydrogen infrastructure as well as other future possibilities for fuel cell research and development. To improve our knowledge specifically on fuel cell technology, we had the opportunity to contact other individuals from fuel cell research institutions. These individuals were not only able to add to our knowledge on the technology but also give us information on competing and primary sources of energy. With this information, we put together an

extensive catalogue of technologies that could have the potential to bring new life to the energy market.

Additionally, the comments we received from ATA members were able to help us discover what current technologies people are using. With this information, we conducted further research and were able to add to our extensive list of sustainable technologies. Our technical background research was vital to providing us with a complete and functional understanding of fuel cell technology.

## **2.4 Cost Analysis**

The second key part of this project was to develop a cost analysis on fuel cell technology. This was done in two parts; the first was an overall cost evaluation of the current fuel cells on today's market. The second part was to identify a target cost at which consumers would be willing to purchase a fuel cell. Ascertaining this value not only took careful analysis of both surveys and interviews, but also required research into other sustainable technologies.

The overall cost evaluation of current technology was completed primarily using literature found in libraries and online sources. Because fuel cell technology is not widely commercialised, little information exists citing exact costs of fuel cells. We used information from Ceramic Fuel Cells Limited (CFCL) as well as estimates given in a number of scholarly articles to form our estimate. A primary resource for economic information about fuel cells was Andrew Neilson, group general manager at Ceramic Fuel Cells Limited.

The target price estimate came from both interviews and surveys. After speaking with multiple fuel cell experts on the future potential of fuel cell technology, a general consensus was reached on the price needed for the technology to be marketable. Even with this figure, determining when the product will be popular with the general public is still a very difficult puzzle to solve. There exist other factors aside from the capital cost that will affect a product's marketability.

One example that would be relevant to hydrogen cars is a fuel infrastructure. Both availability and affordability of hydrogen fuel will affect the marketability of fuel cell cars, regardless of the cost of the car. It is because of this that we also needed to apply our archival research skills in finding information about the potential for a hydrogen infrastructure in the near future. This involved investigating case studies on different types of fuelling stations that are being installed in countries around the world.

During our cost analysis, it was important to consider the levelised cost of energy as well as the net present value. The levelised cost of energy “allows [for] the comparison of various technologies [with] unequal life times and capacities” (Energy Technology Expert, 2011). With this information, we can use the net present value to estimate what the cost of different energy production methods will be in the future. We created a spread sheet to compare different technologies and their respective costs and benefits. This information was vital in comparing the payback period of fuel cells with other technologies. Once we had information from our survey on the price that people would be willing to pay, as well as our economic analysis, we were able to estimate when and if fuel cells would become commercially viable.

## **2.5 Policy Analysis**

Our policy research was split into two main sections. The first section focused on global energy policies in general, and the second investigated specific energy programs in Australia. When researching world policies, official government websites and recent government publications were used. We researched not only the actual policies currently in place, but also the effectiveness of these policies, and the public’s overall opinion of climate change and sustainable energy policies.

Research on Australian energy programs was critical to our policy recommendation. A great deal of our information on this topic was taken from conversations with current ATA staff members Damien Moyse and Craig Memery. Both individuals work directly with Australian energy policy and were very well informed and helpful with our research. Their interviews strengthened our understanding of the current policy mechanisms and other government programs that support a variety of energy technologies within Australia. This then provided us with a good understanding of how fuel cells may fit into government programs and policies, should they become commercialised in the future.

## **2.6 Policy Recommendation**

Our policy recommendation is a critical part of our project and will be of great value to the ATA and its membership. The goal of the policy recommendation is to advise the ATA and its members on the usage and future fuel cell applicability, and as such it was necessary to use all types of research methods.

Although archival research and interviews were an important part, the ATA member surveys allowed us to understand the needs and desires of the general public directly, and in turn speculate on if and when the ATA should support the commercial implementation of fuel cell technology. We not only used the surveys to interpret patterns in the ways that individuals view the technology in different applications, but we also used any further responses as a means of getting the public's opinion on the technology. Patterns were collected and cross-referenced in order to produce a qualitative evaluation of the necessary stage of fuel cell development before they become commercially viable. With all this in mind, we created a comprehensive policy recommendation to assist the ATA in advising its members.

## **2.7 Data handling and storage**

Privacy and confidentiality were important elements in this project that our team took seriously. With this in mind, all documents, interview notes, and survey responses were stored on a password-encrypted computer. Only the four people on this project team (Eric Dickinson, Erik Klinkhamer, Gawain Thomas, and Rachel Winsten) were privy to this information. Further, we were obligated by WPI's Internal Review Board standards not to share any information given by participants of this project without their knowledge and consent.



# Chapter 3: Background Research

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We conducted extensive research into various aspects of energy technology, sustainable technology that is currently in use, fuel cells, and the fuels that power them. We also researched the present and future applications of fuel cells, the environmental impact of fuel cells, and international and domestic policy that will likely have an impact on the implementation of fuel cells.

## 3.1 Energy Storage and Conversion

When examining the merits of any new energy technology, one must consider the role that it will play within the energy distribution process. These roles can be split into two major categories, energy storage and energy conversion. Both categories are vitally important to the present day energy market, and it is important to understand the specific differences between these two main types of technology.

Energy conversion devices convert energy from one form to another. An example of this would be a solar photovoltaic panel, which absorbs energy in the form of light and converts it to electrical energy. Another example is an internal combustion engine, which takes energy in the form of a fuel (chemical energy) and converts it into mechanical energy and waste heat. The brakes in the car are also energy conversion devices, as they remove kinetic energy from the car and convert it to heat. Many current energy technologies, such as wind turbines, solar panels, hydroelectric turbines, traditional power plants, and fuel cells, focus on converting to electrical energy. This is because electricity has a wide range of uses and is easy to transmit using electrical wires. One challenge currently facing our energy distribution system is that there are relatively few methods of converting low-grade heat (low temperature) into other usable forms. This means that a large proportion of wasted energy is in the form of heat. Ultimately, a diverse selection of energy conversion devices is critical to our ability to meet our energy needs.

Energy storage refers to any case where the form of the energy does not change over time. In a physical sense, it usually takes the form of potential energy. One example of an energy storage medium is petroleum. In this case, the energy is stored in the form of chemical bonds within the fuel, and remains there indefinitely until the fuel is burned. Upon burning, it is then *converted* to heat and mechanical energy. Other examples include any other type of fuel (gas, coal, hydrogen, vegetable oil, etc.) as well as batteries, springs, weights, and

virtually anything else that is capable of absorbing energy. Some storage devices may be more useful than others, but any means of storage has the potential to play a role in the effective distribution of energy. Different carriers require different distribution methods. That is, electricity cannot be transported through pipelines, and coal cannot be transmitted through wires. Figure 1 shows the different stages of energy distribution, and demonstrates that conversion and storage both play critical roles.

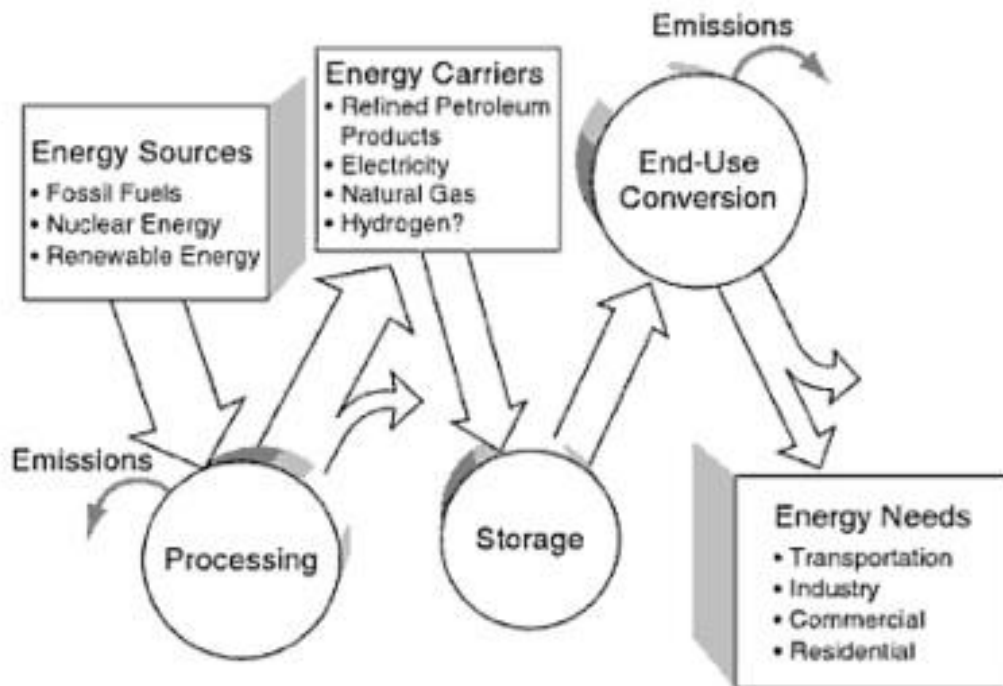


Figure 1. Stages of Energy Distribution (Evans, 2007)

Energy conversion and storage are both vital to the successful distribution of energy. Any piece of energy technology will perform one or the other, or it may often contain elements of both. It is important to understand the distinction, as it is crucial to developing technology that effectively meets the needs of consumers.

### 3.2 Primary Energy Sources

Over the past decade, energy has become a topic of concern in the political and technological world. As resources have become scarce and prices have increased, the need for alternative energy resources has also grown. Therefore, numerous countries have begun to incorporate sustainable technology development into their energy policies, and billions of dollars are being spent globally to fund research and development into such programs. Sustainable technologies include those that are both renewable and clean. Figure 2 below

illustrates the world's total energy production by source. As shown, fossil fuels dominate the energy market, and only 9% of the world's energy comes from renewable sources.

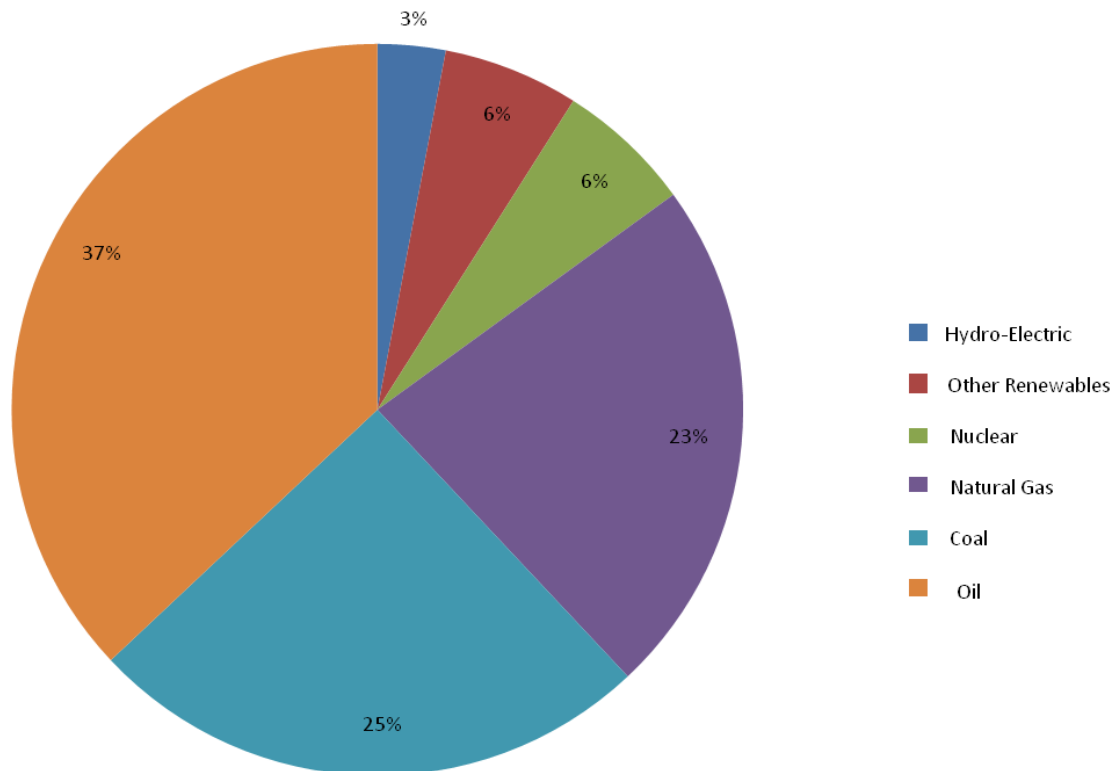


Figure 2. World Energy Production by Source (Source: International Energy Agency, 2007)

Since transportation, household and industrial sectors are all affected by the increase in energy demand and the decrease in supply of fossil fuels, the use of sustainable technologies will need to increase in coming years. Some of the more prominent initiatives promoting sustainable technologies include Denmark's use of wind and biomass energy, India's wind energy generation, and Germany's use of solar energy (Chaudhuri, 2010).

### 3.2.1 Fossil Fuels

Fossil fuels are the most widely used source of energy in the world. The fossil fuel that is used most is oil, followed by coal and natural gas. Since fossil fuels are stored in the ground, extraction methods must be utilised to access them. Common methods of extraction include drilling and mining, both of which are detrimental to the environment. Furthermore, fossil fuels pollute the air, in addition to being non-renewable and in some cases, expensive. Since fossil fuels are non-renewable, their supply is becoming limited. Some estimate that

within the next generation, the earth's supply of fossil fuels will be completely depleted. Therefore, as energy demand increases, so do calls for renewable energy (Morgan, 2009).

Australia, like the rest of the world, is highly dependent upon fossil fuels. The Australian government notes, "in 2007-08, Australia's energy production was dominated by coal, which accounted for 54% of total Australian energy production" (Australian Government & Department of Resources, 2010, p.1). One major reason why Australia is so reliant on coal is due to its low cost. Unfortunately, the efficiency and environmental cleanliness of converting coal to electricity are also inherently low, so the government and private companies are researching technical improvements to increase efficiency and reduce environmental damage. To this end, the use of coal in conjunction with other sources of energy is of interest to various governments and private corporations. For example, integrated fuel cell gasifier systems may increase coal plant efficiencies from around 28% to near 60% (World Coal Association, 2010). Although more expensive, these types of advancements could provide increased efficiency, while causing less damage to the environment than conventional combustion processes (Pimentel & Johansson, 1993).

### 3.2.2 Hydropower

Hydroelectric power is a source of low-cost, clean, renewable electricity. It is the largest available sustainable source of power, and is used in over 150 countries around the world. Norway, parts of Africa, Bhutan, and Paraguay rely almost solely on hydropower for electricity. Overall, hydroelectric power provides around 20% of the world's total electricity. For small-scale applications, hydropower can be a great asset to local energy economies. Expansion of hydropower is expected to greatly increase throughout developing countries in the coming years (Letcher, 2008; Herzog et al, 2001).

Compared to other processes, hydropower is a very efficient way to generate electricity. An article by A.V. Herzog, entitled *Renewable Energy Sources*, states, "modern hydro turbines can convert as much as 90 per cent of the available energy into electricity" (Herzog et al, 2001, p.1). Drawbacks of using hydropower include its social and environmental impacts, such as community displacement and the damming of rivers. Dams require large amounts of land to be flooded, forcing inhabitants to relocate, and causing significant environmental concerns. Because of this, hydropower's potential is limited by economic and social constraints. The construction of hydropower plants often results in a decrease of plant life and fish, as well as affecting water quality, which results in increased

possibility of water-borne diseases. Until these issues are overcome, controversy will continue to surround the use of hydroelectric power (Letcher, 2008; Herzog et al, 2001).

### 3.2.3 Biomass Power

Biomass – living plant and organic matter – is another alternative energy option. Biomass was once the main form of fuel around the world. After the emergence of fossil fuels, the use of biomass fuels decreased significantly. In developing countries, it is still a major source of energy for heating and cooking. Biomass can also be used on larger scales to provide energy for numerous industrial uses. Biomass is renewable and readily available, but the processes required to use it are not completely clean. For industrial uses, most biomass must be converted to gas and liquid form through the use of hydrothermal and thermal processes. These processes release carbon dioxide, and result in the use of biomass being somewhat harmful to the environment (Evans, 2007).

One of the most popular forms of biomass energy is ethanol, which can be added to petrol for use in transportation. The production of ethanol from corn has been heavily subsidised in the United States, but its efficacy is debated. Specifically, the production, transport, and eventual use of ethanol are likely to produce more carbon dioxide than an equivalent amount of petroleum. Furthermore, the effects of ethanol on traditional petrol engines have not been fully researched, and may lead to early engine failure and increased fuel consumption, which would defeat the purpose of using it as an additive (Field, 2008). Other forms of biomass energy include firewood and vegetable oil, as well as methane, which can be captured from agricultural facilities and landfills. Regardless of type, all biomass fuels share the disadvantage that they produce significant amounts of carbon dioxide. Recently, some efforts have been made to reduce these emissions. Biofermenters are a type of conversion device that convert biomass into methane. They can grow large numbers of fungi in a short period of time. (Teng, 2008). Even with this type of advancement, controversy surrounds the use of some types of biomass for socio-economic reasons. For example, some believe that corn-based ethanol production takes up land that could be utilised to produce food. This argument extends to forecast that increased food competition and ecosystem devastation may result from increased use of biomass (McKinney et al, 2003). As more research is put into biomass, developments in the technology will continue to emerge, and may help to ease concern (Evans, 2007).

### 3.2.4 Wind Power

In recent decades, wind power has become a successful large-scale clean renewable energy source. With the oil shortages in the early 1970s, wind power gained a great deal of attention. By the mid-1990s, the world installed wind power capacity grew to over 6,000 MW. By 2008 it rose to 120,790 MW, and this increasing trend is expected to continue. Wind power traditionally provided mechanical energy to pump water and run mills and other machinery, but now it is primarily used to provide electricity for basic residential and industrial uses. The installation of wind turbines is limited by site availability, since adequate wind speeds need to be available to produce power. When sites are available, however, this type of energy is very useful and has little to no harmful impact on the environment. Even though wind power is a clean, renewable source of energy, controversy still surrounds its use. Wind power is a stochastic energy resource, and very little can be done to control the amount of power produced at any given time. Additionally, the installation of wind turbines carries high capital costs. Once installed, however, very little additional maintenance is usually required. Complaints exist regarding land use, danger to birds, and noise. Improvements in wind turbine design are constantly reducing risks, and in turn, decreasing concerns (Morgan, 2009).

The use of wind power has become common throughout the world; leaders include Europe, North America, India, and China. In Copenhagen, Denmark, the largest offshore wind farm exists. Wind power currently supplies about 19% of Denmark's energy needs, and has greatly reduced the country's overall emissions of harmful chemicals.

Wind and solar power account for the majority of Australia's renewable energy production. Numerous less-developed countries have also implemented small-scale wind farms, which often power villages in remote areas. In the next two to three decades, wind energy use and efficiency are expected to greatly increase throughout the world (Morgan, 2009).

### 3.2.5 Solar Power

Solar energy is another common sustainable source of energy. Solar energy can be collected and used for household and industrial applications, and can provide electricity on large and small scales. The use of solar energy has increased greatly over a short period of time. In the 1980s, less than 25 MW of energy was being generated by solar power. By 2000, this number rose to over 150 MW. Solar energy is used in various applications around the

world, and its use is expected to greatly increase in the next few decades (Herzog et al, 2001; EcoWorld, 2006).

Solar photovoltaic and solar thermal technologies are widely used around the world today. Solar photovoltaic systems convert the sun's energy directly into electricity. In past years, solar photovoltaic systems have been costly and required large amounts of maintenance. Nevertheless, these systems have great potential due to the fact that they can be used on both large and small scales. As these systems have become more modernised, prices and maintenance issues have become less of an issue.

Another way to use the sun to produce electricity is through the use of solar thermal systems, which create steam from the sun's radiation. The steam created runs turbines to produce electricity. Solar hot water collectors are a type of small-scale, solar thermal technology. They provide a very efficient, relatively low cost source of hot water. In Australia, solar hot water is already widely used (Commonwealth of Australia, 2010).

A solar thermal power plant is a large-scale, somewhat costly implementation of solar thermal technology. These facilities make use of large mirror fields that concentrate the sun's energy by reflecting it towards absorbers. From there, the radiation is thermally converted to heat. Some solar plants have the ability to store the heat, and use it when needed. There are three main types of solar thermal technologies. These include power towers, parabolic dishes, and parabolic troughs. Power towers are tall towers with tracking mirrors around them. These mirrors reflect the sun's energy to the top of the tower, where heat is accumulated. Parabolic dishes are the most powerful type of solar thermal technologies. Their dish shape allows for little heat loss, and strong reflection abilities. Parabolic troughs are in the shape of a long parabola, and are the most cost-effective of the three collection methods. They are placed horizontally, with an absorption tube running through the middle. Solar thermal plants can produce great amounts of power, but to do so, they often require large amounts of land. Complaints exist regarding the use of land for fields of solar plants. Solar facilities are already implemented in numerous countries. Their cost is expected to decline in coming years, and with this, their overall use will continue to increase (EcoWorld, 2006).

Although solar power has many advantages, it does have some drawbacks. The initial cost of solar cells is high, making installation fees large. Also, solar power is completely dependent upon the sun, and therefore stochastic. Foggy, rainy, or dark conditions present problems, making solar power site-dependent and only effective for part of each day. Both solar photovoltaic and solar thermal technology can be expensive. As solar power becomes

more commonly used, prices will continue to drop, allowing these systems to become even more widely commercialised (Herzog et al, 2001; EcoWorld, 2006).

### 3.2.6 Emerging Technologies

There are numerous emerging renewable technologies that have recently shown great potential. Specifically, wave and geothermal energy are being continuously researched in Australia and around the world. Because Australia possesses some of the world's strongest surf due to surface topography, wave and tidal energy holds significant potential as a reliable source of renewable energy. Geothermal technology is a promising renewable source of energy for Australia as well, and could put the country in a position to establish a leading geothermal industry (Australian Labour, 2010). Geothermal energy makes use of the earth's natural heat. The earth's core stores a vast amount of heat that was generated thousands of years ago from continental shifts and radioactive decay (Herzog et al, 2001). It is estimated that Australia's annual energy requirements would be met for 26,000 years if only 1% of its possible geothermal energy were tapped (Australian Labour, 2010). While these technologies show promise in the future, neither is widely implemented and they are still in their research stage. In the next few decades, the world is expected to become increasingly dependent on sustainable technologies; therefore, it is important to recognise their great potential to supply energy, while decreasing carbon emissions and harmful environmental impacts.

### 3.2.7 Overview

With each type of sustainable technology, cost is an issue. Due to the fact that most of these technologies are not widely commercialised, costs remain high. Tom Konrad PhD provides some insight into the costs of various types of sustainable technologies. Figure 3 shows the overall costs of numerous technologies, based on a 2009 study.



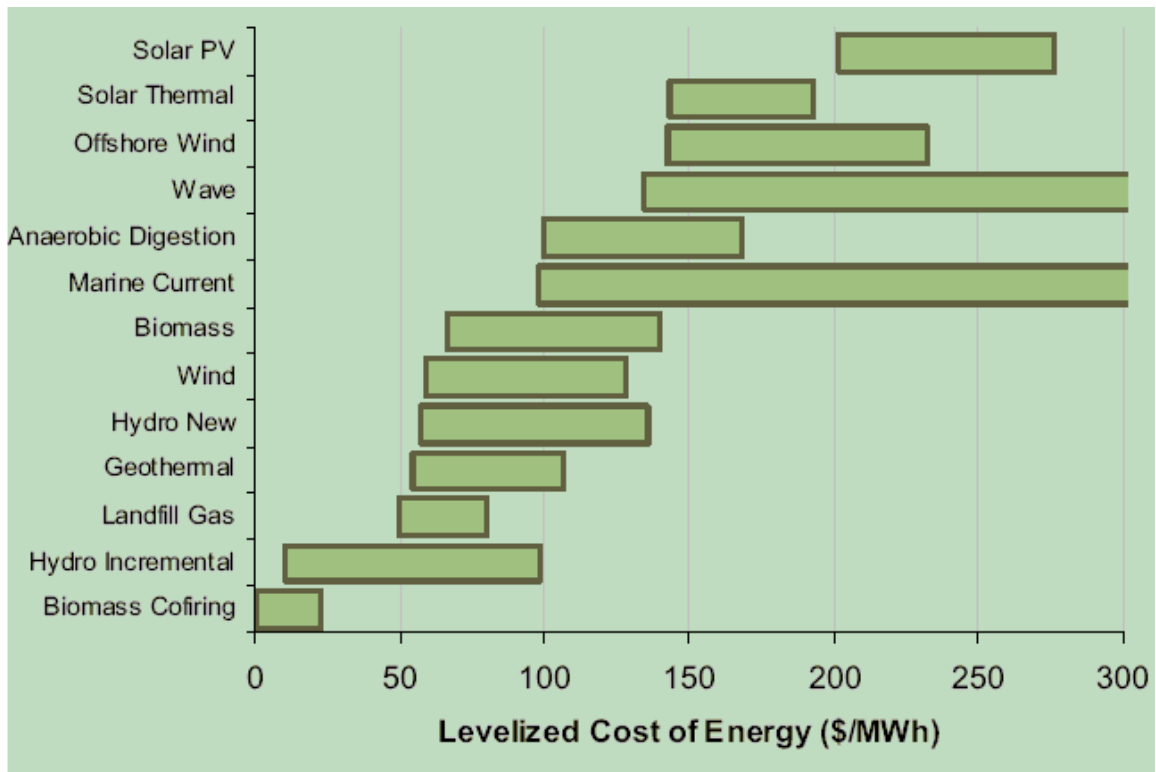


Figure 3. Levelised Cost of Energy (Konrad, 2009)

Table 1 shows a comparison of the costs and capacities of all the sustainable technologies discussed in this section. As shown, some types are rather expensive. As more progress is made in the area of sustainable technologies, costs and environmental impacts may decrease, as efficiencies may increase. Currently, the cost of fossil fuels and coal ranges from around \$25-50/MWh, significantly less than most of these sustainable technologies. . Each day research and development goes into sustainable technologies, and therefore, Table 1 is subject to change (Konrad, 2009).

Table 1. Sustainable Technology Comparison (Konrad, 2009)

Sustainable Technologies Comparison Chart								
	Solid Biomass	Cofired Biomass	Solar Thermal	Solar PV	Wind	Geothermal	Wave	Hydroelectric
Capital Costs \$/kW	3000-4500	300-500	3800-4800	6500-7500	1900-2400	3000-5000	2800-5200	2500-4000
Net Plant Capacity, MW	35	35	200	20	100	30	100	<50
Fixed O&M \$/kW-yr	83	5-15	66	35	50	N/A	150-270	5-25

## 3.3 Fuel Cell Technology

One type of alternative energy technology that shows great promise for both large- and small-scale applications is the fuel cell. A fuel cell is a device that converts hydrogen (chemical potential energy) into electrical energy. At the present time, fuel cell technology has been implemented in many applications, including home power generation and transportation. Australian Prime Minister Julia Gillard and US President Barack Obama were among the world leaders who were transported via fuel cell buses to the G20 Summit in 2010 (Pank & Philip, 2010). With large potential for fuel cells in alternative energy, the technology is sure to impact the energy market in years to come. K. R. Sridhar, CEO of Bloom Energy, envisions that fuel cells have the potential to “power anything from a single home to a whole city” (Zakaria & Fareed, 2010, p.1).

### 3.3.1 History

Although fuel cells are considered by many to be a revolutionary technology, the device was actually invented over 150 years ago. William Robert Grove, in 1843, was the first individual to produce a working fuel cell. His attempts can be traced back another 20 years to when he was renowned for his work on wet-cell batteries. In 1838, Grove introduced his ‘Grove Cell’ battery. The battery was created with two liquid compartments filled with nitric acid and zinc sulphate. Respectively, platinum and zinc electrodes were placed in these compartments which in turn generated about 12 amps of current with a corresponding voltage of 1.8 volts (NOVA, 2011).

From his ‘Grove Cell,’ the discovery of the first fuel cell was just a few short years away. Grove started to experiment with using the elements formed from the decomposition of water to power a battery. He soon realised that when he combined multiple sets of his “Grove Cell” while running a stream of hydrogen and oxygen, the device would produce a flow of electrons. This device was what Groves referred to as a ‘gas battery.’ This gas battery was the first instance of the modern-day fuel cell (NOVA, 2011).

### 3.3.2 Fuel Cell Dynamics

Fuel cell dynamics are rather simple; see Figure 4 for a schematic diagram of the inside of a fuel cell. Like a common battery, a fuel cell has a positive and a negative electrode. The difference between a battery and a fuel cell is that a battery has chemicals sealed within the device (thermodynamically closed) while a fuel cell has fuel constantly

flowing through the device (thermodynamically open). Whereas a battery is constricted to a certain lifetime before it must be disposed or recharged, a fuel cell can run continuously as long as there is a constant flow of fuel.

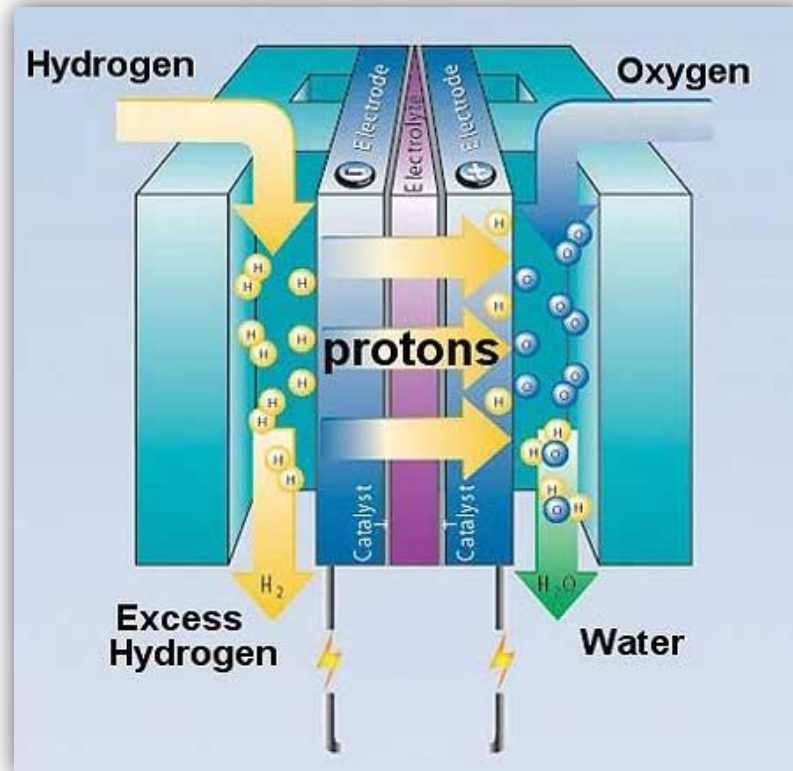


Figure 4. Proton Exchange Membrane Fuel Cell Diagram (Ryan International School Nerul, 2010).

The chemistry inside a fuel cell is quite simple, and can be broken into two chemical reactions. As an example, we examined the Proton Exchange Membrane Fuel Cell. The hydrogen fuel (H<sub>2</sub>) enters the negative side (the anode) and is catalysed to form protons (H<sup>+</sup> ions) and electrons (- charge). The positive ions will travel through an electrolytic substance to the positive side of the cell (the cathode), leaving the electrons concentrated at the anode. This electrolytic substance is specifically designed to allow the passage of the proton while blocking the negatively charged electron. The ions arrive at the positive end of the cell and bond with dissociated oxygen ions (O<sup>2-</sup>), forming water molecules (H<sub>2</sub>O). The electron, trapped on the anode side is then diverted into the load (the application being powered by the cell) and through to the cathode creating a flow of electricity. Because hydrogen fuel cells tend to deliver a low voltage (around 0.7 volts per cell), many researchers have devised ways

to 'stack' fuel cells in an attempt to increase the overall power output. This stack of cells is the core component of any commercial and industrial fuel cell (NOVA, 2005)

### 3.3.3 Characteristics and Categorising

There are many different types of fuel cells. The primary way to categorise a fuel cell is by the type of electrolytic substance found in the centre of the device. This yields six main types of fuel cells: Proton Exchange Membrane fuel cells (PEMFC), alkaline fuel cells (AFC), Phosphoric Acid fuel cells (PAFC), Molten Carbon fuel cells (MCFC), Solid Oxide fuel cells (SOFC), and Direct Methanol fuel cells (DMFC). These terms are the standard and most commonly used descriptions for the different types of fuel cells (Fuel Cell Fundamentals, 2006).

Another method to characterise the fuel cell is by the charge of the ion that is sent through the electrolyte. This ion can be either positive or negative. These ions include hydrogen ions ( $H^+$ ), hydronium ions ( $H_3O^+$ ), hydroxide ions ( $OH^-$ ), carbonate ions ( $CO_3^{2-}$ ), and oxygen ions ( $O^{2-}$ ) (Principles of Fuel Cells, 2006).

An intuitive way to categorise the fuel cells types is by their operating temperature. The three categories refer to high, low, and intermediate operating temperatures. Molten carbonate and solid oxide fuel cells operate at a very high temperature (between  $600^\circ C$  and  $800^\circ C$ ), while alkaline and polymer electrolyte fuel cells operate at a relatively low temperature (between  $100^\circ C$  and  $200^\circ C$ ). Phosphoric acid and direct methanol fuel cells operate at an intermediate temperature (between  $200^\circ C$  and  $300^\circ C$ ). Scientists use this information, as well as specific information on each type of fuel cell, to determine which types are most appropriate for certain applications (Principles of Fuel Cells, 2006). Additional information on the different types of fuel cells is provided in Appendix F.

### 3.3.4 Advantages of Fuel Cell Technology

Fuel cell technology has the opportunity to provide the community with a new way of providing electricity to specific applications. This technology, with proper research and development, has potential to greatly impact different energy sectors. Advantages of fuel cells can be easily identified in terms of their energetic potential as well as their physical characteristics.

Like any other technology, the efficiency will vary depending on specific type of fuel cell as well as operating conditions. However, under optimal operating conditions, fuel cell

technology has the potential to have electrochemical efficiencies peaking at about 80%. With this incredibly high efficiency, fuel cell technology would allow a decreased rate of fuel consumption with an equivalent output of electricity, compared with the low efficiency of a power plant. With all sustainable energy technology, part of the motivation for its use is based upon preservation of the environment and combating climate change. Because of this, one of the greatest selling points for fuel cell technology is its zero emissions chemistry. When hydrogen is fed into the cell, water is the only waste product released. Because of this, a fuel cell has the potential to be part of a completely clean energy system (Principles of Fuel Cells, 2006).

### 3.3.5 Disadvantages of Fuel Cell Technology

While fuel cells show promise as a more sustainable technology, there are still many disadvantages to the technology. The majority of the disadvantages, however, may be improved with additional research and development. Some disadvantages include the start-up time of the equipment, the operating temperature, and the overall lifetime of the fuel cells. Additionally, there are some negative views on the characteristics of various fuels that power the fuel cell. These fuels, primarily hydrogen and methane, while having many beneficial uses also carry some challenges, such as storage and CO<sub>2</sub> emissions.

SOFCS currently in production for residential use can take as much as 25 hours to start up. This means that the device cannot be switched on and off frequently and therefore cannot be used for backup power. Additionally, once the cell is running at full capacity, the operating temperature can approach 750°C. The high operating temperature can be concerning to some consumers, as well as causing increased production of waste heat.

The other main disadvantages of fuel cells involve the fuels that are being supplied to the cell. Currently, hydrogen is the most promising fuel for use with fuel cells, and there are different methods to acquire the hydrogen needed. One of these methods is electrolysis, a way of getting hydrogen from water, which can be a clean but expensive process. The other method involves using the energy storage characteristics of methane. In the case of Ceramic Fuel Cells Limited's BlueGen fuel cell, methane is distributed to the fuel cell through city gas pipelines, and the methane is reformed within the cell, producing a carbon dioxide by-product. This by-product demonstrates that although the cell itself is a clean technology, there needs to be much consideration put into how the hydrogen is produced.

## 3.4 Fuels That Power Fuel Cells

While the fuel cell device can be considered a completely clean technology, the operation that is used to produce the fuel is not. The two fuels that have been the most commonly used fuels are methane and hydrogen. The production of these two fuels heavily impact the acceptance and future commercial implementation.

### 3.4.1 Methane

In the early 1990s, it was found that other carriers could be used to transport the hydrogen needed to power a fuel cell, including methane. Methane is found in natural gas, and can be easily transported to the site of use and then reformed inside the cell. While this process does release CO<sub>2</sub>, fuel cells powered by natural gas may offer a more clean generation of electricity compared to the use of traditional gas or coal power plants.

When compared with using hydrogen in fuel cells, methane has the advantage that it is more naturally abundant than hydrogen, and has the ability to be made into hydrogen fairly easily. Furthermore, the greatest advantage of using methane is the mobility. That is, methane can be transported more easily than hydrogen due to an existing natural gas infrastructure and its ability to be pressurised more easily than hydrogen. For this reason, methane fuel cells are likely to be used until a suitable hydrogen production and distribution infrastructure is in place. The methane would flow in from city pipelines, be converted into hydrogen and CO<sub>2</sub> inside the cell, then pass through creating water, carbon dioxide and consistent flow of electricity (Coxworth, 2011; Dicks, 1996).

### 3.4.2 Hydrogen

Hydrogen is a flammable gas that has primarily been used in laboratory research until recently, but is beginning to show promise as a fuel. The main reason hydrogen is attractive as a fuel is that it produces no CO<sub>2</sub> emissions, and it also works very well with the chemistry of fuel cells. Fuel cells can operate using a variety of fuels, but hydrogen is the most favourable due to its cleanliness and ease of manufacture (Drennan, Hunter & Little, 2005). Also, the initiative to use hydrogen as a primary fuel stems from a number reasons including energy security, the protection of the environment, and possible economic growth (Abraham, 2004). However, a significant concern is that the Earth does not have large natural reserves of hydrogen, as is the case with petroleum, so hydrogen must be manufactured from other energy sources in some way. Because of this, hydrogen should be thought of not so much as

an energy *source*, but an energy *carrier*. Hydrogen provides a convenient way to store and transport energy that is obtained from other sources. Before it can be widely used, however, there are some considerations that need to be taken into account.

### *Potential Advantages and Disadvantages of Hydrogen*

There are some potential concerns with using hydrogen as a primary fuel. The core disadvantage of using hydrogen is that it is not an abundant natural resource. It requires some means of production from a variety of sources, some of which will produce CO<sub>2</sub> emissions. There is also a need for advancement in research for new storage and transportation methods for the fuel (International Energy Agency, 2006). Furthermore, since Australia is such a large player in the global energy economy with its significant non-sustainable energy production, it may not make economic sense to adopt hydrogen as a primary energy carrier (Wright, 2006). Lastly, there are always concerns with the efficiency of the conversion of an energy source into hydrogen, and whether or not the loss of energy is worth the conversion (Myer, 2004). Although there are an abundance of disadvantages with using hydrogen as a primary fuel source, there are also some great advantages.

The cleanliness of hydrogen is the most significant advantage to adopting it as a fuel. When pure hydrogen is utilised in a fuel cell, it produces no CO<sub>2</sub> emissions and will enable Australia to move towards its goal of a cleaner future environment (Wright, 2006). Some have suggested that safety may be a concern when using hydrogen, but according to a paper published by the Rocky Mountain Institute, hydrogen is not as dangerous as some may think (Lovins, 2005). Although it burns with a clear flame and can be hard to see, hydrogen in the air is difficult to ignite and its explosive power is 22 times weaker than that of petrol (Lovins, 2005). Furthermore, burning hydrogen produced by a non-sustainable method in an automobile produces about 40 to 67 per cent less CO<sub>2</sub> than burning hydrocarbon fuel in an otherwise identical petrol powered internal combustion car (Lovins, 2005). There has been ongoing research and development in the fields of hydrogen production and storage, but widespread distribution of the fuel is not currently practical according to the International Energy Agency (IEA, 2006). Hydrogen also possesses the advantage that almost any source of energy can be converted into hydrogen (Lemus, 2010). Steps are currently being taken towards the adoption of hydrogen which involves addressing the production, storage and distribution methods of the fuel.

## Hydrogen Production

The production of hydrogen is possibly the greatest concern that will affect its use in fuel cells. There are various methods of creating hydrogen, including production from fossil fuels, reformation of methane using steam, electrolysis, and biomass gasification (Holladay, 2009). Figure 5 displays numerous potential hydrogen production options, some of which are already being implemented.

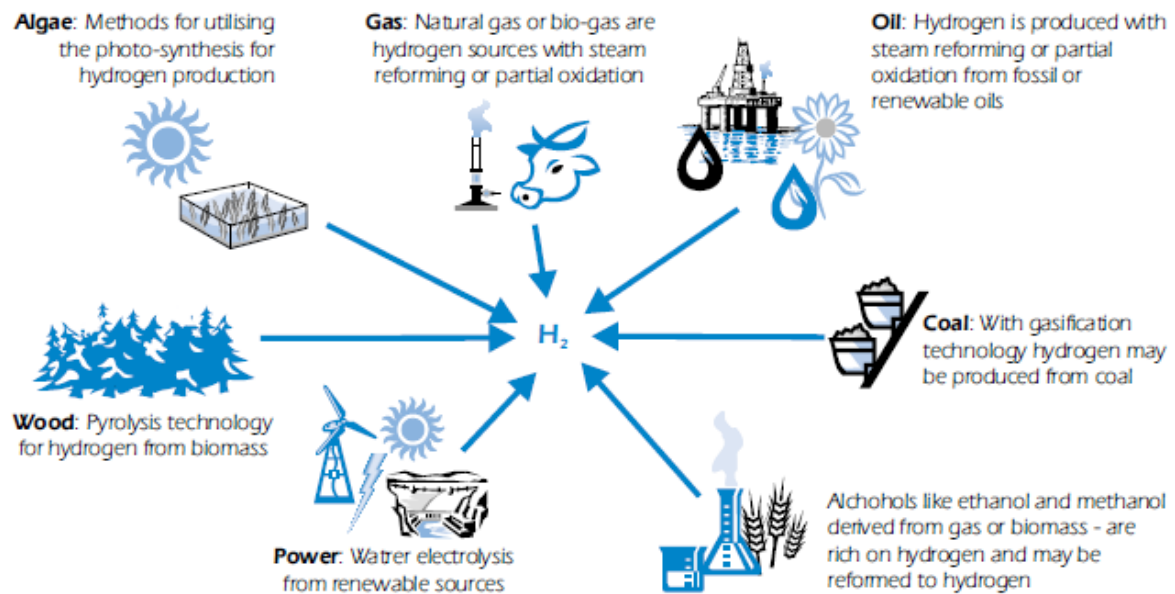


Figure 5. Hydrogen Production Methods (IEA, 2006)

Fossil fuels appear to be a short term implementation option for hydrogen production (IEA, 2006). One option would be to utilise oil and petroleum for producing hydrogen at the site of the consumer. This would be advantageous because existing oil and petroleum pipelines can be used to bring fuel to an onsite reformer where steam reforming can produce hydrogen (McLellan et al, 2004). The problem with this method is that there will still be greenhouse gas emissions present, although less CO<sub>2</sub> will be released than if the oil or petroleum were burned conventionally. Coal provides another practical production option because it is the most abundant fossil fuel on the planet and there are prevalent reserves in Australia. Hydrogen can be produced from coal through gasification and also by coal-generated electricity, but these processes also produce unwanted CO<sub>2</sub> emissions. Another issue with coal is that the existing infrastructure in Australia presents a large obstacle to the implementation of a new energy source in sectors where coal is currently used. Such a change would most likely be detrimental to the current power plants and the economy that revolves



around them. The last promising production method involving fossil fuels that can be used to produce hydrogen is natural gas, which is the cleanest out of all the fossil fuels, making it the most attractive option. The methane in the gas can be easily reformed into hydrogen through the use of steam (McLellan et al, 2004). As with all fossil fuel-powered hydrogen production methods, there still will be CO<sub>2</sub> emissions, but in smaller quantities. Overall, it is important to consider the potential of these production methods until sustainable production increases sufficiently.

Water provides various considerable options for hydrogen production. Electrolysis uses electricity to separate hydrogen from water, and if the electricity is produced by solar power or another sustainable means then the process ultimately releases no carbon dioxide. Using electricity from the grid to produce hydrogen would not be effective in reducing carbon emissions, since power plants are currently one of the largest sources of carbon dioxide. Another process involving water in the production of hydrogen involves harnessing tidal energy. A recent proposal has been made to produce large amounts of hydrogen in the Kimberley region of Australia through the use of tidal power captured from seawater (McLellan et al, 2004). Moreover, an interview conducted with Robin Goodhand, principle scientist at AECOM, suggested that research should be further conducted pertaining to offshore tidal energy units that will allow hydrogen and drinking water production, as well as transportation of both to shore for consumer use (R. Goodhand, Personal Communication, 4 February, 2011). At this time electrolysis is the most favourable production method that uses water.

The last method that exhibits potential is the production of hydrogen through the use of two different production methods associated with biomass. The first method involves collecting gas, like methane, from organic wastes, sewage, food production, and agriculture and forestry industries, and once collected; the gas can be reformed into hydrogen similarly to natural gas (McLellan et al, 2005). This method offers an alternative to releasing harmful methane into the atmosphere since it is collected and put to use as opposed to allowing it to be a detriment to the environment. A second approach to producing hydrogen from biomass is using dedicated energy crop plantations, particularly sugar cane in Australia. A gasification process similar to the one used with coal to obtain hydrogen from the sugar cane may open up a new market for struggling sugar cane farmers (McLellan et al, 2005). The drawbacks to using biomass are that there is an inconsistent quality of the material used if it is not purpose-grown for energy, and there are also potential health risks with the materials used (IEA,

2006). These two processes offer practical production methods using waste materials that would otherwise be burned, and will assist in the elimination of greenhouse gases if hydrogen is adopted as a primary fuel.

### *Hydrogen Storage and Distribution*

Efforts have also been made in the exploration of hydrogen storage and distribution techniques. Hydrogen can be stored in gaseous and liquid states, both of which require different storage materials. Storage containers such as composite tanks and glass microspheres are currently commercially available and show promise for implementation, but possess various safety, durability, and weight issues. There are also conflicts with the container size and shape as a spherical tank is desired, but conforming the storage tanks to available space in areas such as transportation may not be practical (IEA, 2006; Myer, 2004). Another storage method currently being researched involves storing hydrogen in the form of metal hydrides, and with further research may provide a promising way to store more fuel in a smaller and lighter container with fewer safety concerns than other storage practices (Grochala & Edwards, 2004). The current issues with hydrogen storage methods must be addressed in order to promote its use as a primary fuel.

It is also important to examine the issue of transporting the hydrogen once it is produced, which may not be as easy or practical as some methods of transporting other fuels. Some production resources such as fossil fuels may be transported to an onsite reformer where they can be stored and then converted to hydrogen, as previously mentioned. This may be applicable in areas of transportation or other applications where hydrogen can be produced at the site of use, and is important for the transition to increased hydrogen production (IEA, 2006). This can eliminate the costly transportation of hydrogen, as advantage can be taken of existing oil and natural gas pipelines. Another way to produce the hydrogen on a larger scale is at a centralised plant by either sustainable or unsustainable means. This type of production has the potential for low unit costs, but there may be a conflict with the high price of the decarbonising process needed to reduce CO<sub>2</sub> emissions if an unsustainable means of production is utilised (IEA, 2006). The transportation of the hydrogen energy will be much more costly using this method, when compared with fossil fuel transport. This is especially because of the carbon capturing technology needed, and also because of the specific pipelines required to transport hydrogen over long distances. Regardless of whether hydrogen is

produced at the site of the consumer or at a centralised plant, both methods have the potential to greatly reduce CO<sub>2</sub> emissions.

The production and distribution of hydrogen is critical to the future of fuel cells. If hydrogen is not produced by a clean and renewable means, then fuel cells powered by such hydrogen cannot be considered clean and renewable themselves. Ultimately, the adoption of fuel cell technology depends upon the sustainable and efficient production of hydrogen.

### *Hydrogen Highway*

The current and future implementation of hydrogen fuelling station networks worldwide is receiving significant attention, and has been referred to commonly as the *Hydrogen Highway*. There is a drive to create a hydrogen infrastructure involving a network of fuelling stations to allow the use of hydrogen powered vehicles and initiating the hydrogen economy. On the eastern coast of the United States, a company called SunHydro plans to build hydrogen fuelling stations along the length of Interstate 95. These stations would produce hydrogen on-site using solar electrolysis, and are expected to power a fleet of 10-20 fuel cell cars (Maine Public Broadcasting Network, 2010). A number of communities in the US have already implemented hydrogen fuelling stations and others are following suit, with considerable advancement in California. These stations are used for a variety of different applications, ranging from personal vehicle refuelling to commercial and private applications, and also use numerous production methods (Fuel Cells, 2009). In coordination with automobile manufacturer General Motors and others working on the advancement of fuel cell vehicles, there is a California Fuel Cell Partnership in place. According to Guilford, a metropolitan area is a prime location to install a network of hydrogen fuelling stations in an effort to promote the use hydrogen fuel in fuel cell electric vehicles (Guilford, 2010). Once a small infrastructure is organised, it can then expand and widespread hydrogen fuelling stations will become a common sight along highways and in populated areas.

Other countries around the world are also working towards the construction of small scale hydrogen fuelling station infrastructures. All around Europe, countries are implementing infrastructures of fuelling stations, most notably in Germany. This is in part because hydrogen is already used extensively as a commercial gas in European countries, and 1600 km of hydrogen pipeline is already in place (Madsen & Andersen, 2009). Germany is taking the lead in implementing hydrogen fuelling stations, and like the US, they are used for various applications relating to transportation. As a result, a majority of the hydrogen fuelling

stations offer both liquid and gaseous hydrogen in order to accommodate various hydrogen applications (Fuel Cells, 2009). Following other European countries, Iceland began implementing hydrogen fuelling stations; its first station reformed hydrogen on-site through electrolysis and stored it as pressurised gas. The hydrogen infrastructure development in Iceland was guided by the safety and regulation models set forth by Germany and Norway. Since there is an abundance of hydroelectric and geothermal power in the country, Iceland is in a prime position to adopt a hydrogen economy with no carbon dioxide emissions (Maack, Skulason, 2005).

## 3.5 Cost

The cost of fuel cells and the hydrogen production and distribution infrastructure will be a deciding factor in the ultimate applicability of fuel cell technology. The overall cost is based on various factors. These include capital cost, fuel costs, and maintenance costs. These expenses add up to produce the overall lifetime cost of a product.

### 3.5.1 Fuel Cells

So far, the cost of fuel cells has been sufficiently high to be prohibitive to a typical consumer. This high price includes not only the fuel cell itself, but also fuel and maintenance costs. The authors of *Hydrogen-Based Autonomous Power Systems* note, “the main component of the initial cost is the manufacturing cost, which is strongly related to the production volume and the incorporation of economics of scale” (Zoulias & Lymberopulos, 2008). Since production volume is low, the price is high. For fuel cells to enter the main market, awareness of them needs to be spread. Once this occurs, more companies will undertake research and development into the production of fuel cells. Once developed, the product can enter the market. Consumers must then be interested enough in the product to adopt it. Once adopted, the price will begin to drop as production increases, allowing the product to be distributed on a wider scale.

Various factors impact the cost of the fuel cell. Currently a fuel cell’s capital cost is rather high, especially when compared to other related technologies. Data from the U.S. Department of Energy helped to create Table 2 below (Department of Energy, 2010). This table demonstrates capital cost differences between fuel cells, diesel generators, and natural gas turbines. As shown, fuel cell capital costs are significantly higher than those of a diesel generator or natural gas turbine.

Table 2: Cost Comparison Chart

Cost Comparison		
Fuel Cell	Diesel Generator	Natural Gas Turbine
\$15,000/kW	\$800-1,500/kW	\$400/kW

After speaking with associates from CFCL, it was found that the cost of a fuel cell would need to be reduced to about \$10,000 for an entire 1.5 kW unit in order to be commercially popular; a price that will not likely be reached until production is increased significantly. Further, there is also concern about the dropping price of solar photovoltaic and hot water systems. Current prices for a comparable solar photovoltaic system start around \$3,000, a large difference from the \$25,000 that will likely be asked by CFCL for their BlueGen system (Ceramic Fuel Cells Limited, 2011). Although fuel cells have distinct characteristics from those of solar power, as the price drops for fuel cells, so will the price for solar panels.

Organisations around the world are researching how to reduce the costs of sustainable technologies, like fuel cells. The International Energy Agency predicts, “the [capital] cost of fuel cells must fall below US \$50/kW to make them competitive” (International Energy Agency, 2006). While this price is far less than that of a diesel or gas turbine, experts have also included the capital cost with any operational costs associated with fuel cells. Therefore even with a significantly low capital cost per kW, the lifetime cost would be comparable. With this, one must consider the life cycle of a fuel cell compared to its overall operating cost. For a PEM fuel cell, the life span is dependent on a variety of factors including temperature, weather conditions, and fuel purity. As of 2011, the average lifetime for a PEMFC is around 2,200 hours, but can vary between 1,000 and 10,000 hours (Principles of Fuel Cells, 2006).

Since the lifetime of a fuel cell is limited, right now they may not be a viable technology. Some countries are looking into ways to speed up the process of reducing fuel cell costs. For example, in the United States, a program known as the Solid State Energy Conversion Alliance (SECA) includes a cost reduction program on fuel cells, which has a

goal of reducing fuel cell costs to around \$400 per kilowatt by 2020. Programs like these have the potential of commercialising fuel cells even sooner than predicted.

Fuel cells have the great potential change how energy storage and electricity generation are managed; however, this may not occur in the near future. Until costs decrease, interest in fuel cells may remain low. As more research and development is put into fuel cells, the chances for commercialisation may increase (NuEnergy, 2011).

### 3.5.2 Hydrogen

The cost of hydrogen greatly affects the cost of operating a fuel cell, and in turn, the overall lifetime cost of the product. There are various methods of producing hydrogen, each with different processes and associated costs. Most methods of producing hydrogen are rather expensive, but some options are more viable than others. Presently, the production of hydrogen from fossil fuels is one of the cheapest options. More research and development is allowing natural gas reforming to become even more efficient and cost effective. Coal gasification and water-gas shift reaction processes cost more than using some natural gases, but are also commonly used. Figure 6 shows hydrogen cost predictions for 2030 compiled by OECD from numerous sources. The data suggest that hydrogen produced from coal and natural gas will be the most cost-effective in coming years. Further, production from electrolysis and nuclear will also be reasonable options (Organisation for Economic Co-operation and Development, 2005).

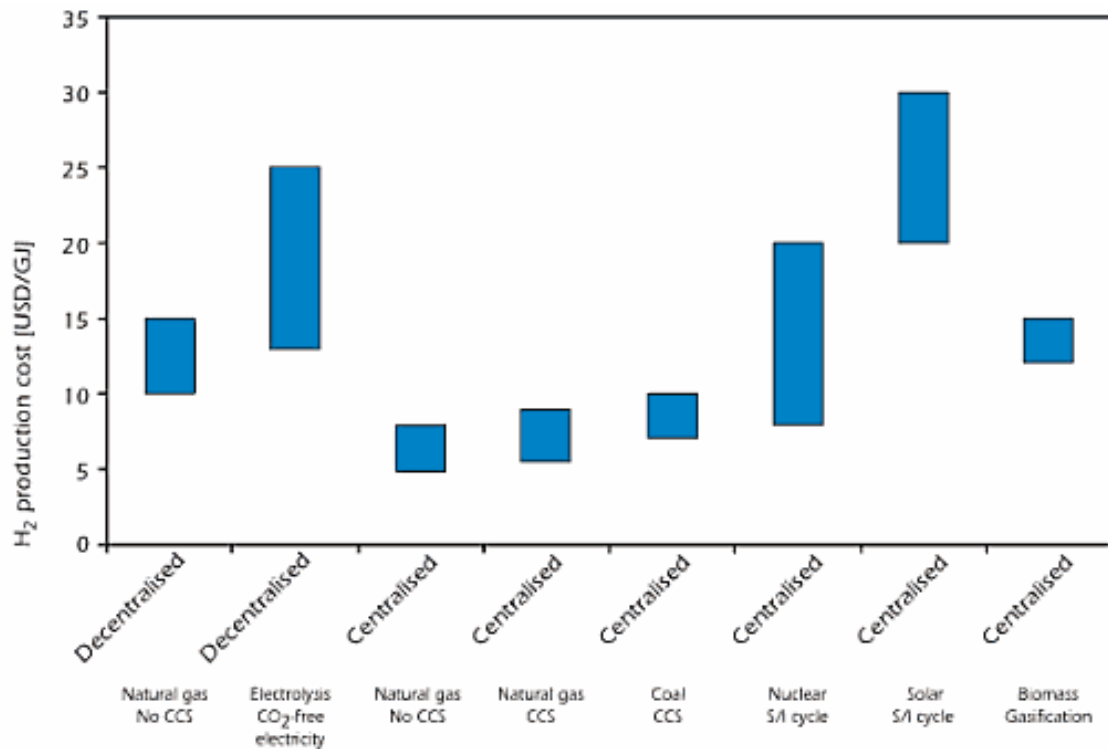


Figure 6. Hydrogen Production Cost Predictions for 2030 (Organisation for Economic Co-operation and Development, 2005).

Storage costs also affect the overall cost of using hydrogen. When analysing this cost, it is necessary to look into the storage capacity and energy requirements. The cost efficiency of storing hydrogen is dependent on the storage time. Higher rates come with lower storage time due to the hydrogen escaping the container, and therefore, lower costs per unit of storage are required. Storage costs can be a small factor in the overall cost of working with hydrogen, but in some cases, storage costs can greatly exceed costs of production.

Transportation costs can also be significant. High-capacity pipeline transportation is the least expensive option, which costs around \$0.10/kg to travel 100km. Liquefaction often requires transportation by road, which is an expensive process with a cost of as much as \$0.25/kg/100km. Costs differ according to distance and capacity. Figure 7 below compares costs for several hydrogen transportation technologies. As shown, pipeline transport is the cheapest, while liquid shipping is the most expensive (Ekins, 2010).

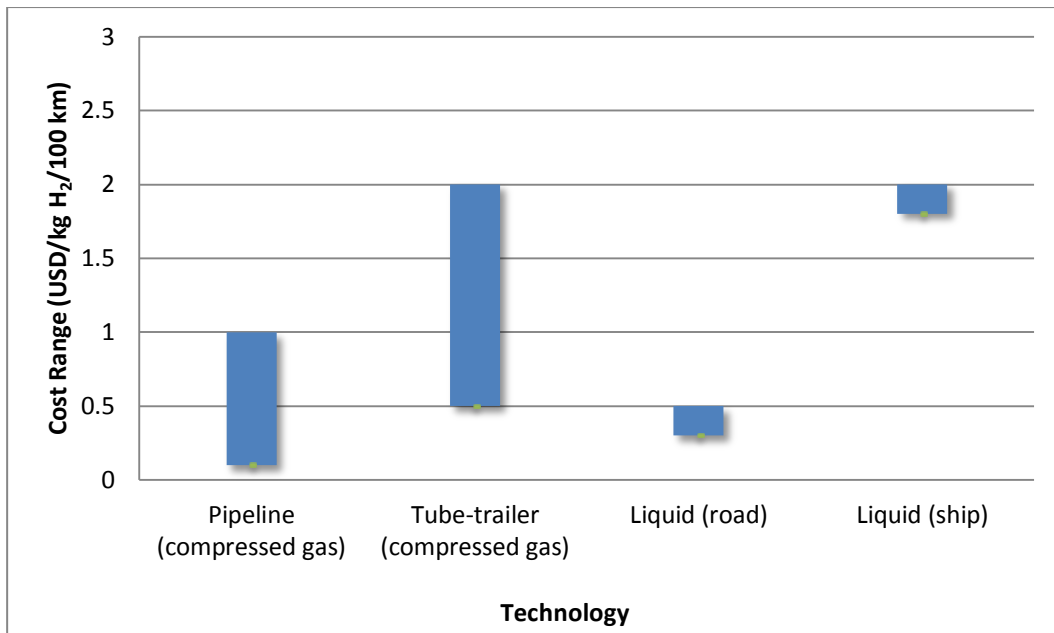


Figure 7. Costs for Various Hydrogen Transport Methods (Ekins, 2010)

As shown, the cost of hydrogen is dependent on a variety of factors. Currently, hydrogen produced from fossil fuels and natural gas is the least expensive method. Once produced, storage as a compressed gas and transportation by pipeline is the most cost-effective option. The overall cost of hydrogen can be high, and therefore, the cost of operating fuel cells may be affected. Since their operating costs are highly dependent upon hydrogen costs, fuel cells will not be an economically viable option until hydrogen costs decrease (Ekins, 2010).

### 3.6 Present Applications

Currently, there are a small number of fuel cells in production. Generally, they are still in the research and development stage. However, there are certain areas in which fuel cells have the potential to be commercialised in the near future. These include automotive applications and power generation.

#### 3.6.1 Power Generation

One company that sells commercial fuel cells for residential use is the ONSI Corporation. This fuel cell is known as the 200 kW PC25 power plant. In the next few years, several other firms also plan to release commercialised fuel cells. Additionally, much progress has been made in industrial fuel cells. The Hyatt Regency Hotel in Irvine, California



recently achieved the longest sustained operation of an industrial fuel cell unit, which was reported to be 5 years of sustained operation (National Fuel Cell Research Center, 2010).

### *Coast Guard Pilot Testing*

Fuel cell power generation pilot testing has also been conducted in the US military. In 1997, the US government issued an energy objective requiring the Coast Guard to reduce their energy costs by 20% from 1995 to 2005. A year later, the Coast Guard began looking into the use of fuel cells. They identified an ideal location to implement a fuel cell at the Air Station Cape Cod in Massachusetts. After years of research, design, and development, the U.S. Coast Guard Research and Development Centre installed one of New England's first fuel cells for electricity generation, in 2004 (United States Coast Guard, 2004).

The main purpose of this project was to show how fuel cells could provide power even under adverse conditions, such as storms, natural disasters, and power outages. Additionally, the Coast Guard wanted to demonstrate how fuel cells could work independently from the electric grid, generate power without harm to the environment, and provide noiseless, constant, and reliable power. The DF300 Model, fuelled by natural gas, was manufactured and installed by FuelCell Energy. To reduce costs, no attempts were made to design the fuel cell to export power to the grid, and predictions regarding the amount of power the site would need were undervalued. Even with cost reduction attempts, a total cost of \$1.8 million was put into this project (United States Coasts Guard, 2004).

During the first year of the fuel cell's operation, the fuel cell's electrochemical efficiency was found to be 96.2%. The fuel cell not only provided electricity for basic electrical and heating needs, but also supplied emergency power to the facility during numerous grid outages. In conclusion, the report states, "the most significant lesson learned is that site loads must be accurately determined prior to the design of a fuel cell project" (United States Coast Guard, 2004). If correct load predictions had been made, the fuel cell may have been able to export power, or more buildings could have received its power. Also, it was found that fuel cell benefits are dependent on the comparative costs of competing electric power sources and fuel for the fuel cell. The implementation of this fuel cell also led to the realisation that maintenance costs could be great. Overall, this project yielded many new insights on the technology. Today, the Air Station Cape Cod is still making improvements to their fuel cell (United States Coast Guard, 2004).

## *Ceramic Fuel Cells Limited*

With a long history in fuel cell research, Ceramic Fuel Cells Limited has made the first step in introducing a residential fuel cell to the market. Ceramic Fuel Cells Limited started from initial research on fuel cell technology conducted by CSIRO in the early 1990s. The company is currently producing one product, called BlueGen, which is a 1.5kW natural gas powered cogeneration unit for residential installation.

The BlueGen is intended to provide for all of the power consumption of a residence, and feed surplus power back to the grid. Having an “overall efficiency of up to 85%, compared to about 25% efficiency of Victoria’s current coal-fired power stations” (Ceramic Fuel Cells Limited, 2011), the BlueGen fuel cell has the potential to change how people think about home power generation. As informed by the official website, the product has the lifetime of 10 – 15 years. Unfortunately, however, the fuel cell stacks may need to be replaced several times during this lifetime, meaning that maintenance costs can be quite a significant expense. With an estimated residential market price of around AU\$25,000 for the entire product and a stack replacement approaching a quarter of that cost, the BlueGen generator is still somewhat expensive compared to other competing generation technologies. At this time, however, the product is being sold to large utility companies, with only about 60 units sold worldwide. According to CFCL associate Andrew Neilson, the company expects full scale residential production within the next year. It is CFCL’s production goal to get the price of the power generator down to around AU\$10,000. This price is estimated to be reached once the production volume reaches 100,000 units. Neilson commented that costs for early customers will be much higher due to low production volume, and costs will decrease as production increases. With a new production facility just recently opened in Germany, CFCL may very well be the first fuel cell company to break into the residential market (Ceramic Fuel Cells Limited, 2011).

CFCL’s fuel cell module, Gennex, is used in the BlueGen units and also marketed to production companies with the goal of incorporating the fuel cell inside other power and heat generation products. This operation is meant to reduce costs through the production of a single module that can be used in multiple products. The fuel cell operates at a reported 60% efficiency, with patented thermal insulation for the high operating temperature. CFCL’s innovative products are beginning to show great potential in the alternative energy market (Ceramic Fuel Cells Limited, 2011).

### 3.6.2 Transportation Applications

Research and development into the use of polymer electrolyte membrane (PEM) fuel cells for automotive applications is on the rise in the United States. In 2006, the Organisation for Economic Co-Operation and Development (OECD), in cooperation with the International Energy Agency's Committee on Energy Research and Technology and US Department of Energy (DOE), completed a study of this topic (Department of Energy, 2010).

The DOE began to realise the possibilities for fuel cells in the early 1980s. The DOE has invested about US\$400 million for fuel cell transportation research since the early 1990s. They have made significant advancements in the technology, and have conducted in-depth analysis on their work. This particular study determined that commercialisation of automotive fuel cells will not be feasible for many years because of technological limits and cost. Still, the research produced noteworthy information on how fuel cells can affect the environment, the economy, and national security, by potentially benefiting each. Additionally, numerous public and private organisations, such as universities, companies, and research facilities, have followed the DOE's example and begun investing millions of dollars into research in fuel cell design. Furthermore, the DOE's research led to various technical accomplishments in areas including fuel processing, systems integration, and other technological advancements. Overall, the work completed by the DOE led to numerous advancements in technical knowledge, and a better understanding of the potential impact fuel cells can have on society (Department of Energy, 2010).

#### *Honda Clarity Study*

On July 25, 2008, Honda of Santa Monica, California introduced their first hydrogen fuel cell powered car to the road. The model is known as the FCX Clarity Fuel Cell Electric Vehicle (FCEV), and was leased out to select Southern California residents. The FCX Clarity is an electric car, whose layout integrates a lithium-ion battery, a power drive unit, and an electric drive motor. These features work in conjunction with the fuel cell, which utilises hydrogen to produce power that is sent to the electric motor. The battery is used to store electricity generated by braking. The FCX Clarity is very environmentally friendly, and releases only water as exhaust. Presently, the car has had few problems, and Honda claims that it is three times more efficient than a compact gasoline vehicle. The FCX Clarity is shown in Figure 8 (Honda, 2010).



Figure 8. Honda's FCX Clarity FCEV (Honda, 2010)

In 1999, Honda created its first version of a fuel cell car. Since then, they have greatly transformed the vehicle to make it lighter and more comfortable for passengers (Honda, 2010). In designing the FCX Clarity, Honda made safety a top concern. To deal with the concern of hydrogen safety, Honda installed sensors around the car to detect hydrogen leaks. If a leak does occur, the ventilation system is designed to turn on and close the valves on the hydrogen tank. The vehicle went through numerous flood and fire tests, and was proven to be very safe and dependable (Honda, 2010).

The FCX Clarity came with the option of including a home refuelling solar station. At this solar station, the car could be refuelled for up to eight hours; after this time, it would be able to travel about 50 km. Users could opt out of the home fuelling station and choose to refuel at 'fast-fill' public stations instead, located at Honda's headquarters. Here, five minutes of refuelling allowed the car to travel about 385 km (Honda, 2010; Abuelsamid, 2007).

Honda had been leasing the vehicle to 200 customers from 2008-2011. Since the unveiling, almost 80,000 people showed interest in leasing the car. The 200 selected were residents of California and were charged US\$600/month, including maintenance fees. Honda also covered any extra costs due to collisions, or any other accidents causing physical damage to the vehicle. Customers were responsible for refuelling costs. In 2007, hydrogen fuelling stations in California were selling hydrogen for around US\$5/kg. To travel 385 km, it would cost a FCX Clarity owner about US\$19.85. For the driver of a petrol-fuelled Accord, the same distance ride would cost US\$43.20. After analysing customer satisfaction, safety, and

economic feasibility of this pilot test, Honda will determine whether the car can be commercially released. At this time, Honda is planning to release the FCX Clarity to the public around 2018 (Honda, 2010; Abuelsamid, 2007).

### *GM Solar Hydrogen Fuellers*

Despite the challenges to producing hydrogen, some efforts are being made to introduce it into today's fuel market. There is one such effort in the United States, where General Motors has also been experimenting with solar driven processes to produce hydrogen from water through electrolysis. They coordinated efficiencies in the solar to hydrogen system in order to optimise hydrogen production and implemented the technology into their “GM Solar Hydrogen Fueller” displayed behind the automobile in Figure 9. The hydrogen generated through this process can be utilised in the Chevrolet Equinox, one of GM’s fuel cell electric vehicles, which is also pictured in Figure 9 (Kelly, Gibson, Cai, Spearot & Ouwerkerk, 2009).



Figure 9. GM Solar Hydrogen Fueller (Kelly et al, 2009)

In Australia, there have also been some hydrogen vehicles in use. The Perth Bus Trial involved a fleet of buses from 2004 to 2007 that ran on hydrogen. The fuel was provided by BP in the form of natural gas that was reformed into hydrogen at a nearby fuelling station (Myer, 2006). There has been significant progress with the use of hydrogen fuel recently.

Continued research and development in relation to hydrogen use is pertinent if Australia, or moreover the world, is to adopt a hydrogen economy.

### **3.7 Future Research and Applications**

The widespread use of portable electronics has revealed the need for portable energy sources that will meet consumer demands. Recent development of rechargeable batteries, although significant, still will not fulfil the energy storage needs of consumers. Currently, there is a constraint between battery runtime and weight, since the amount of power is directly proportional to the battery weight (Makuch, 2004). Fuel cells have the potential to overcome barriers such as this, but the technology is currently far from meeting the needs of consumers.

Micro fuel cells work in the same manner as a standard fuel cell except on a smaller scale, applicable for powering portable electronics. In most cases, the fuel cell will be incorporated into the device itself. The direct methanol fuel cell is currently the most promising for these small scale applications, especially because methanol allows easy storage of a high energy density fuel until there are advancements made in the development of hydrogen storage (Venugopalan, 2007). With this technology, consumers could easily replace a fuel cartridge in their fuel cell powered device that would recharge it in a matter of seconds. Additionally, if extended runtime is desired, there will only be a need to carry multiple fuel cartridges which will be far lighter and more convenient than carrying additional batteries (Makuch, 2004). There have been significant developments made, such as the prototype of Fujitsu's 15W micro fuel cell designed to run a laptop computer, which is exhibited on the back of the laptop in Figure 10. The fuel cell attaches to the exterior of the laptop and allows for replacement fuel cartridges to be interchanged when needed (Venugopalan, 2007). With further research and design work, manufacturers will be able to reduce the size and weight of the fuel cell units and eventually fully integrate them into the portable electronic devices themselves.



Figure 10. Fujitsu's Laptop Fuel Cell (Venugopalan, 2007).

As with all emerging technologies, there are some technical challenges in the development of micro fuel cells that hinder commercialisation. The first challenge is safely packaging the fuel in conveniently sized cartridges that are effective in reducing the size and weight that a consumer would be required to carry. If pressurised fuel cartridges are to be used, then the regulations that they will be required to meet also need to be taken into consideration. Technical challenges also lie in scaling down conventional fuel cells to a size that is practical for powering portable electronics (Makuch, 2004). Furthermore, challenges can also be found in areas such as cost, product handling, and especially the management of the exhaust water because of the close proximity to electrical components (Venugopalan, 2007). In order for widespread micro fuel cell use to become popular, these technical challenges must be overcome. For now a narrow niche market must first be targeted, which may be provided by industrial or military markets.

The military market provides a valuable opportunity for the implementation of micro fuel cells. The goal in implementing micro fuel cells is to develop smaller energy sources. This would directly influence the safety and mobility of soldiers in battle. Today, soldiers are required to carry large batteries to keep their equipment powered for long periods of time. The goal is to allow soldiers to instead carry multiple smaller hydrogen packets, about a tenth of the size and weight of the batteries currently used, with potential to hold a longer charge. In battle, space and mobility are critical to a soldier's ability to manoeuvre, and the further research and future implementation of micro fuel cells could be a life-saving innovation (Makuch, 2004).

## 3.8 Environmental Impact

When considering the environmental impact of any technology, it is crucial to examine not only the direct impact of using the technology but also that created by anything that is added to the system, such as fuel. Hydrogen fuel cells are often looked upon favourably because they produce no CO<sub>2</sub> emissions. However, since hydrogen is a secondary fuel it must be produced from another energy source, and this can be a very carbon-intensive process. Because of this, hydrogen fuel cells may produce even greater overall CO<sub>2</sub> emissions than a fuel cell that releases CO<sub>2</sub> directly, such as a methane fuel cell.

### 3.8.1 Production by Natural Gas Steam Reforming

A study by C. Koroneos et al at the Aristotle University of Thessaloniki examined the life cycle emissions of various hydrogen production processes. Currently, the most common method of hydrogen production involves using steam to reform methane gas. This method is used in large reforming plants, as well as in smaller units fuelling individual fuel cells, allowing fuel cells to be run on city gas. The process releases the carbon from the methane as CO<sub>2</sub>, in addition to any CO<sub>2</sub> released by combustion when producing the steam. Table 3 shows the amounts of several major pollutants produced during the reforming process. According to the table, each kilogram of hydrogen that is produced also generates approximately 10.6 kg of carbon dioxide.

Table 3. Emissions of Major Pollutants by Methane Reforming (Koroneos, 2004)

Compound	Emissions (g / kg H <sub>2</sub> )
Benzene (C <sub>6</sub> H <sub>6</sub> )	1.4
Carbon dioxide (CO <sub>2</sub> )	10662.1
Carbon monoxide (CO)	5.9
Methane (CH <sub>4</sub> )	146.3
Nitrogen oxides (NO <sub>x</sub> as NO <sub>2</sub> )	12.6
Nitrous oxide (N <sub>2</sub> O)	0.04
Non-methane hydrocarbons (NMHCs)	26.3
Particulates	2.0
Sulphur oxides (SO <sub>x</sub> as SO <sub>2</sub> )	9.7

### 3.8.2 Production by Electrolysis

Another common method is electrolysis, wherein an electric current is run through water, separating it into hydrogen and oxygen. The electrolysis process can typically achieve



a thermodynamic efficiency of about 77%, meaning that approximately one quarter of the electrical energy is converted to heat during electrolysis, and the rest is stored in the hydrogen.

### *Electrolysis Using Grid Power*

If electrolysis is performed using grid power, then the overall environmental impact is determined by the power plants supplying the electricity. The U.S. Department of Energy estimates that a coal-fired power plant produces 0.957 kg of CO<sub>2</sub> per kWh of electricity generated. At an estimated 50 kWh per kilogram of hydrogen produced through electrolysis, this process creates approximately 47.8 kg of CO<sub>2</sub> for each kilogram of hydrogen, neglecting transmission losses (U.S. Department of Energy, 2000). This is nearly five times the amount produced by methane reforming.

### *Electrolysis Using Sustainable Electricity*

A carbon-free method of producing hydrogen also uses electrolysis, but uses clean (zero carbon) electricity. Since no carbon is involved in the electrolysis process, the hydrogen produced is completely free of CO<sub>2</sub> emissions. The drawback is that a sufficiently large clean electricity infrastructure does not exist to produce large amounts of hydrogen. Such a procedure would therefore need to be implemented on a small scale. For example, a household with a wind generator could use excess wind power to generate hydrogen rather than feeding into the grid, and then feed the hydrogen into a fuel cell for power on calm days. The advantage of converting electricity to hydrogen is that it can be stored indefinitely in large quantities, and has the potential to be more efficient and more economical than batteries.

## **3.9 Global Energy Policies**

Over the past four decades, governments around the world have been implementing policies that encourage the prudent use of existing energy resources, the increased use of sustainable energy resources, and more recently, the reduction of greenhouse gas emissions.

### 3.9.1 International Energy Policies

Energy strategies in many European countries are characterised by a large degree of government involvement in climate change mitigation efforts. The strategies primarily involve consumer- and industry-level incentives for reduction of carbon emissions, with research and development of new technologies being the second priority (Watt & Outhred,

2001). Several European countries, including Sweden and France, have accomplished a significant reduction of their per-capita carbon emissions since the 1970s through the construction of numerous nuclear and hydroelectric power plants (UNEP, 2010).

China's total investment in renewables in 2009 was about US\$33 billion, a 53% increase over 2008. This was largely a result of heavy government support for corporate wind energy projects, and accounted for 28% of the world's total estimated renewable energy investment in 2009. Even with this increase, renewables currently account for about 4% of China's generation capacity, and government sources have announced a goal for renewable production to reach 15% by 2020 (UNEP, 2010).

In the US, renewable sources account for approximately 9% of the nation's electricity generation capacity. By 2012, an increase in use of wind power is expected to increase this amount to 14%. President Barack Obama's American Recovery and Reinvestment Act of 2009 provides more than US\$70 billion to be spent on "clean energy" programs (REN21, 2009). According to the president's State of the Union address in January 2011, these clean energy programs will include solar, wind, nuclear, clean coal, and natural gas. In the same address, the president indicated his ambition for 80% of the nation's energy to be produced by renewables by the year 2035.

### 3.9.2 Australian Energy Policy

In 2004, the Australian government released a white paper outlining its energy objectives and announcing initiatives that would be used to reach them. The content of this paper indicated that the government was largely aware of the need to reform the energy market and promote the use of sustainable energy, but it also included such initiatives as exploration of offshore petroleum resources, additional funding for coal-fired electricity, and support for a number of other non-sustainable energy practices (Australian Government, 2004). Additionally, the Australian government provides heavy subsidies for non-sustainable technology. In 2006, 96% of Australia's energy subsidies were targeted toward the use of fossil fuels – about AU \$10 billion – and the remaining 4% was used to subsidise the installation of renewable technology (Institute for Sustainable Futures, 2007). Many claim that the Australian government has not taken nearly enough action in support of sustainable technology. Nevertheless, some consumer-level programs have been implemented to encourage small-scale purchase of sustainable energy production systems.

### 3.9.3 Australian Energy Programs

The Australian government has designed incentives to promote the use of alternative energy to both industry and consumers. Some of these programs are optional, such as GreenPower, and others are mandatory, such as the RET and the Cap & Trade program. All of these have been designed with the primary goal of combatting climate change and reducing Australia's dependence on a limited supply of fossil fuels.

#### *GreenPower*

GreenPower is a national program originally started by the NSW Sustainable Energy Development Authority. With this program, electricity customers can choose to pay more for their electricity, and the extra money is invested in new sustainable generation facilities. This is an excellent way for customers who are not in a position to buy their own sustainable technology to still invest in renewable power.

Part of the promise of the GreenPower program is that all of the money is invested in *new* generation systems, built after the time of the program's establishment in 1997. This is simply because older sustainable technology, while it does not contribute any greenhouse gas emissions, is already providing power to the grid and therefore does not contribute to the *reduction* of greenhouse gas emissions either (Alternative Technology Association, 2010).

The GreenPower program has a set of accreditation standards to ensure that its sources provide a real and tangible benefit to the environment. These standards include ensuring that native forest wood is not used in biomass generators, ensuring that rivers are not diverted to build hydroelectric dams, and making sure that the energy produced for GreenPower is *in addition to* the retailer's mandatory requirements under RET (see below). This is because GreenPower and RET are separate programs, and an energy retailer cannot use one to meet his requirement for the other.

#### *Renewable Energy Target (RET)*

In August 2009, the Australian government established another program designed to commit the country to lowering their carbon emissions. This program is known as the Renewable Energy Target (RET), and is a continuation of the Mandatory Renewable Energy Target (MRET) established in 2001, but with an increased target – RET stipulates that the government will work “to ensure that 20% of Australia's electricity supply will come from renewable sources by 2020” (Australian Government, 2010). A year after RET was enacted,

several amendments were added to the legislation. These amendments separated the RET into two main parts: the Small-scale Renewable Energy Scheme (SRES) and the Large-scale Renewable Energy Target (LRET). It is predicted that these new programs will allow Australia to exceed the target of the original legislation. The purpose of the SRES is to aid homeowners, communities, and small businesses with installation of alternative energy systems. It generally targets technology that is implemented in small installations, such as solar photovoltaics. By contrast, the LRET offers support to corporations and large-scale businesses interested in incorporating alternative energies into their practices. This change is intended to provide security for smaller investors, ensuring that their feed-in tariff does not drop drastically due to a change in the large-scale energy market. Overall, the RET is expected to greatly increase interest and investment in the manufacture and implementation of a wide range of alternative technologies in both residential and business applications (Australian Government, 2010).

### *Cap & Trade Programs*

Another measure, which passed recently and is set to go into effect in July 2011, is a cap and trade program similar to those that have been proposed for the United States and several countries in Europe. The government has set a limit (cap) on the total amount of GHGs that can be released nationally per year, and companies will need to buy permits in order to continue releasing these pollutants. If a company reduces its emissions, it can then sell its extra permits to another company and make a profit. The goal of this system is to make coal and oil less competitive compared to other more environmentally friendly options. It can also be expected that this measure will dramatically increase the cost of electricity, which may lead to more conservative energy use as well as increased interest in energy-efficient appliances (Betz & Owen, 2010).

### *Feed-in Tariffs*

A third policy mechanism, enacted in a number of Australian states, is a feed-in tariff (FiT). A FiT provides a price incentive for locally generated electricity to be fed into the grid. Currently, only solar photovoltaic (PV) generators (and small wind generators in New South Wales) are eligible to receive a premium FiT in Australia. A premium FiT allow a micro-generation proponent to access a premium rate for the electricity fed back into the grid from their system – often up to three times higher than the retail market price for electricity.

As of January 2011, New South Wales and the Australian Capital Territory offered a gross-metered FiT, while the remaining states offered a net FiT based on an import / export metering arrangement. This distinction is important: with gross metering, the customer is paid for all electricity generated: all of the electricity generated from their solar panels is fed directly to the grid, and in turn that customer buys all of their electricity needs from the grid at a retail market price.

A net-metered FiT is only paid for electricity in excess of what the customer's household uses. The ATA and other organisations around Australia have been lobbying for one nationally consistent gross FiT, as they are much simpler to understand from both a network and consumer perspective and provide a better and more consistent financial return to those installing eligible micro-generation.

As stated above, Australian FiTs generally only apply to residential solar PV systems (apart from NSW). This further reduces the appeal of purchasing other generation technology and has caused a marked increase in the purchase of rooftop solar PV systems. A FiT offered for electricity generated by fuel cells might make them more attractive, but the tariff needed to produce a reasonable payback period would likely be quite high in comparison with other technologies, due to the inherent high cost and fuel demands of fuel cells. (D. Moyses, Personal Communication, 31 January 2011).

### *Summary*

In recent years, the Australian government has taken considerable steps in creating sustainable energy programs. Although there are currently no direct incentives for the use of fuel cells, there exists the potential for fuel cells to be incorporated into such programs in the future. Currently the government is not supportive of fuel cells, and this is because they have not yet been proven to be as practical or cost-effective as other forms of technology.

# Chapter 4: ATA Member Survey Analysis

We conducted a survey which was sent out to the ATA membership. This survey focused on their concerns and opinions of both sustainable and fuel cell technology. Using information from this survey, we were able to strengthen our policy analysis and make certain speculations and conjectures based on the data.

## 4.2 Survey Demographics

Before analysing the survey for information about fuel cells, it was important for us to gain basic information about our respondents. With this in mind, we checked for noteworthy information about the age and residency status of our sample. As shown in Figure 11, the majority of participants are above the age of 50. We found that 32% of the participants were between 51 and 60 years of age, and another 31% were over 60. Since the average age of retirement is 64 (65 for men and 64 for women), we determined that many of the ATA members who took the survey were either retired or very near retirement (Australian Social Trends, 2009).

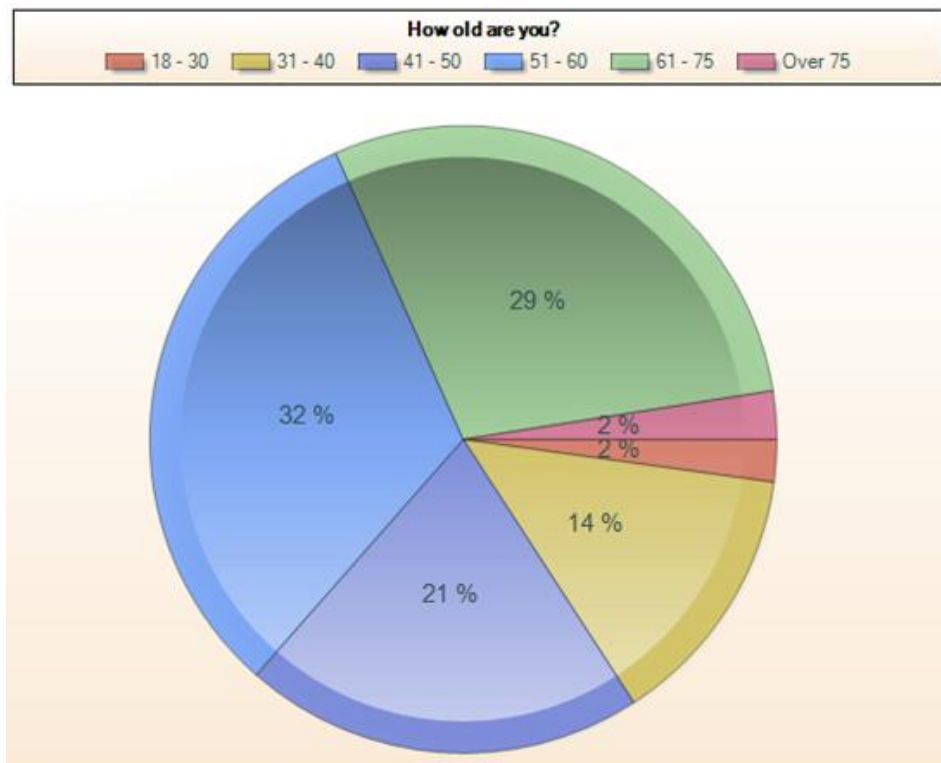


Figure 11. Age of ATA Member Participants

We wanted to compare the ATA member data with the average age of the CFCL sample. Thirty-two per cent of individuals taking the survey were between 61 and 75 years old, with another 29% between 51 and 60. This shows that the vast majority (even more than the ATA member survey) were near or above the average retirement age.

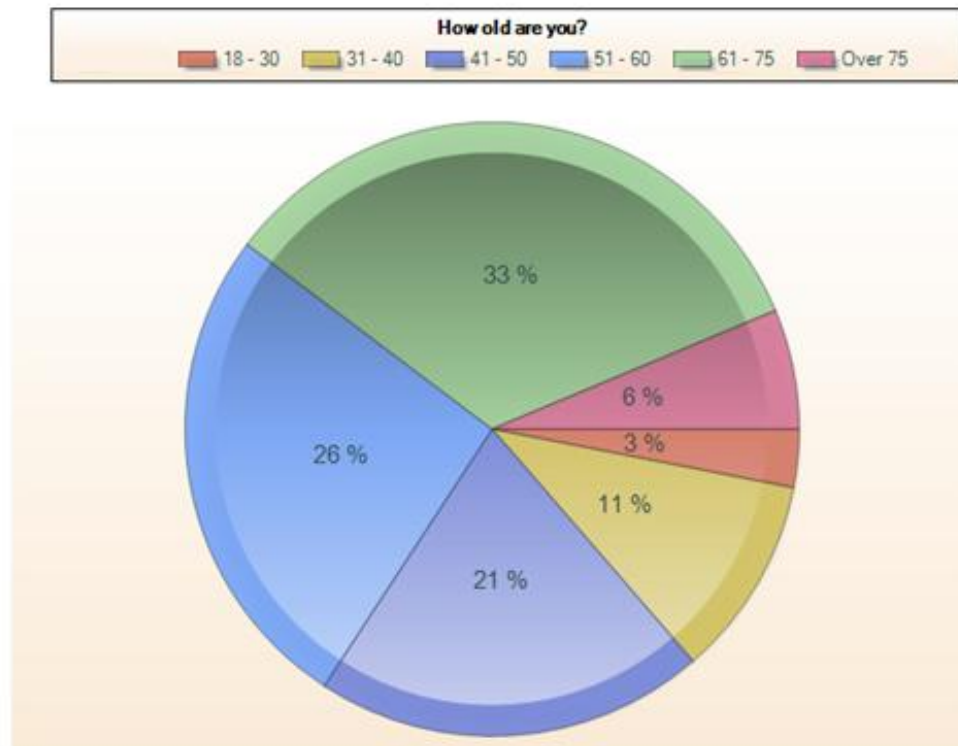


Figure 12. Age of CFCL Survey Participants

After analysing the age of participants, it was important to gain a sense of whether the survey participants owned their own residence or rented. This information was crucial when analysing the needs of individuals. For example, a person who is renting an apartment is less likely to employ fuel cell devices in his or her home, either due to financial constraints or because of restrictions in the rental agreement. We found that 89% of ATA members who took the survey have a privately owned house, while 83 % of the CFCL respondents own their own house. This information told us that the majority of people who took the survey are in a position to incorporate sustainable technology in their residence if they so choose. Further, ownership of a private residence indicates a certain level of financial stability which would also be necessary to consider investing in fuel cell technology.

The other large factor that we looked into was whether the individuals' places of residence were grid-connected. We found that 94% of survey takers who were ATA members

were connected to the grid, while 98% of the CFCL sample who took the survey were connected to the electrical grid. While this information comes as no surprise, it could show that the interest in fuel cell home power generation system would be for an on-grid generation system, similar to the BlueGen fuel cell.

Our last basic questions asked the participants to tick off any sustainable technologies that are currently used in their place of residence. We found that small-scale technology – such as compact fluorescent lights and water-saving shower heads – was widely used, while large-scale equipment was much less common. Out of a total of about 1,100 participants, only 6 individuals reported that they currently use fuel cell devices, while about 1,000 of them said they use compact fluorescent lights.

For more information on the basic findings of our survey, please refer to Appendices C and D.

## **4.3 Technology Assessment**

In order to begin our in-depth statistical analysis, we first began by analysing each survey question by itself. Before analysing correlations between multiple questions, it was important for us to understand the basic opinions and pre-existing knowledge of the participants. Specifically, we looked at the different technologies that participants had already implemented in their households. We then analysed the different features of a technology/product, and finally we examined what cost factors have an effect on an individual's willingness to purchase a product. After our preliminary analysis, we focused on the questions concerning fuel cell technology and applications. This analysis involved looking at the respondents' familiarity and interest in different fuel cell products.

### **4.3.1 Currently Implemented Technology**

Our first goal was to determine what forms of sustainable technology people have already implemented in their homes. See Figure 13 for the percentages of people that have started to implement each specific technology listed below. Although a negligible portion of our sample said they were using fuel cell technology, we were more focused on looking at other relevant technologies. Specifically, we focused on the current implementation of solar panels (both solar hot water and photovoltaic panels). After reviewing the comments received through our survey, it was clear that a large portion of the respondents were content with their existing sustainable technologies. Many respondents indicated that they had no intent to



invest in fuel cells because they already had functioning solar and/or wind systems installed. This indicates that many individuals are inclined to compare fuel cells against other sustainable generation technologies such as wind and solar, even though fuel cells are likely to play a much different role in energy distribution.

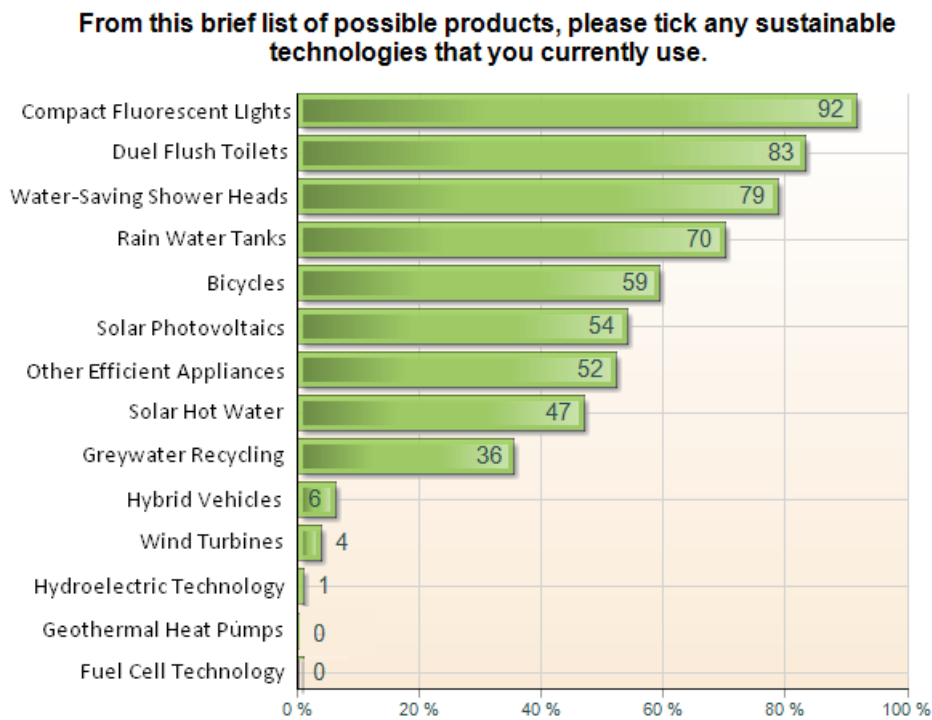


Figure 13. Currently Implemented Sustainable Technologies (ATA members, n=645)

### 4.3.2 Product Characteristics

Whenever a new product is adopted, one must be very careful in judging how this new product will affect the consumer. Thus, we devised two questions to analyse how people felt when purchasing any new technology. The first question dealt with each individual's motivation for purchasing the technology. The results gave yielded a bar graph in which we took a weighted average for each product feature (please see Appendix H for the mathematical calculation). Because there were four choices, the weighted average is out of a possible four. As can be seen in Figure 14, the most heavily weighted choice was helping the environment with a weight of 3.92. Reducing the carbon footprint and reducing cost of household utilities were the second (3.7) and third (3.2) priorities, respectively. The interest in a new technology and convenience came as the least important of the motivations. We concluded that since our sample was for ATA members, their priority was towards helping the environment rather than the actual cost and interest in an alternative technology.

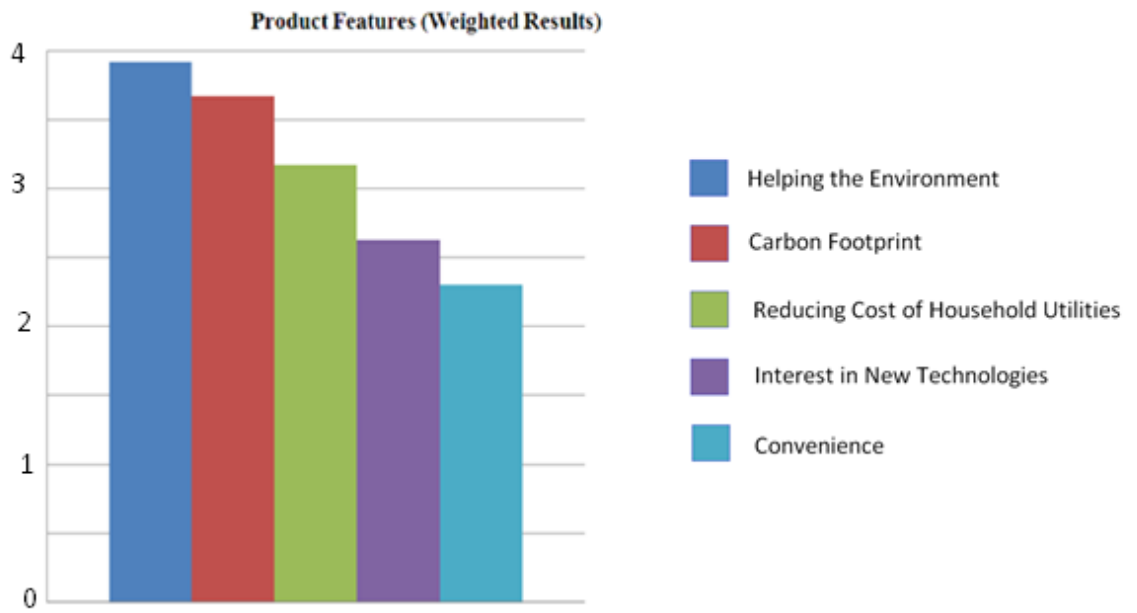


Figure 14. Motivations for Using Sustainable Technology

Our second question dealt primarily with concerns when purchasing a new product. The choices were cost, efficiency, environmental impact, and safety of the product. Figure 15 shows a weighted average that was calculated using the raw data (please see Appendix H for calculations). The bar graph clearly shows that efficiency and environmental impact were the top two priorities. Looking back at our last question, the results here were relatively intuitive, with environmental concern being weighted the heaviest. Safety and cost were commonly an individual's lowest priorities. While cost will surely continue to be a large factor into the production of the technology, the responses suggest that environmental impact and efficiency will be the driving motivators.

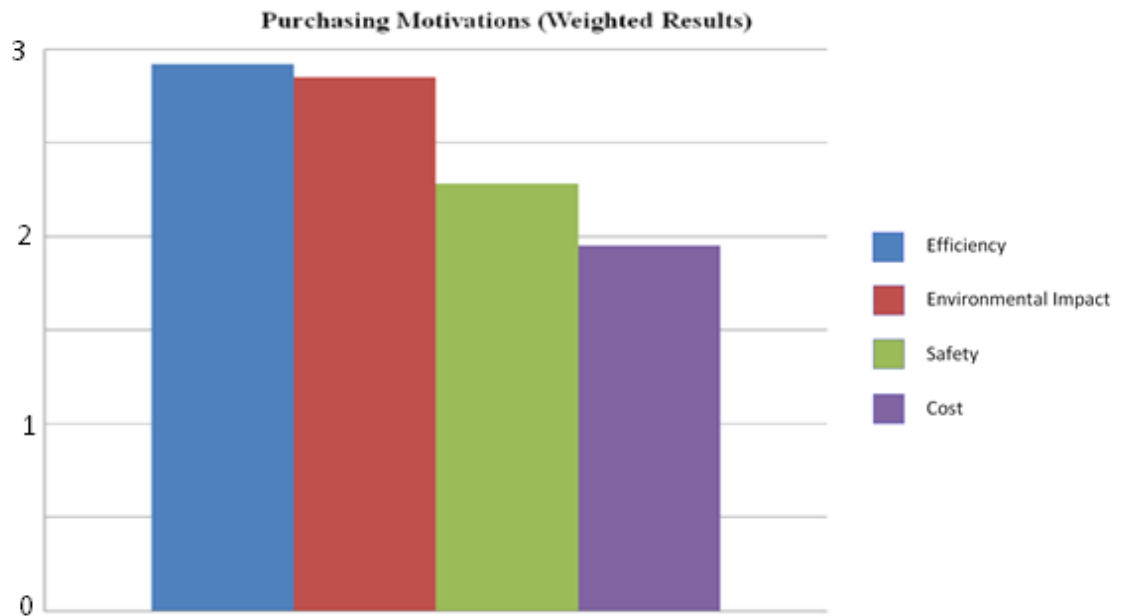


Figure 15. Priorities When Purchasing Sustainable Technology

#### 4.3.3 Product Expenditure

The next area of emphasis lies with the cost of the product. More specifically, this question focused on the distinction between three aspects of the cost: the initial (capital) price, the ongoing cost of use and maintenance (operations), and the overall life time cost, which includes both operations and capital expenditure. According to Figure 16, the majority (59%) of participants ranked the overall lifetime cost as their first priority. Furthermore, we saw that many individuals were more concerned with the operational cost of the product, having 22% ranking this as first priority, and an additional 52% saying that they consider this second priority. This tells us that the marketability of fuel cells does not depend solely upon the cost of the device itself. If fuel cells are to be viable for the market in the future, there would need to be a dependable and affordable source of fuel, as well as reasonable maintenance expenses.

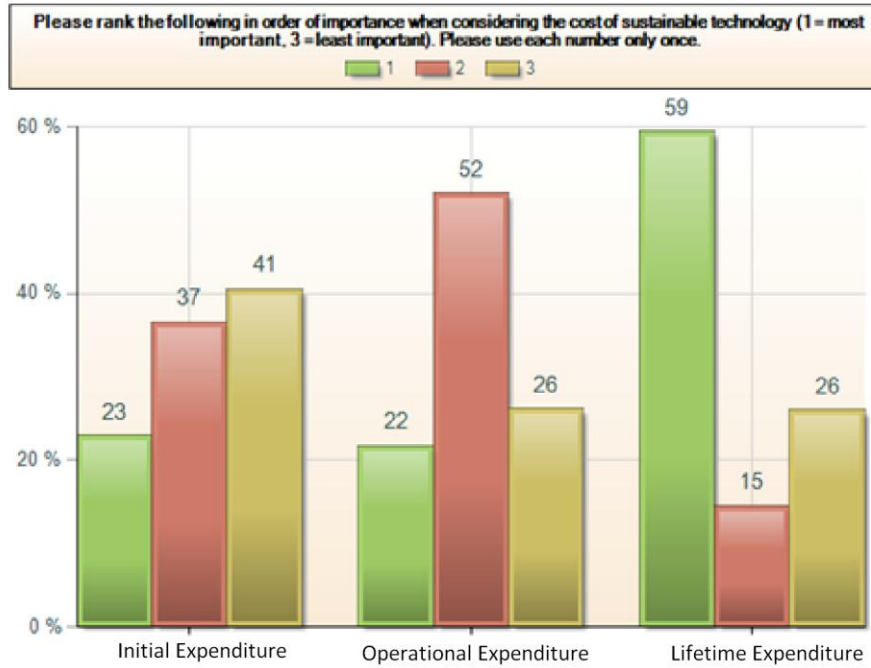


Figure 16. Cost Priorities

In order to clearly see the descending priority of the product expenditure, we used the raw data to calculate a weighted average of each choice. Because there are three choices, the average is out of 3. As Figure 17 shows, the lifetime expenditure is clearly the highest weighted with operational and initial expenditure in a close tie for second and third priority respectively.

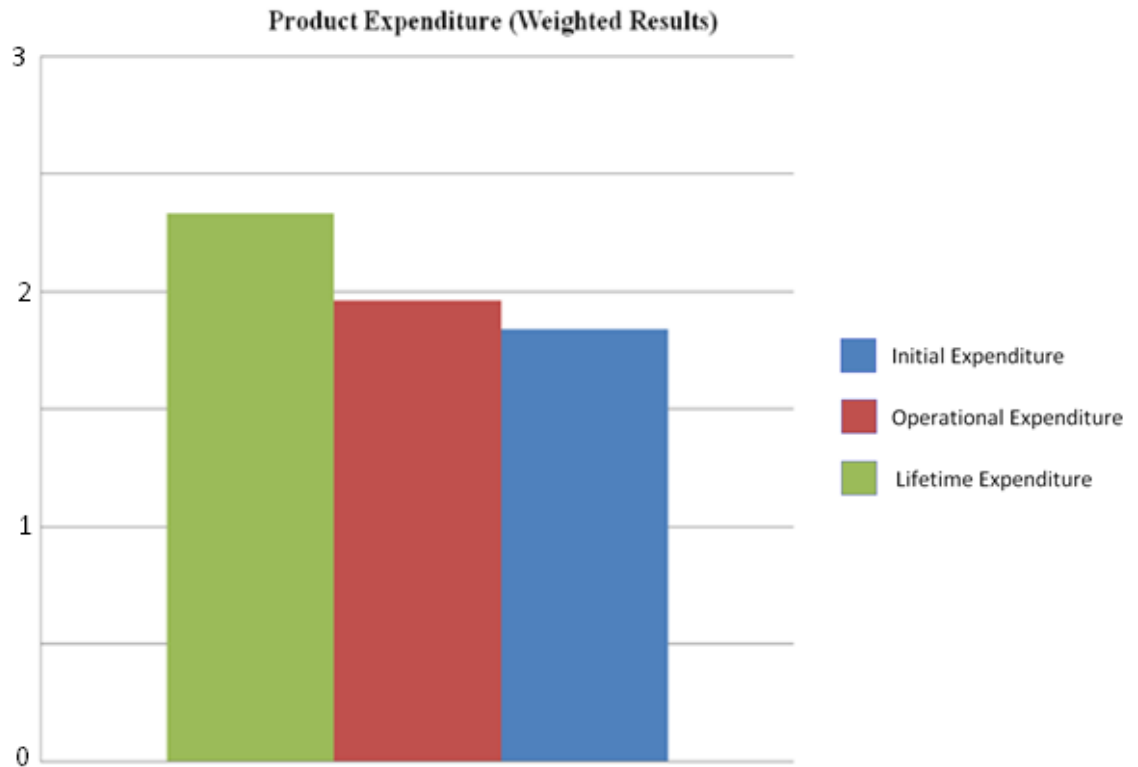


Figure 17. Weighted Cost Priorities

#### 4.3.4 Fuel Cell Technology Analysis

To gauge the respondents' knowledge of fuel cell technology, we simply asked about their familiarity with fuel cells. Fewer than 13% considered themselves either well informed or an expert in the field. Similarly, only 3% of our sample reported that they had never heard of fuel cell technology. The majority (54%) noted that they were somewhat familiar with the basics of fuel cell technology. Because this survey targeted ATA members, we can assume that the general public would have either the same or less knowledge about fuel cells. Based on the familiarity of most participants, we are confident that the answers were mainly representative of valid concerns and opinions about fuel cell technology. Please refer to Figure 18 to see statistics on the familiarity of our respondents with fuel cells.

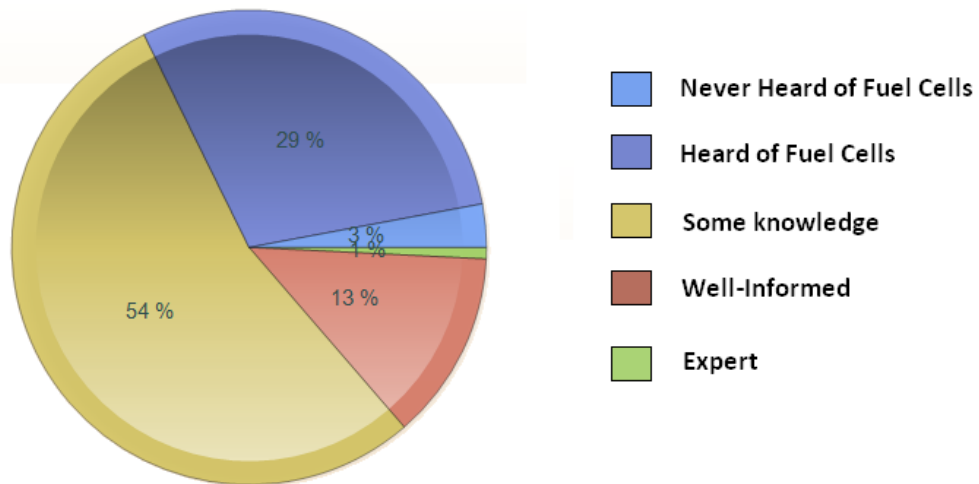


Figure 18. Familiarity With Fuel Cell Technology

We then wanted to determine which fuel cell applications people were most interested in seeing developed. The categories provided were personal transportation, home power generation and portable applications. We found that many participants (48%) were interested in a fuel cell car. Further, 46% chose home power generation, while only 6% of the individuals who took the survey said they were most interested in portable applications. See Figure 19.

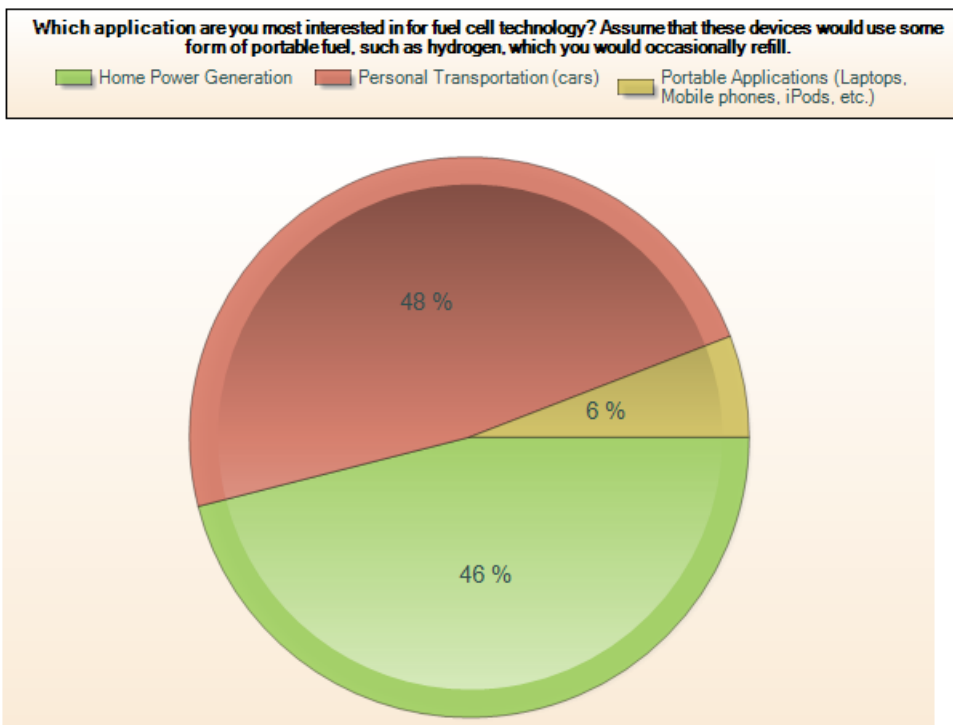


Figure 19. Preferred Applications

### 4.3.5 Cost of Products

One of our most important survey questions was an analysis of how much money an individual would spend on a fuel cell product. We broke these products up into fuel cell powered cars, off-grid home power generators, laptop computers and portable devices such as music players and mobile phones. Because many products have a wide range of prices and each individual has their own base line on how much he or she would pay, we simply asked how much more money the respondent would be willing to spend on each type of product.

#### *Fuel Cell Car*

We found that 83% of the sample was unwilling to pay more than AU\$10,000 extra for a fuel cell powered car, with 13% of that specific sample completely uninterested in a fuel cell powered car. While this may cause concern for any near future applicability with fuel cells in the transportation sector, what is encouraging is that 62% of the sample has noted that they would be willing to pay between AU\$1,000 and AU\$10,000 extra, indicating that there is some interest. Please refer to Figure 20 for details.

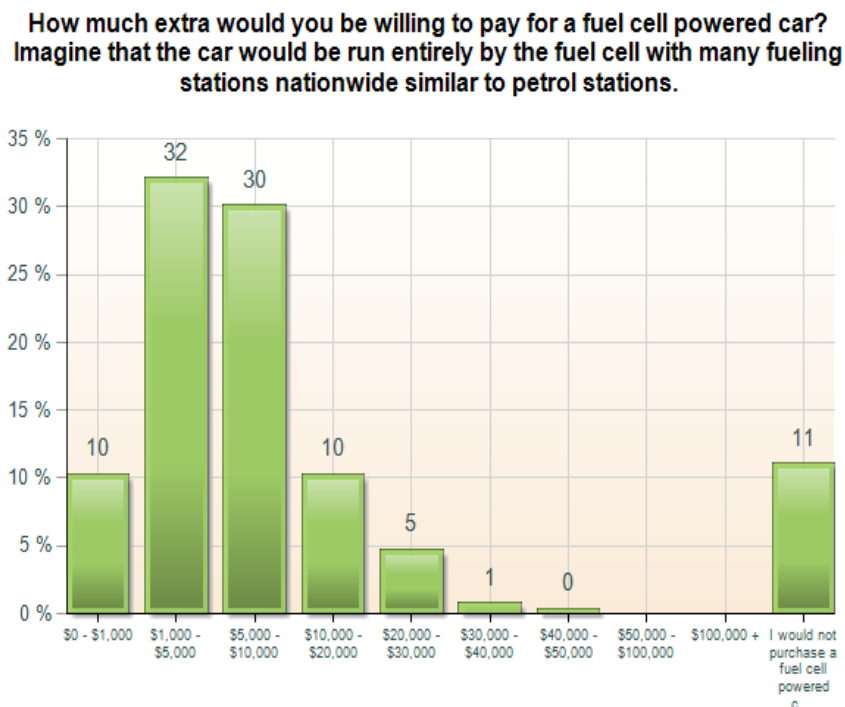


Figure 20. Extra Expenditure for a Fuel Cell Car

## Fuel Cell Portable Appliances

One potential application of fuel cell technology in the remote future is fuel cells for portable products such as computers and portable music players. We wanted to determine how much more people would be willing to spend on these devices. We specifically asked about two examples: a fuel cell powered computer and portable appliance such as a music player. Figures 21 and 22 show that in general, there was more interest for a portable device such as a music player or cell phone than a computer. Sixty-nine per cent of participants were willing to spend up to AU\$100 extra for such a device. When we examined the data for the fuel cell computer, we saw that 57% were willing to spend up to AU\$200 more than what they would normally pay for a laptop computer. A significant percentage of people stated that they would not be interested in either of these technologies and only 6% of people chose portable applications as their main choice for fuel cell innovations. For any future small scale applications to be marketable, the price of these devices would have to be very competitive with current market products.

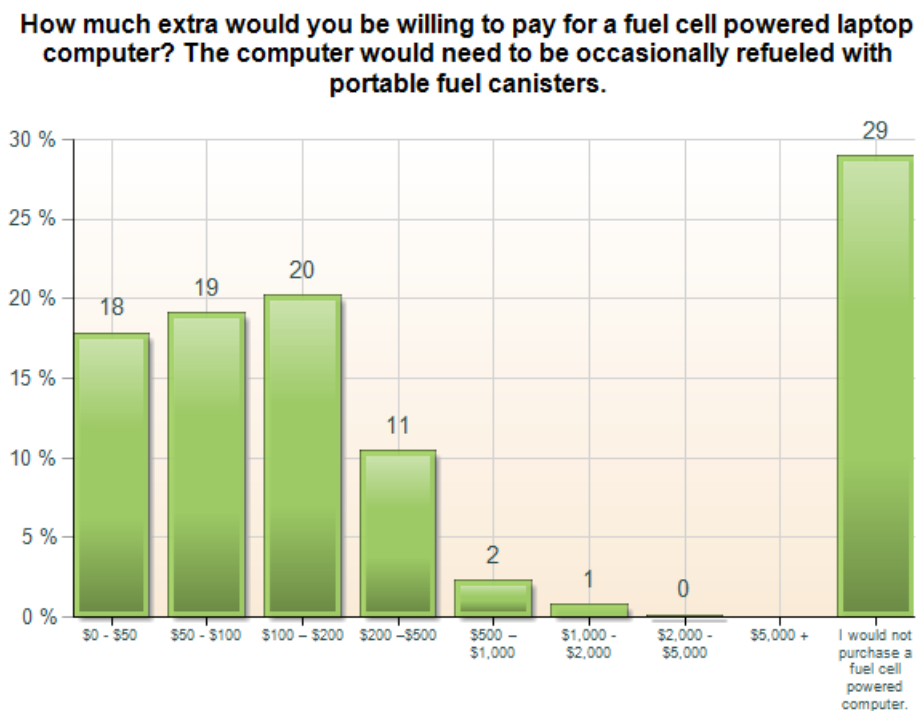


Figure 21: Expenditure for a Fuel Cell Computer



**How much extra would you be willing to pay for small fuel cell powered home appliances? This would include mobile phones and portable music players. The devices would need to be recharged with hydrogen. Assume that recharging would be simple and relatively inexpensive.**

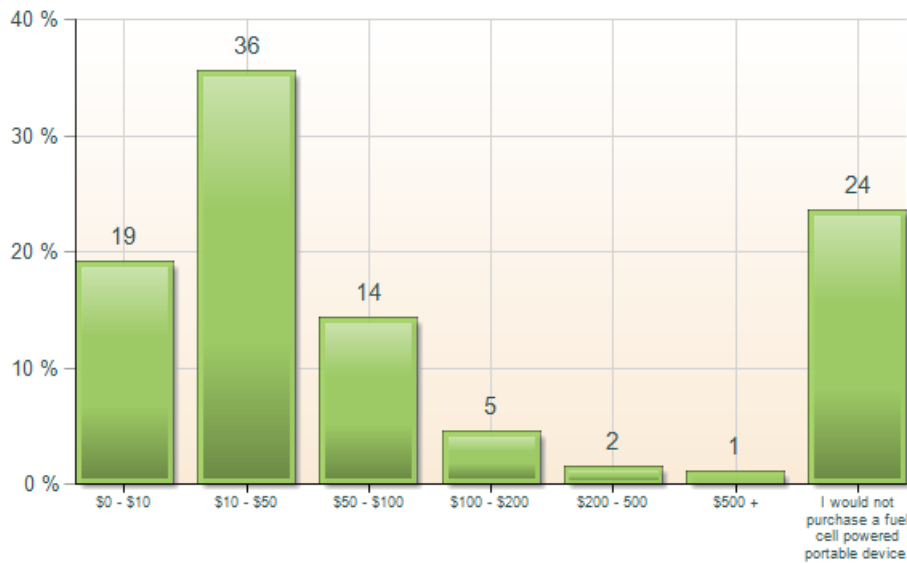


Figure 22: Expenditure for a Portable Fuel Cell Device

### *Fuel Cell Home Power Generator*

Fuel cell home power generators have the potential to be very competitive products in today's market. For that to happen, though, the cost must become competitive with current technology. The BlueGen generator currently costs AU\$45,000, and we wanted to analyse how low the price would need to be for this or similar products to become more popular with the general public. To do this, we asked the ATA membership how much they would be willing to pay for a fuel cell home power generator. As Figure 23 shows, most of the participants (86%) would not be willing to pay more than \$20,000 for a fuel cell home power generator. Of that sample of eighty-six per cent, nineteen per cent of those people were not at all interested in a fuel cell powered generator. Although there is a significant amount of interest in this application, the cost will once again have to drop significantly before a large number of consumers will be interested in purchasing such a device.

**How much altogether would you be willing to pay for a fuel cell powered home generator? The generator would be used to completely power your residence and take you off the electrical grid.**

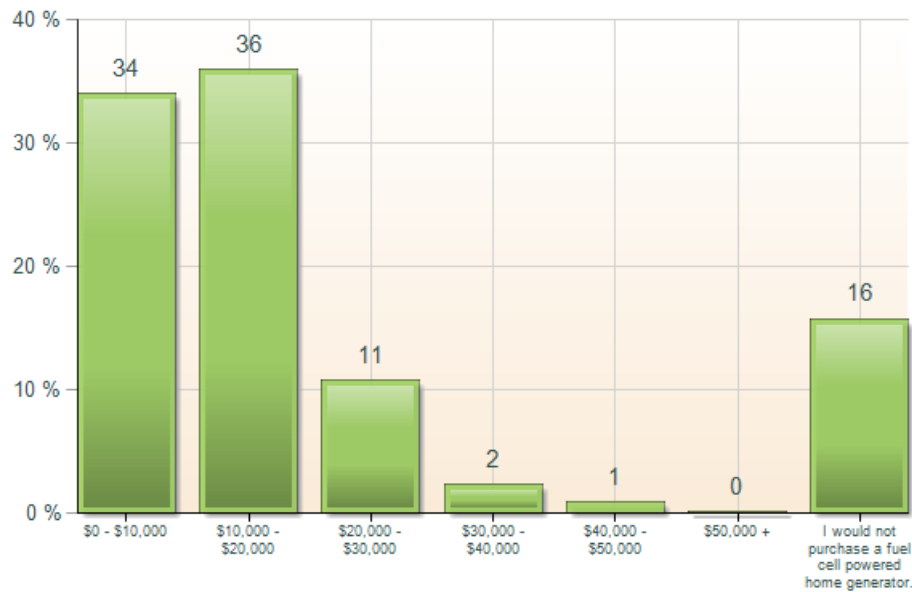


Figure 23. Expenditure for a Home Generator

## 4.4 Trends and Correlations

We were interested to see if there were any correlations between the age of the participant and which application they would prefer. After analysing the data we found very few correlations that led to any in-depth conclusions. In order to be as thorough as possible, we attempted to make correlations between cost factors, age and familiarity, all of which yielded the same results.

With our age comparison, we wanted to see if there were any correlations between an individual's age and which application they were most interested. When we closely looked at the data, our results from our general question were very similar. The two highest from each age group were home generation and transport while the portable application was the least popular.

We further analysed how familiarity affected people's choice in which application they showed interest in and how much they would pay for that application. Once again, we were not able to find any significant differences between samples.

Whether the correlation was between age, cost, or familiarity, our analysis showed that there were no significant differences in the responses between various groups of respondents.

## **4.5 Summary**

Our survey analysis played a critical part in gaining information on the opinions of the ATA membership. We learned that the ATA membership, a sample familiar with sustainable technology, were somewhat familiar with fuel cell technology. We can make the assumption that the general public is equally or slightly less informed, and in turn may need to receive more information about the technology before making a purchase decision. Furthermore, we see that interest lies primarily in the transportation and home generation applications. While portable applications have the potential to become more popular in the future, demand will be found first in fuel cell cars and home generation units.

# Chapter 5: Discussion

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As with any emerging technology, different types and applications of fuel cells are expected to become commercially viable at different times. In this section, we will discuss the various barriers to fuel cell implementation, and how we expect them to affect the fuel cell market within the next few decades.

## 5.1 Economic Analysis

In order to gain an understanding of what the cost of fuel cells would have to reach to become commercially marketable, we completed a spreadsheet which analysed both fuel cell technology and other various technologies. The purpose of this was to calculate the payback period for fuel cells compared with grid power (our baseline) and solar PV power. We used CFCL's BlueGen as a case study, due to the availability of fairly accurate figures directly from the company.

### 5.1.1 Sensitivity Analysis

The graphs discussed in this section examine the profitability of various energy technologies over a period of 25 years. This is intended to demonstrate how the cost of today's technology would be compounded over a long time period. It is important to understand that the cost of these technologies is likely to change, and in turn a similar graph created in five years' time could be completely different. The cost of manufacture and maintenance of the home generation units is expected to decrease dramatically over the next 5-10 years. Additionally, the astoundingly high profitability of solar PV panels depicted in the graphs is the result of government feed-in tariffs, which may be reduced as the popularity of these devices increases.

### 5.1.2 Payback Period

Our first graph was based on a business as usual (BAU) model; in this case the amount of money spent over a period of time on grid connected power. This model assumes no capital expenditure, and the operational expenditure is what the average household pays for electricity each year. This assumption was based on the cost of electricity, as well as the average consumption of energy. For a list of our assumptions, please refer to Appendix I. Figure 24 below shows the running total amount of money paid for electricity by an average household over a period of 25 years. It is important to note that we have calculated the net

present value for our charts below which in turn predicts the value of our future currency in terms of today's value.

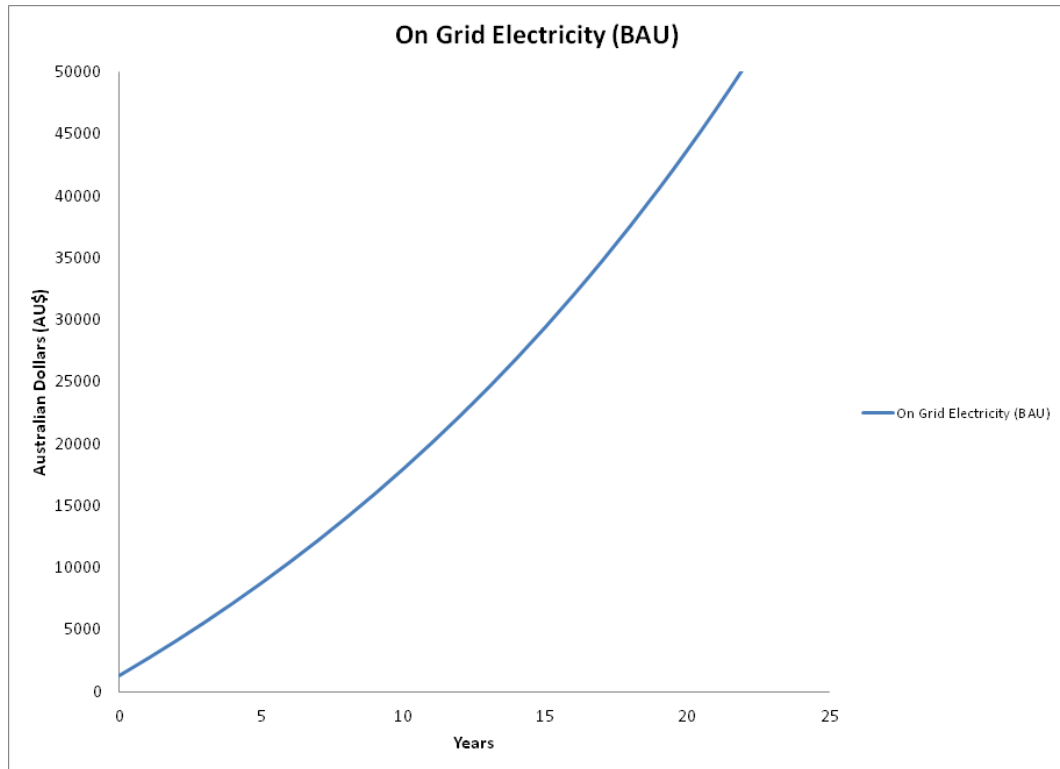


Figure 24. Cost of electricity, running total

Our next analysis drew a comparison between a CFCL fuel cell and our BAU baseline. As is often the case with some high cost products, we assumed that CFCL would offer a warranty deal after the initial warranty expires. Specifically we assumed that CFCL offers an initial two year warranty with all expenses and maintenance charges included in the purchase price. After that period expires, we assumed a three year warranty that would cost AU\$7,000. The other option would be to not purchase the warranty, and replace each component as needed. We calculated a yearly operational cost for both options. For the capital expenditure, we used AU\$25,000. Please see Appendix I for all assumptions and calculations.

Figure 25 shows that the payback period for an AU\$25,000 fuel cell is about 17 years. With an approximate lifetime of 15 years for a BlueGen fuel cell, a payback period of 17 years will make the product very hard to become residentially marketable. It is important to keep in mind that this comparison uses many assumptions, involving both the expenditure and benefits associated with a fuel cell. We made certain conjectures on the average cost of

gas, and calculated approximately how much hot water the fuel cell could produce with its waste heat. This total was subtracted from the total hot water an average family uses to calculate the amount of money saved.

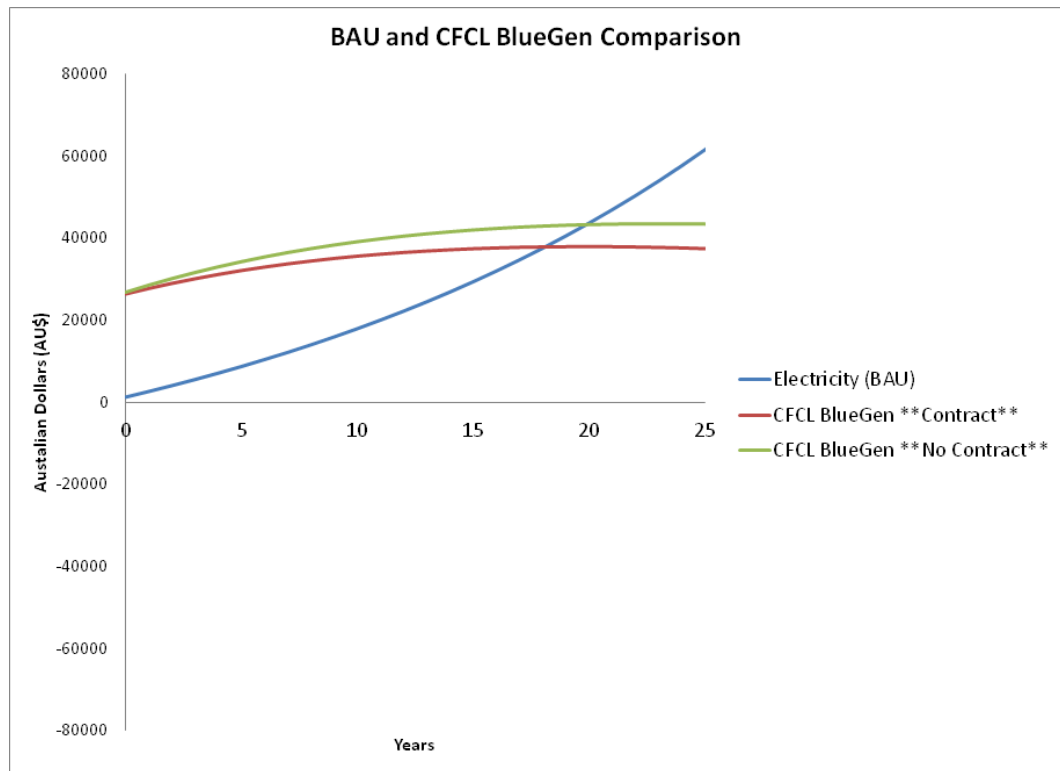


Figure 25. BAU and CFCL Blue Gen Comparison

While fuel cell technology should not be directly compared to solar PV panels, we realise that many people do use this comparison, and this will create some market competition between fuel cells and solar PV systems. Because of this, we wanted to compare the BlueGen power generator and a comparable solar PV system with our BAU example. We made the assumption that Australia typically receives 4 peak sun hours per day, so a 9kW solar array would be needed to produce the same daily output as a 1.5kW fuel cell. We also assumed a gross feed-in tariff of AU\$0.60 per kWh for the solar system.

As can be seen in the figure below (Figure 26), solar PV panels still have a lower payback period than that of fuel cell generation. Although the two technologies are not entirely similar in terms of energy source and other characteristics, when comparing them on a similar output basis, one can clearly see that solar PV panels become profitable after about 4 years, whereas the fuel cell payback period is about 17 to 20 years.

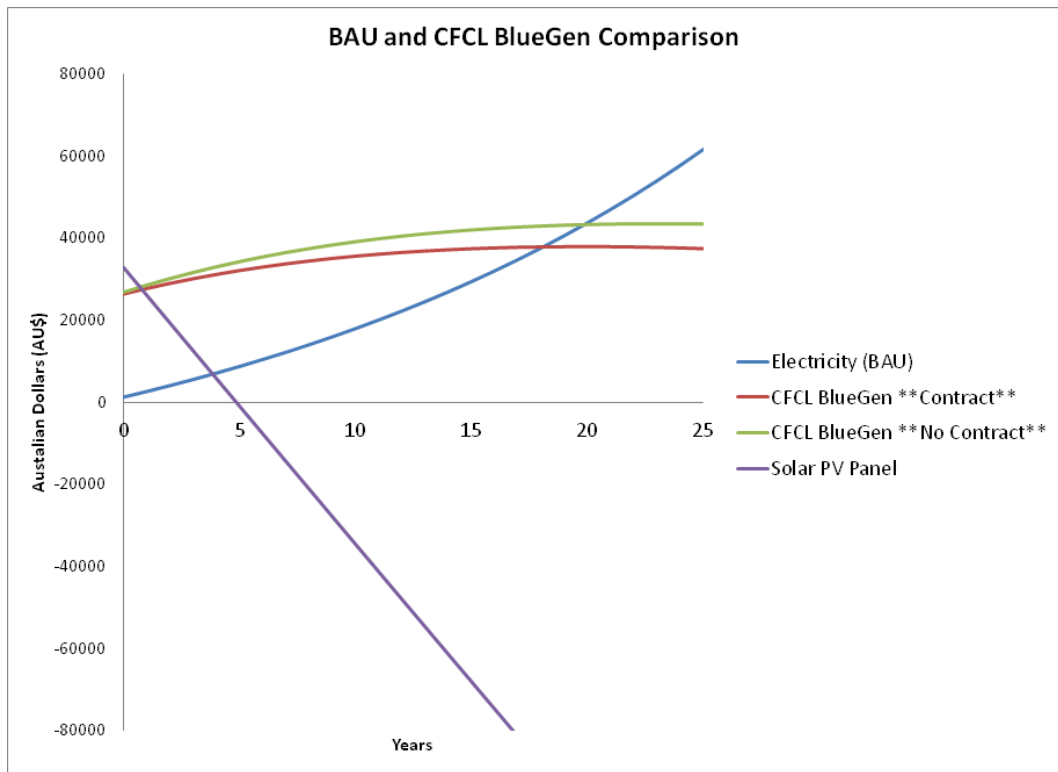


Figure 26. BAU and CFCL BlueGen Comparison

With this information in mind, we wanted to analyse what it would take to make a fuel cell purchase a reasonable investment. In this example, we set all operational expenditure and capital costs to CFCL’s target goal. Further, we assumed that at this time there will be a government subsidy to offset the capital cost of the product. Please refer to Figure 27. While a CFCL fuel cell is still not competitive with the solar panels in this example, the payback period compared to conventional grid power is reduced to about 6 to 8 years. Furthermore, since the capital expenditure for a fuel cell in this example is much lower than that for a solar panel, a feed-in tariff could easily make a fuel cell generator even more profitable than solar panels.

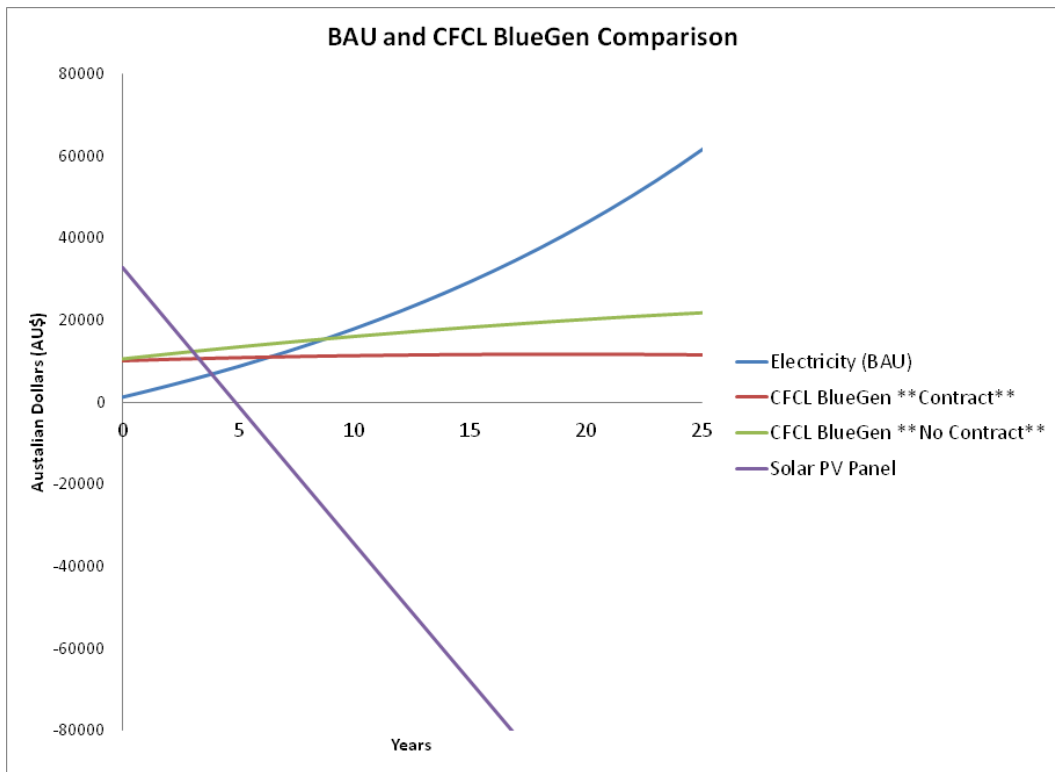


Figure 27. Payback Period

Figure 27 makes two things very clear. First, government subsidies can make an expensive technology quite profitable. Second, the main cost associated with operating a fuel cell within the next few years will be the cost of maintenance. Fuel costs and revenue from grid export are negligible compared to the rather high maintenance charges. If this cost is reduced significantly – and we expect it will be – fuel cells will become a competitive alternative to grid power.

## 5.2 Barriers

Fuel cells are still mainly in their research and development stage, for various reasons. Before they reach commercialisation, they will have to overcome numerous barriers, some of which include the implementation of hydrogen fuelling station infrastructure, resolving misconceptions surrounding the technology, entering the market, and overcoming social and technical barriers.

### 5.2.1 Hydrogen Fuelling Station Infrastructure

After analysing our survey and speaking with technical experts, it is clear that fuel cells have the potential to greatly impact the energy sector. We have seen evidence that shows particular promise in the transportation and home generation sectors as likely markets where fuel cells will penetrate first. For this to happen, however, some type of fuelling



infrastructure is needed. Similar to the petrol infrastructure, with around 8,000 petrol filling stations throughout Australia, hydrogen will need to be widely available before hydrogen-fuelled fuel cell cars can become popular. Otherwise, integrated options, such as the Honda solar-powered electric car, may gain popularity first. Home generation fuel cell applications do not currently directly require hydrogen – they can be run on natural gas – so existing infrastructure can be used for now. Even so, constructing a networked fuelling infrastructure is an obstacle that must be overcome for fuel cell popularity and exposure to increase.

There is a notable amount of discussion of hydrogen fuelling stations around the world. Our research revealed that there are small-scale networks of fuelling stations already being installed in cities worldwide. Hydrogen fuelling stations in the United States are currently supplying fuel for trial fuel cell vehicles. Other countries around the world, particularly in Europe, are creating their own networks of fuelling stations. In Australia, BP is doing work with the bus trial in Perth, where they are reforming natural gas into hydrogen fuel and dispensing it at a fuelling station. BP's final goal will be to create a hydrogen infrastructure similar to the present day petroleum network, thus providing consumers with easily accessible fuel.

The creation of fully developed hydrogen fuelling station infrastructure will still take a considerable amount of time, and specific steps will need to be taken in order to achieve this goal. The first step in developing an infrastructure, which is already taking place around the world, will be to set up small networks of stations in metropolitan areas where consumers would be most likely to adopt the new technology. Strategically placed stations on highly populated routes, similar to the placement of petrol stations, will also be necessary. Once small networks of hydrogen fuelling stations have been implemented, there may eventually be expansion to adjacent cities. The process of developing this infrastructure is going to take considerable time and funding, similar to the development of the petroleum infrastructure currently in place. The evolution of the petroleum industry has been underway in Australia since around 1901, with stations still being installed today (Jamieson, 2003). Even though other options are available, this may portend what the future holds for hydrogen fuel. Production, storage, and transportation of the fuel also become an integral part of this plan for the development of a hydrogen infrastructure, and all of these areas require further research and development. Although a fully formed network does not need to be created for the use of hydrogen fuel to gain popularity, we feel that there is a necessity for a hydrogen fuelling

station infrastructure with some degree of functionality to support the development and use of fuel cell technology, mainly in the transportation sectors.

### 5.2.2 Market Demand and Commercialisation

In researching fuel cells, we found that various factors will affect their potential to be commercialised. As previously discussed, the global population is constantly increasing, carbon emissions are damaging the environment, and energy demand is rising exponentially. Therefore, the increasing need for sustainable forms of technology is inevitable. The need for fuel cells in particular, however, is uncertain. In order for fuel cells to become commercialised, they must prove themselves against competing sustainable technologies. To do so, they need to power a product that is in high demand, and stand out against other devices with similar functions. In addition to these barriers, fuel cells must overcome economic and technological limitations. In this section, we will discuss how we believe fuel cells can reach commercialisation.

In order for fuel cells to become commercialised, their market demand and competitiveness must be understood, and the public must accept them. Convenience, cost, functionality, and safety issues are just some of the factors that the public may consider. Once accepted, private organisations and researchers will work with the help of the government to overcome any technical obstacles to allow for commercialisation (Woodruff & Fukasaku, 2002). Paul Ekins, author of *Hydrogen Economy: Economic and Social Challenges*, argues that fuel cells will have three main markets: micro-fuel cells, auxiliary power units (APUs), and vehicles (Ekins, 2010).

The demand for fuel cells will rely on various factors. Ekins explains, “Because fuel cells will be embedded in other products, the demand for fuel cells will partially depend on the demand for those products” (Ekins, 2010). The products that can be powered by fuel cells will need to compete with other similar products. Fuel cell demand will also be connected to the demand for power. With this, fuel cells will need to compete with other types of power sources. Market demand is a complicated subject, since it is so volatile and unpredictable. Figure 24 below helps to explain how fuel cell demand may work. As shown, fuel cells will compete with other energy sources and energy-saving technologies. The demand for each is similar, and therefore will be dependent on the consumer demand.

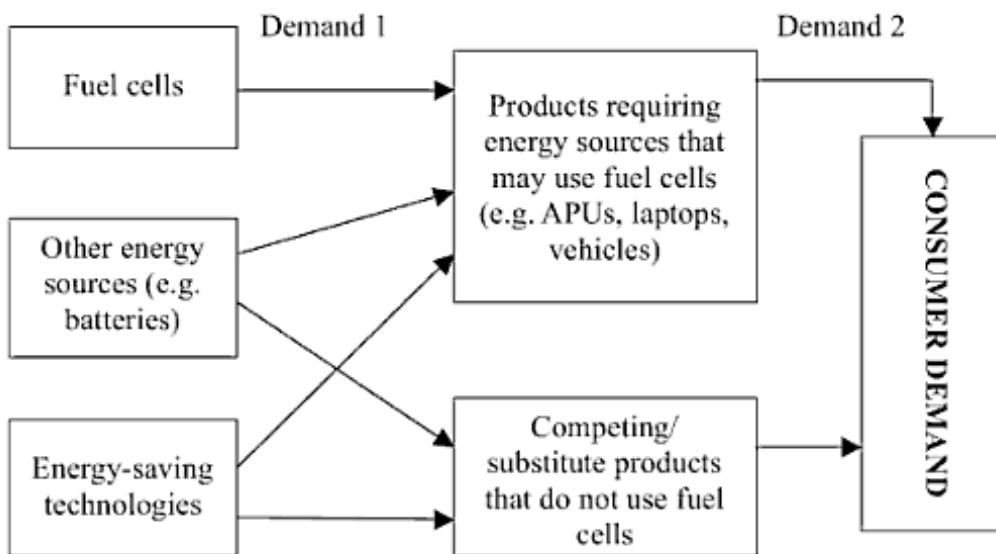


Figure 24. Representation of Fuel Cell Demand (Ekins, 2010)

### 5.2.3 Misconceptions about Fuel Cells

After analysing the results from our survey, we found that many participants had misconceptions about fuel cells. In the comments that we received, a significant number mentioned solar photovoltaic panels. Even though solar PV is not directly comparable to fuel cells because of the difference in the source of energy, the comments we received showed the general public draws a strong comparison between two. There was a general consensus that those with solar PV would not likely be willing to “switch” to fuel cells. Many participants noted that the benefits of solar PV panels lie in their affordability, and they seemed to be more comfortable with solar PVs because they have been around longer. Some of the comments implied the participant’s hesitation to accept a new technology. The main issue with this thought process is that solar PV panels and fuel cells are not directly comparable to one another. A fuel cell would more likely be directly comparable to batteries and other fuelled generators, including power plants.

Due to the reasonable cost of solar PV systems, they are a widely-used product and often come to mind first at the mention of sustainable technologies. Other technologies, like fuel cells, may be overlooked if each technology is not completely understood. Distinctions need to be made between each type of sustainable technology, so the general public will realise the potential and limitations of each. For example, solar PV panels are not a viable option to power cars alone. Fuel cells, on the other hand, have the potential to do so, since they work in conjunction with hydrogen fuel which can be stored and transported. Therefore,

the two are not in direct competition, but since they are both sustainable technologies that provide power, they are often associated. Instead of comparing fuel cells to solar or wind power, they should actually be compared to batteries or internal combustion engines.

It is necessary to spread awareness about each type of sustainable technology. The public needs to understand that each type has different applications, and that they cannot all be compared equally. Comparisons can be made to simplify the technologies to basic terms, such as relating fuel cells to batteries. With this, less commercialised technologies may gain appeal, and have greater chances to enter the market. Until fuel cells are completely understood, they may not emerge as a viable technology to be used in residential and small-scale applications.

#### 5.2.4 Safety Concerns

There are various safety concerns associated with fuel cells, and especially the fuel they use. The idea of using a new, unfamiliar, and complex technology may prevent an average person from even considering it. Concerns over high operation temperatures of some fuel cell types may also deter potential consumers. Fuel cells can operate using a variety of fuels, but hydrogen is the most favourable due to the fact that it produces no carbon dioxide emissions, and because it fits optimally with the chemistry of fuel cells. After looking over comments in our survey, we found that several consumers may be worried about safety when using a hydrogen-based power supply, due to their negative associations with the dangerous history of hydrogen. Additionally, it is possible that some people may be uncomfortable with storing pressurised fuel in their homes or vehicles. However, hydrogen is currently being used around the world for a wide range of private and commercial applications. If hydrogen is to become a primary energy carrier, consumers will need to be assured that it is no more dangerous than current fuels like natural gas or petrol. Adopting sufficient safety regulations and ensuring the public that fuel cells and their fuels are not overly dangerous when compared with other fuels is paramount if hydrogen is to be widely used as a fuel.

#### 5.2.5 Technical Barriers

Fuel cell technology has very specific technical issues to overcome before it will be widely implemented. These include storage and distribution of the different fuels used to power the cells, as well as operating conditions of the fuel cell itself. Combined, these barriers make the current implementation of fuel cells difficult.

Issues concerning the fuels used to power fuel cells have concerned researchers for many years. Hydrogen is the most common fuel used in fuel cells, but many different carriers of energy can be utilised. The two main methods are transporting hydrogen in its molecular form (H<sub>2</sub>) or via a carrier molecule such as methane. Hydrogen can be easily reformed from methane, but this process releases CO<sub>2</sub>. Furthermore, even if hydrogen is produced via clean methods (electrolysis), the required means of transportation and containment are very complex. Since hydrogen is a very small molecule, it can diffuse through many materials, including metals. Because of this, containers for storing significant amounts of hydrogen are very heavy and expensive.

Another great technical barrier that needs to be overcome relates to the operation of the fuel cell. For example, from initial start-up, a typical SOFC today takes about 24 hours to begin performing at full capacity, meaning that it cannot be used for backup purposes. Once the cell is running, the operating temperature can reach about 750 degrees Celsius, which could be perceived as a potential safety hazard. Insulating materials in use today are highly sophisticated and effective, but some consumers may still have concerns about the high operating temperature of these devices.

Another technical aspect that is impeding the progress of fuel cell implementation is the overall lifetime of the cells. Currently, the lifetime of a cell that is run continuously is around two years. For a home power generator, this means spending several thousand dollars every two years, and therefore may not be practical investment. Further technological advances are needed to increase the lifespan of the technology or to reduce the cost significantly.

Whether the concern is with the fuel cell or with the fuel itself, there are many technological issues that are hindering the acceptance and development of the technology. These issues will need to be mitigated in order to see fuel cell technology reach the potential that many researchers and experts predict.

#### 5.2.6 Consumer-Level Policy

Government incentives, including feed-in tariffs, grants, and tax deductions, are often an excellent way to provide an economic ‘boost’ for emerging technologies. Currently, there are no consumer-level government incentives for implementing fuel cells. Although feed-in tariffs and other incentives are currently only available for certain types of technologies, they

could easily be applied to other systems such as fuel cells. However, due to the high cost of the units as well as significant maintenance costs, the tariff would need to be quite high to make these systems attractive. In 2005, the United States implemented a federal fuel cell tax incentive program. This policy is noteworthy because “in addition to the research and development, demonstration and market transition programs for fuel cells and hydrogen, the law contains new incentives for the purchase of fuel cells” (US Fuel Cell Council, 2005). One of the incentives offered is the Investment Tax Credit (ITC), which offers \$1,000 per kW to fuel cell owners, who could be individuals or businesses. Most US states also have state-level financial incentives regarding the installation of fuel cells. For example, in California, feed-in tariffs are offered to customers who use fuel cells that run on renewable fuels. The feed-in tariff allows customers to enter contracts where they agree to sell the fuel cell’s power, up to 3 MW, to the grid at market prices. Other countries also have implemented similar policies in support of fuel cells (US Fuel Cell Council, 2005).

Though consumer-level government policies surrounding fuel cells are not very common, numerous governments around the world are funding fuel cell research and development projects. In Australia, the government provided AU\$2.5 million to fund a pilot test in Western Australia of hydrogen fuel cell buses (Australian Government, 2009). Demonstrations of support such as this will help to promote interest in fuel cells. With increased government support, public and private research and development will also expand. Once social and technological barriers are overcome, governments may begin to consider implementing more consumer-level incentives regarding fuel cells. With this, it is clear there is a cycle surrounding the commercialisation of a new technology, which often begins with government funding.

One example of a program that could be put into place would be a rebate scheme similar to those currently in place for solar panels under the RET. We expect that a residential fuel cell generator will cost about AU\$20,000 - \$30,000 within the next ten years. Some consumers may be willing to pay this price, but a discount equivalent to about 30% off the capital expense would be needed to bring the cost within the acceptable range reported by a large number of our survey respondents. Under this scheme, the government would pay about \$7,000 - \$10,000 per unit. This is significantly more than is currently offered for solar photovoltaic panels with equivalent daily energy output. For this reason, such a rebate would not be economically practical until the cost of the devices is further reduced.

Government policies and programs have the potential to propel innovative technologies to the mass market. Unfortunately, this stimulation can only go so far, and the overall cost of fuel cells is still quite high. The cost of fuel cells must be further reduced by research and development, corporate investment, and increased public interest before government incentives will be helpful.

## **5.3 Present and Near Future Applications**

Fuel cells are already being manufactured in numerous countries around the world. Although there are currently very few fuel cells being commercially sold, we feel that widespread commercialisation of some fuel cell products may occur within the next decade. The areas of transportation and home power generation are likely to be the first areas in which fuel cells are implemented, and we believe there will soon be an increasing number of fuel cells on the market in these applications.

### **5.3.1 Home Generation**

Presently, home generation fuel cells are being produced, and pilot programs are in progress. The Australia-based company, Ceramic Fuel Cells Limited is currently manufacturing natural gas powered fuel cells to be marketed in Europe. These fuel cells, although costly at this time, allow for use of grid-connected fuel cells. This system is designed to utilise the existing natural gas infrastructure, as opposed to waiting for a fully developed hydrogen network that will take quite some time to be developed. Although these fuel cells still produce CO<sub>2</sub> emissions, they provide a great opportunity for consumers to reduce their carbon footprint. Since these units use cogeneration, hot water will also be generated for additional energy savings. Cogeneration is an attractive characteristic for present application of fuel cell technology. We envision a scenario, within the next twenty years, in which a significant number of households will have their own fuel cell that runs on natural gas and produces less carbon dioxide than obtaining energy from coal-fired grid power. Of course, this will only be possible if fuel cell manufacturers can commercialise home generation units and significantly reduce the capital and maintenance costs.

### **5.3.2 Transportation**

Car manufacturers have recently developed fuel cell vehicles, and prototype fuel cells have also been installed on buses around the world. Trial fuel cell cars are currently being tested in the United States and Germany, where companies are working to commercialise the

technology for transportation purposes. However, a considerable amount of research needs to occur in the development of the technology itself. Furthermore, the fuelling infrastructure needed to support the widespread use of fuel cell vehicles is a paramount concern when considering commercialising the technology for transportation applications.

## **5.4 Future Possibilities**

After analysing extensive amounts of literature, conducting numerous interviews, and reviewing case studies, we determined where we believe fuel cells will be applicable in the future. We predict that by 2050, fuel cells will be used in portable applications and in other applications to facilitate the storage of sustainable energy. These uses will take longer than cars and home generation due to technical barriers and cost factors. Though it may be a while before fuel cells are used to facilitate the storage of renewable electricity or power portable applications, they do show promise of doing so in decades to come.

### **5.4.1 Storage of Electricity**

The earlier discussion on energy storage and conversion sought to enlighten the reader about the different ways in which energy can be stored, transmitted, and converted from one form to another. Although fuel cells are strictly conversion devices, it is important to realise that fuel cells can play a very unique role within the energy distribution process for two reasons. First, they are able to convert a fuel (chemically stored energy) into electrical energy. Second, hydrogen fuel cells are able to make this conversion without the release of any toxins or greenhouse gases.

Electricity is an energy carrier. It can be produced from a variety of resources, it can move energy from one place to another, and it can be used in a wide range of applications. But the disadvantage of electricity is that it cannot be stored. Many people often think of batteries as a way of “storing electricity,” but in fact, the use of batteries requires a conversion to and from chemical energy, which is often highly inefficient. Batteries are an innovative technology and they have made great progress in providing for our energy storage and transportation needs, but the limits of this technology are beginning to be felt by electronics consumers and car manufacturers as the energy demands of their devices continue to increase.

Hydrogen fuel cells offer the potential to solve this dilemma. Fuel cells can fit a very similar niche to that of batteries. Hydrogen can be produced in a way that would be



analogous to charging a battery – by electrolysis. The difference is that while the storage capacity of a battery is limited by the size of the battery itself, the amount of hydrogen that can be stored is only restricted by the capacity of the containers used, and not the size of the end-use device. This allows for a large external storage capacity, which would be readily available for use in small or large amounts as needed.

Another notable advantage is that the fuel can be produced by a stochastic (i.e. random) energy source – such as a wind turbine or solar panel – and stored until it is needed, then used by a fuel cell to provide a deterministic (i.e. controllable) supply of electricity. If such a system were implemented on a residential scale, it would theoretically eliminate the need to rely on grid power during the night (in the case of production by solar panels) or on calm days (in the case of wind turbines), while also not always relying upon an external source of fuel for backup power.

The other main advantage of fuel cells over other energy converters is portability of the fuel for transportation uses. Generally speaking, all vehicles require their energy source to be stored on-board in one way or another. This has typically been accomplished through storage of a combustible fuel (gasoline, for instance) or batteries. A fuel cell and hydrogen or methane tank could take the place of batteries in an electric vehicle.

Within the near future, the high cost and technological limits may prevent these ideas from being realised. Nevertheless, the potential exists for a completely sustainable and reliable energy distribution system, which may incorporate fuel cells. A fuel cell alone cannot provide energy – it is not an energy source. But used in combination with other means of capturing and transferring sustainable energy, fuel cells may indeed prove to be invaluable as a way of producing sustainable electricity when and where it is needed.

#### 5.4.2 Portable Applications

In determining the viability for a product to be commercialised, convenience must also be considered. Many people are not willing to have their daily routines interrupted, even if it means living a more sustainable lifestyle. When analysing the potential for fuel cells to be commercialised as portable appliances, convenience becomes a major issue. Currently, fuel cells as external chargers seem to be closer to commercialisation than devices integrated with fuel cells. Unfortunately, some experts predict that the average user would not be willing

to deal with the inconveniences of fuel cells as external chargers. Integrated fuel cells may be more appealing to the masses, but technological limits are in the way (Ekins, 2010).

Micro-fuel cells have been envisioned as a way of increasing the energy capacity and run-time of portable devices. Unfortunately, factors besides convenience also restrict the progress of this technology. One of these is manufacturing scalability – issues such as the brittle nature of graphite when cut to the size needed for a micro-fuel cell, for example – as well as producing small and lightweight hydrogen containers. The miniature prototype fuel cells that have been produced primarily use DMFCs fuelled with methanol, due to the inability of any device to compactly store small amounts of hydrogen for use with a PEMFC. These prototypes have also been very expensive, because of the need for miniature pumps, fans, valves, etc. for fuel supply and temperature control. Needless to say, micro-fuel cells are likely to be several decades away from commercialisation, and until that time, small electronic devices will continue to rely upon conventional rechargeable batteries. Nevertheless, fuel cells may eventually become an economical way of compactly storing energy for portable applications.

## **5.5 Timeline**

Figure 25 shows a projection of fuel cell applicability in Australia to 2050. This timeline was formulated from all of the information we collected, including our survey and interview results, literary research, and discussions, but the accuracy cannot be guaranteed due to uncertain factors. It encompasses our informed predictions on the future applications of fuel cell technology. Presently, fuel cells are being manufactured for home power generation applications, which we expect to continue to expand. The next sector where fuel cells will become applicable is transportation. Although fuel cell vehicles are already in existence, the widespread application of fuel cells for transportation relies heavily upon the development of a hydrogen fuel infrastructure. The last sector where the technology will become applicable will be in portable electronic devices. Micro fuel cells will be used first as portable charging devices and eventually become integrated within portable electronics. Alongside the development of fuel cells will be the construction of a hydrogen infrastructure that will take a considerable amount of time to complete. By 2050, we believe that a sufficient infrastructure will most likely be in place, and also predict that fuel cells will be applicable in all small-scale power generation sectors.

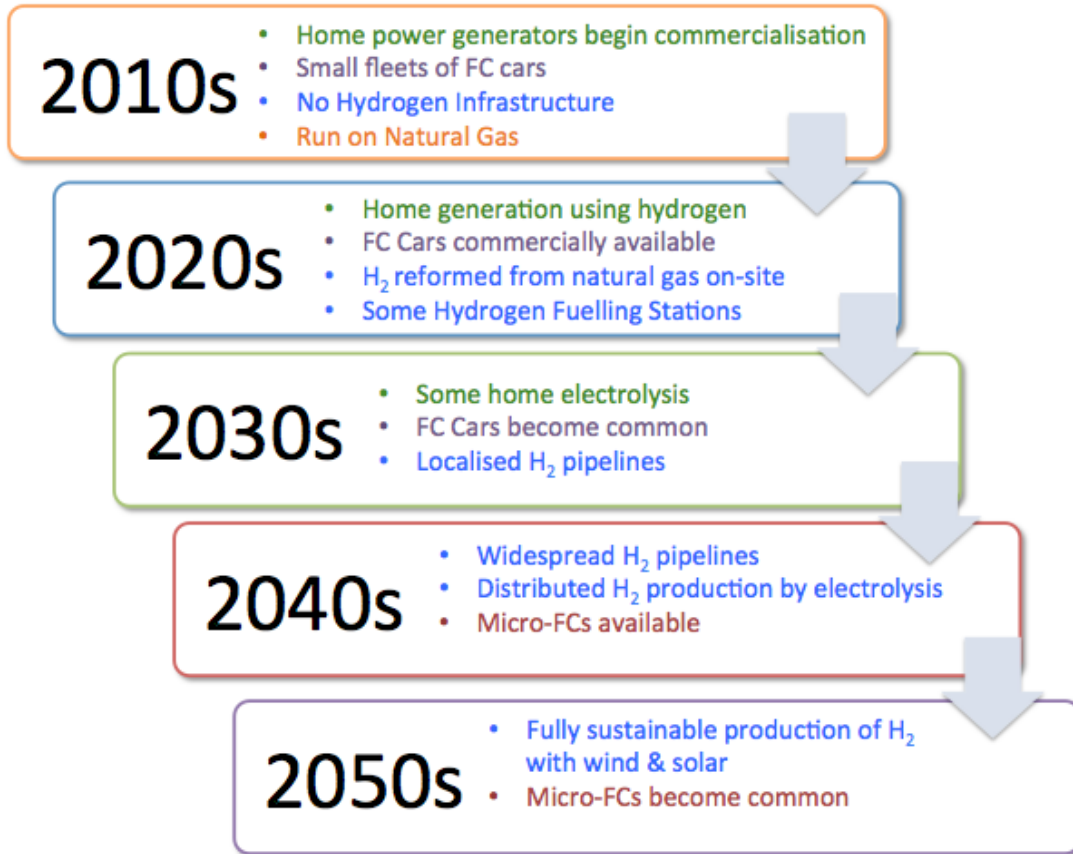


Figure 25. Timeline of Fuel Cell Applicability

# Chapter 6: Conclusion

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Global climate awareness, diminishing supplies of fossil fuels and steadily increasing global population have all escalated the population's interest in alternative and sustainable technologies. With some of the world's highest CO<sub>2</sub> emissions per capita, Australia has an added motivation for an increased interest in alternative energy technology. It is because of this that the Alternative Technology Association has taken an interest in the present and future applicability of fuel cell technology. We conducted extensive background research, interviewed technical experts, and surveyed the ATA membership in order to gain valuable information to determine if and when fuel cells will become applicable in the global energy market.

There are three areas in which fuel cells are likely to be implemented: small-scale (residential) stationary power generation, transportation, and portable electronics. These three applications are expected to become economically competitive at different times. Residential fuel cell generators are already in limited production, and although the current technology still relies upon the use of natural gas, they do provide a cleaner option than coal-fired grid power. Fuel cell cars are being developed and piloted, and are expected to be available on the market within the next ten years. Most models currently being developed utilise hydrogen, which can be reformed from fossil fuels or generated by electrolysis. Portable fuel cells are still predominantly in their research stage; the cost and functionality of these devices are not currently in a position to be competitive with conventional rechargeable batteries.

Hydrogen fuel cells show promise as a way of producing carbon-free electricity, because they generate no CO<sub>2</sub>. Unfortunately, the earth does not offer vast natural reserves of hydrogen, so it must be produced from another energy source. Thus, the overall emissions created by a hydrogen fuel cell are dependent not only upon the emissions of the fuel cell itself, but also on the method used to create the hydrogen.

There are two main methods for producing hydrogen. The first involves reformation of methane (natural gas) with steam. This process is inefficient and releases waste heat, as well as a great deal of CO<sub>2</sub>. The second method, electrolysis, involves using electricity to separate water molecules and releases only oxygen gas (O<sub>2</sub>) as a by-product. This method, when combined with a sustainable source of electricity such as solar panels, generates no carbon emissions.

In the short term, the use of fuel cells run by reformed natural gas should not necessarily be discouraged. The reforming process used to produce hydrogen is less carbon-intensive per unit of energy produced than coal-fired power plants, and the popularisation of these devices will promote additional research into fuel cell technology. However, natural gas will not meet our energy needs forever, so a shift to sustainable production of hydrogen is to be encouraged whenever possible. We expect that sustainable hydrogen production will emerge as a network of distributed home electrolysis systems. The energy from these systems could come from various sources including solar, wind and hydro power energy converters. Each of these electrolyzers would provide power for a residence and hydrogen for cars. Excess power could be sold either in the form of hydrogen – contributing to a wide-scale infrastructure – or by exporting electricity to the grid, gradually eliminating the need for coal-fired plants.

Recently, there has been very little government action specifically targeting fuel cells. In the near future, any government funding for fuel cells should be directed towards research and development of low-cost consumer products. After some of these products have entered the market, it would then be practical to introduce feed-in tariffs and other incentives for individuals and homeowners to begin employing the technology. Australia currently has feed-in tariffs for solar panels, and in some places, wind turbines. Similar incentives might be able to increase the popularity of fuel cells as well. Due to the high capital cost of fuel cells, rebate programs intended to reduce this cost would be likely to stimulate the fuel cell market. For the same reason, however, rebates would be expensive for the government and the same money might be more effectively used to subsidise other sustainable technologies. Once the cost of the technology becomes affordable, feed-in tariffs and rebates will both be effective in increasing the public's awareness and interest in fuel cells.

Fuel cells have the potential to provide new ways in which energy can be stored and distributed. Unfortunately, the cost of fuel cell technology is still quite high, and only a very limited selection of fuel cell products is currently available. As more research is conducted and the technology improves, the range of applications for fuel cells will expand from home generation to transportation to portable applications and more. Lobbying and advocacy on the part of the ATA will significantly accelerate the progress of this technology as Australia heads towards a future of sustainable and carbon-free electricity.

# Chapter 7: Policy Recommendations

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Based on extensive research and investigation into fuel cells and their applicability, we have developed several Australia-specific recommendations for the ATA. We hope that by adhering to these recommendations, the ATA may become further prepared for the implementation of future programs and policies regarding fuel cells. Further, we anticipate that our recommendations will help the ATA take an informed stance in its policy advocacy around fuel cells.

**We recommend promoting the development and use of fuel cells for the purposes of transportation and energy storage.** Fuel cells are unique from many other sustainable technologies in that they facilitate the storage of electrical energy in the form of a fuel, without producing carbon emissions. This allows them to be used in a variety of applications where mobility is essential, such as cars and portable devices. The technology has limitations which prevent it from being widely implemented in these areas today, but research and development towards these goals should be encouraged so that these barriers can be overcome.

**We recommend supporting the development of sustainable technologies to assist in the storage, distribution, and production of hydrogen.** Hydrogen fuel must be used if fuel cells are to be considered a sustainable, carbon-free generation technology. Currently, very limited infrastructure exists for the sustainable production and distribution of hydrogen fuel. This is likely to be the greatest hindrance to the implementation of hydrogen fuel cells, particularly in vehicles. In the initial stages of fuel cell development, hydrogen may be produced from natural gas. However, natural gas is neither clean nor renewable, so the community's ultimate goal should be to produce hydrogen using energy from sustainable sources such as wind and solar power. Though this may not currently be cost effective, we expect that rising energy costs and environmental concerns will make sustainable hydrogen production increasingly attractive.

**We recommend that the ATA make preparations for fuel cell powered home power generation systems to be fully commercialised within 10 years.** From our research, it became evident that stationary residential power generation will likely be the first area in which fuel cells will be commercialised. Currently, fuel cells are already being manufactured for home generation uses, and numerous pilot tests are also being conducted. Since fuel cell

powered home power generation systems can be integrated with other technologies or linked to the grid, consumers will not have to become completely dependent on the fuel cell alone for their power needs. We believe that fuel cells will become an attractive technology to the consumer for home power generation, once prices decrease, which we expect will happen in the near future.

**We recommend that the ATA plan for a preliminary hydrogen infrastructure that will be functioning within 10-15 years.** Since fuel cells rely upon fuel to run, it is necessary for a fuelling infrastructure to be developed before fuel cell vehicles can be commercialised. The term “preliminary” implies a set of networked fuelling stations, similar to the common petrol fuelling stations, which would be able to support a small but growing number of commercialised hydrogen vehicles. We feel that hydrogen holds the most promise as the fuel to run fuel cells, and therefore, that most research and development of an infrastructure will go into this area. Since hydrogen fuelling stations are already in existence, the construction of this infrastructure is already underway. We predict that a more developed infrastructure will be formed within the next 10-15 years.

**We recommend that the ATA plan for fuel cell cars to become available within the next 10-15 years.** Accompanied by the development of a hydrogen fuel infrastructure, we expect fuel cell cars to be marketed starting in about 10 years. Fuel cell vehicles are currently being pilot tested, and have been shown to be both efficient and practical. Hindering the commercial success of these vehicles, however, will be fuel supply and distribution. Some early models may be equipped to use natural gas instead of hydrogen, until a sufficiently robust hydrogen infrastructure is in place. We predict that after this infrastructure is developed, there will be little to prevent fuel cell vehicles from becoming widely popular.

**We recommend that the ATA postpone indefinitely any expectations of fuel cells being used in portable applications.** From our research, we found that fuel cell powered portable applications are still far from being commercialised. Due to numerous technical and cost factors, it will take increased research and development before they can reach the market. Micro fuel cells and fuel cell powered phones and computers will likely gain increased attention as the functionality of the technology becomes competitive with that of batteries. Therefore, we predict that it will take an extensive amount of research and development before fuel cell powered portable applications become commercialised.

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# Glossary

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**Carbon Capture and Storage (CCS)** – a way of collecting carbon dioxide emissions from fossil fuels and storing them in a way so they do not enter the atmosphere

**Chemical Energy** – energy that is stored in chemical bonds within a substance, and is released through chemical reactions

**Cogeneration** – generating hot water from waste heat produced by another process.

**Deterministic** – controllable; predictable

**Electrical Energy** – energy associated with the flow of an electric charge through a conductor

**Energy Carrier** – anything that enables the storage or transport of energy, to be converted to another form before use

**Energy Density** – the amount of usable energy stored per unit volume of a fuel

**Energy Source** – a natural resource that provides usable energy (e.g. petroleum)

**Energy Storage** – any case in which energy remains in the same form for a period of time.

**Gasification** – the process by which raw material such as coal and biomass is heated until a gas is formed.

**High-Grade Heat** – refers to high temperature heat that can be collected from a conversion of energy and used in another process

**Hydrocarbon** – organic compound composed of only hydrogen and carbon; found in fossil fuels

**Hydrogen Economy** – term used to describe a situation where hydrogen is the sole energy carrier and thus the economy revolves around the fuel

**Hydrogen Highway** – common term used to describe an interconnected network of hydrogen fuelling stations that are strategically placed along major highways

**Kinetic Energy** – energy associated with motion. Can take the form of mechanical energy, thermal energy, electrical energy, or electromagnetic radiation

**Low-Grade Heat** –heat at ambient temperatures that cannot easily be collected

**Mechanical Energy** – energy associated with the motion of a macroscopic object

**Non-Renewable Energy** – an energy source that diminishes over time

**Off grid** – not connected to the electric grid

**On grid** – connected to the electric grid

**Potential Energy** – energy that is stored. Can take the form of chemical energy, gravitational energy, elastic energy, or nuclear energy

**Renewable Energy** – an energy source that does not diminish with time

**Stochastic** – random; not controllable

**Sustainable Energy** – Renewable energy that meets the needs of the present population, without compromising the ability of future generations to meet that need



# Appendix A: Alternative Technology Association (ATA)

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Recently, Australia has become much more conscious of its energy use and impact on the environment. One major part in Australia's success in leaving a smaller carbon footprint is due to the incredible work of the Alternative Technology Association, more commonly known as the ATA. The ATA is "Australia's leading not-for-profit organisation, promoting sustainable technology and practice" (ATA, 2010). More specifically, ATA lobbies to government officials, as well as advocating to members of industry in an effort to help the Australian community move towards using more energy efficient equipment and technology.

With fourteen branches around Australia and New Zealand, the ATA looks to help the community by "[providing] practical information and expertise, based on our members' hands-on experience" (ATA, 2010). This information includes offering advice on more energy efficient building methods, promoting the use of sustainable technology, and lobbying on the consumers' behalf to emphasise the importance of sustainability and green practices to the government.

The ATA goes to great lengths to spread the word about how to avoid leaving a large carbon footprint. One method they utilise is the publication of two quarterly magazines on sustainable living. The two journals are ReNew, which covers the latest sustainable practices and technology including alternative fuels and renewable energies, and Sanctuary, which focuses on leading practices and solutions for homes in Australia. Along with their two publications, the ATA also has released a guide to help the community live a more energy-efficient lifestyle. The Renters Guide to Sustainable Living is the ATA's publication designed to spread this message. It is a free 16-page short book explaining to renters how they can reduce their carbon footprints. It includes information on how they can work with their landlord to get them to implement sustainable technologies. They recommend that renters remind the landlords about rewards that they are eligible for if they implement these technologies. Aside from The Renters Guide to Sustainable Living, the ATA also provides general tips for the public to reduce overall energy usage. Some of these general guidelines include: take short showers, use energy saving lights, wash clothes in cold water, and so forth. Further, the ATA also recommends various water saving practices. Some of these practices include reducing water use, fixing leaks, and installing flow restrictors.

Along with providing tips and guidelines on how one can lead a more sustainable life, the ATA also conducts projects that test new forms of efficient technologies. Some recent tests include wind turbines, solar photovoltaic, and heat pumps. The ATA online store sells many of the pretested sustainable products. These products include energy-efficient lights, solar equipment, power meters, T-shirts and DVDs, as well as information and literature about green technology.

The Alternative Technology Association is Australia's leading non-profit organisation whose goal is to spread the message of a more sustainable lifestyle. For easy access to all their helpful guidelines and publications, the ATA has a comprehensive website on how to live a sustainable lifestyle. This website offers great resources on the ways this can be done, and the rewards that come from doing so. Furthermore the ATA has a membership program which offers such benefits as free advice service with answers to sustainability questions, discounts from the ATA shop, opportunities to engage in local activities as well as meeting other people with an interest in sustainability.

# Appendix B: Survey Questions

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Below are the survey questions that were given to both ATA members and CFCL enthusiasts. For complete results, please refer to Appendices C and D for the ATA member survey result and CFCL enthusiast's survey results, respectively.

1. How old are you?
  - a. Under 18
  - b. 18-30
  - c. 31-40
  - d. 41-50
  - e. 51-60
  - f. 61-75
  - g. Over 75
  
2. What type of residence do you live in? (Please tick the most applicable)
  - a. Privately owned house
  - b. Privately owned apartment/unit
  - c. Rented
  
3. Is your home connected to the electricity grid?
  - a. Yes
  - b. No
  
4. From this brief list of possible products, please tick any sustainable technologies that you currently use.
  - a. Wind turbines
  - b. Dual flush toilets
  - c. Geothermal heat pumps
  - d. Compact fluorescent lights
  - e. Fuel cell technology
  - f. Rainwater tanks
  - g. Bicycles
  - h. Hydroelectric technology
  - i. Hybrid vehicles
  - j. Water-saving shower heads
  - k. Greywater recycling
  - l. Solar hot water
  - m. Solar photovoltaics
  - n. Other efficient appliances

5. Please rank the following motivations in order of importance when you choose to purchase sustainable technology (1 = most important, 5 = least important). Please use each number only once.
  - a. Helping the environment
  - b. Reducing your carbon footprint
  - c. Reducing the cost of household utilities
  - d. Convenience
  - e. Interested in new technology
  
6. Please rank the following in order of importance when you consider purchasing a product that uses sustainable technology (1 = most important, 4 = least important). Please use each number only once.
  - a. Cost
  - b. Efficiency
  - c. Environmental impact
  - d. Safety
  
7. Please rank the following in order of importance when considering the cost of sustainable technology (1 = most important, 3 = least important). Please use each number only once.
  - a. Initial cost (cost of buying the product, including installation)
  - b. Operational cost (cost of fuel, maintenance, etc.)
  - c. Overall lifetime cost
  
8. How would you rate your familiarity with fuel cell technology?
  - a. Expert- I have direct experience with fuel cell research
  - b. Well-informed- I have studied or been exposed to fuel cell technology
  - c. Some knowledge- I understand the basics of how fuel cells work
  - d. Heard of fuel cell technology
  - e. Never heard of fuel cell technology
  
9. Which application are you most interested in for fuel cell technology? Assume that these devices would use some form of portable fuel, such as hydrogen, which you would occasionally refill.
  - a. Personal Transport (cars)
  - b. Home Power Generation
  - c. Portable Applications (Laptops, Mobile phones, iPods, etc.)
  
10. How much extra would you be willing to pay per month for electricity if it were generated by a more sustainable energy source such as a fuel cell? The electricity generated would have greatly reduced carbon emissions and in turn leave a small carbon footprint.
  - a. \$0-\$20
  - b. \$20-\$50

- c. \$50-\$100
- d. \$100-\$200
- e. \$200+

11. How much extra would you be willing to pay for small fuel cell powered home appliances? This would include mobile phones and portable music players. The devices would need to be recharged with hydrogen. Assume that recharging would be simple and relatively inexpensive.

- a. \$0-\$10
- b. \$10-\$50
- c. \$50-\$100
- d. \$100-\$200
- e. \$200-\$500
- f. \$500+
- g. I would not purchase a fuel cell powered portable device.

12. How much extra would you be willing to pay for a fuel cell powered car? Imagine that the car would be run entirely by the fuel cell with many fuelling stations nationwide similar to petrol stations.

- a. \$0-\$1,000
- b. \$1,000-\$5,000
- c. \$5,000-\$10,000
- d. \$10,000-\$20,000
- e. \$20,000-\$30,000
- f. \$30,000-\$40,000
- g. \$40,000-\$50,000
- h. \$50,000-\$100,000
- i. I would not purchase a fuel cell powered car.

13. How much extra would you be willing to pay for a fuel cell powered laptop computer? The computer would need to be occasionally refuelled with portable fuel canisters.

- a. \$0-\$50
- b. \$50-\$100
- c. \$100-\$200
- d. \$200-\$500
- e. \$500-\$1,000
- f. \$1,000-\$2,000
- g. \$2,000-\$5,000
- h. \$5,000+
- i. I would not purchase a fuel cell powered computer.

14. How much altogether would you be willing to pay for a fuel cell powered home generator? The generator would be used to completely power your residence and take you off the electrical grid.
- a. \$0-\$10,000
  - b. \$10,000-\$20,000
  - c. \$20,000-\$30,000
  - d. \$30,000-\$40,000
  - e. \$40,000-\$50,000
  - f. \$50,000+
  - g. I would not purchase a fuel cell powered home generator.

15. Please use the space below to leave brief comments about the survey. Additional comments or correspondence may be sent to [atafuelcells@gmail.com](mailto:atafuelcells@gmail.com).

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# Appendix C: ATA Member Survey Results

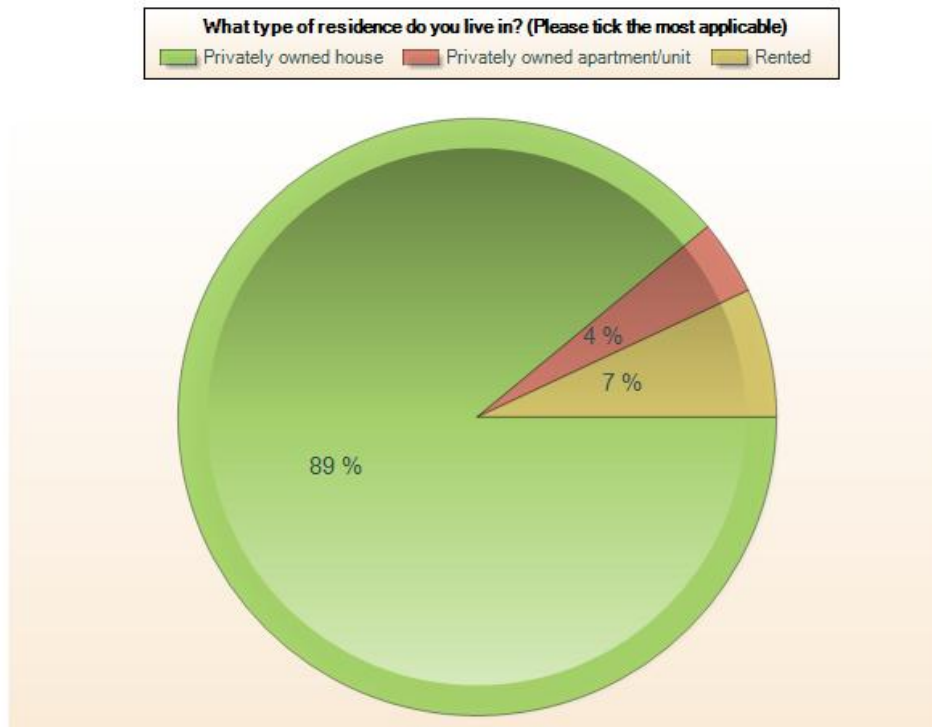


Figure C-1. Type of Residency

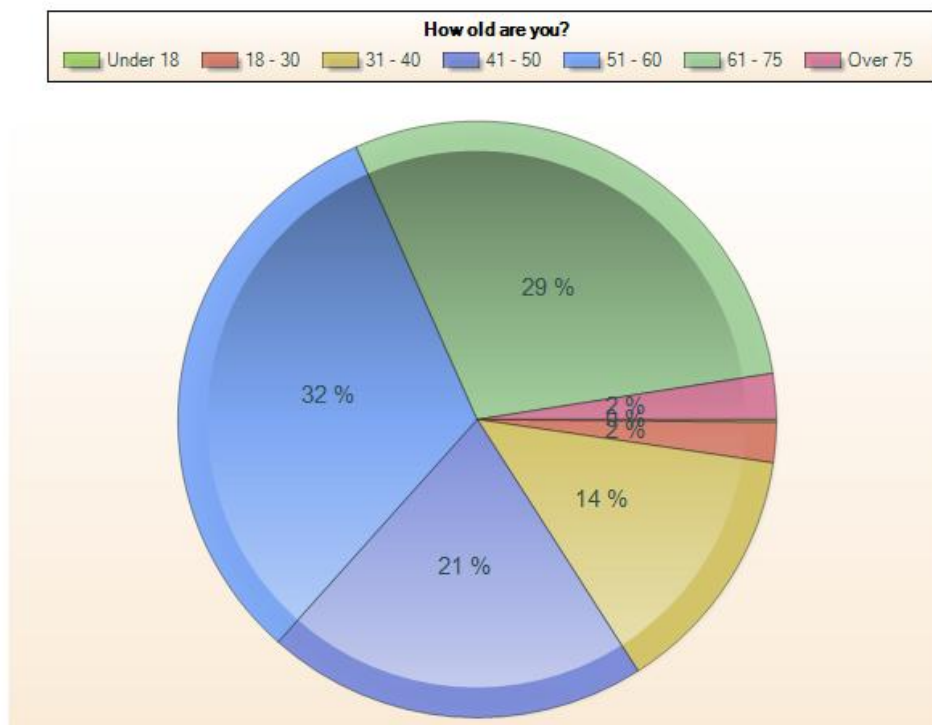


Figure C-2. Age Range

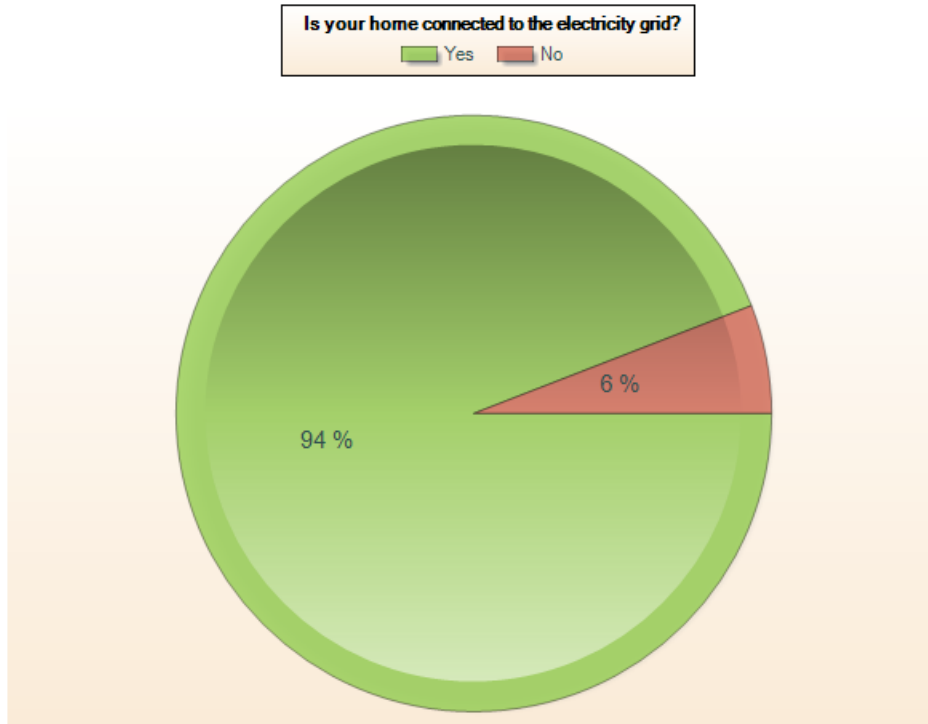


Figure C-3. On or Off Grid Connected

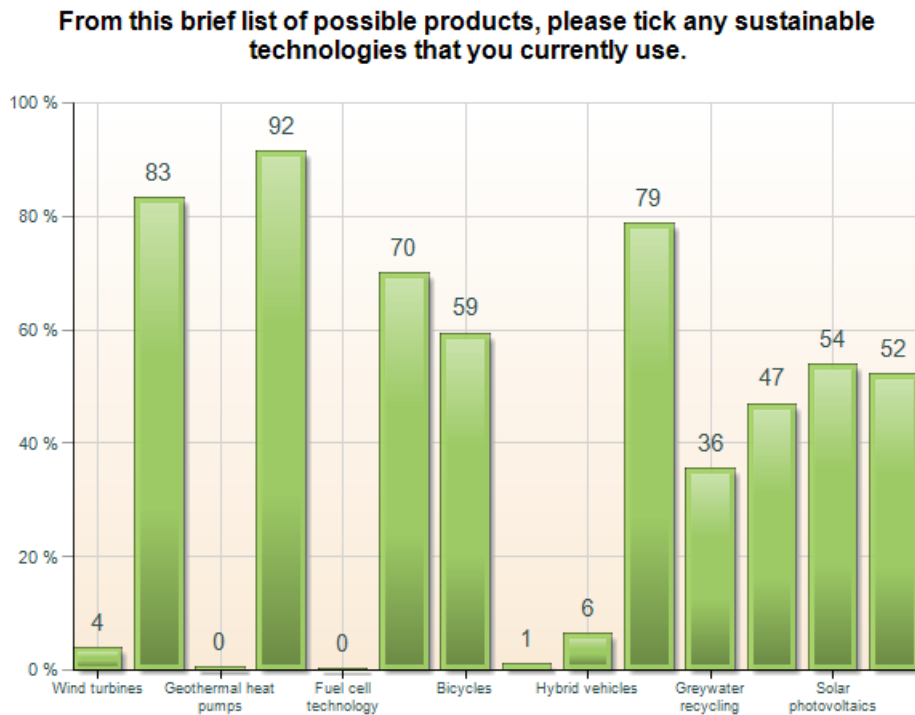


Figure C-4. Implemented Technologies



Please rank the following motivations in order of importance when you choose to purchase sustainable technology (1 = most important, 5 = least important). Please use each number only once.

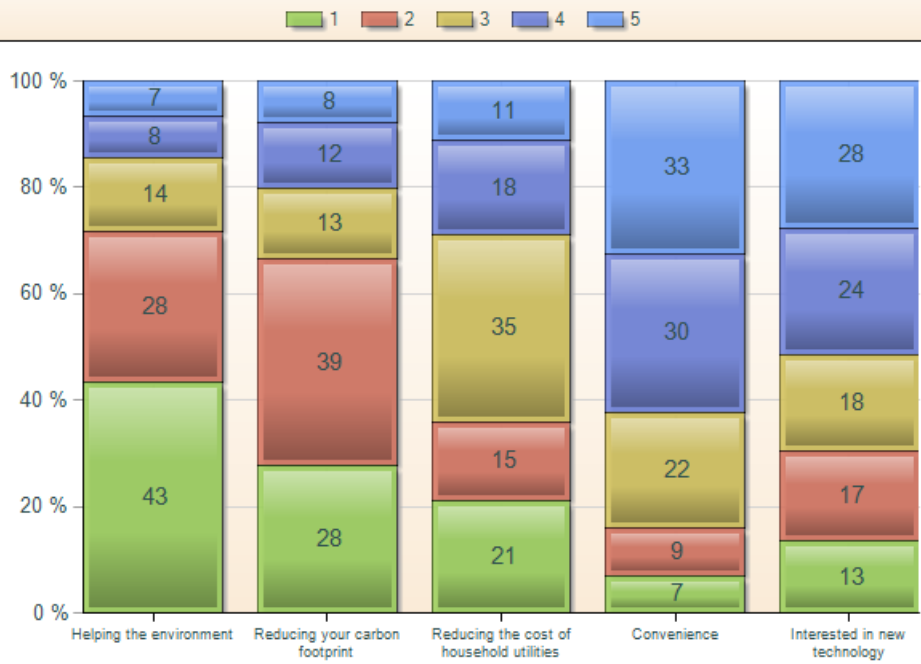


Figure C-5. Product Features

Please rank the following in order of importance when you consider purchasing a product that uses sustainable technology (1 = most important, 4 = least important). Please use each number only once.

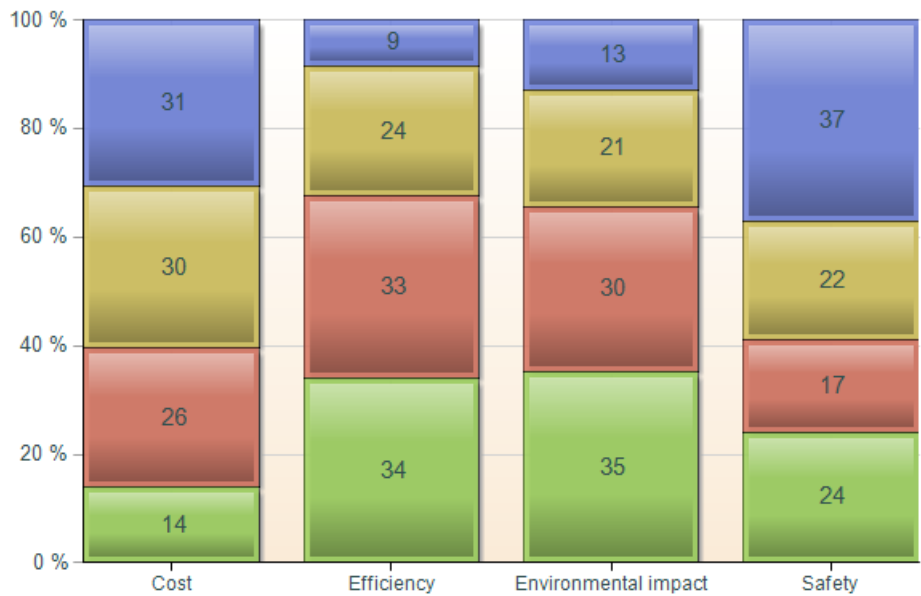


Figure C-6. Purchasing Motivations

Please rank the following in order of importance when considering the cost of sustainable technology (1 = most important, 3 = least important). Please use each number only once.

1 2 3

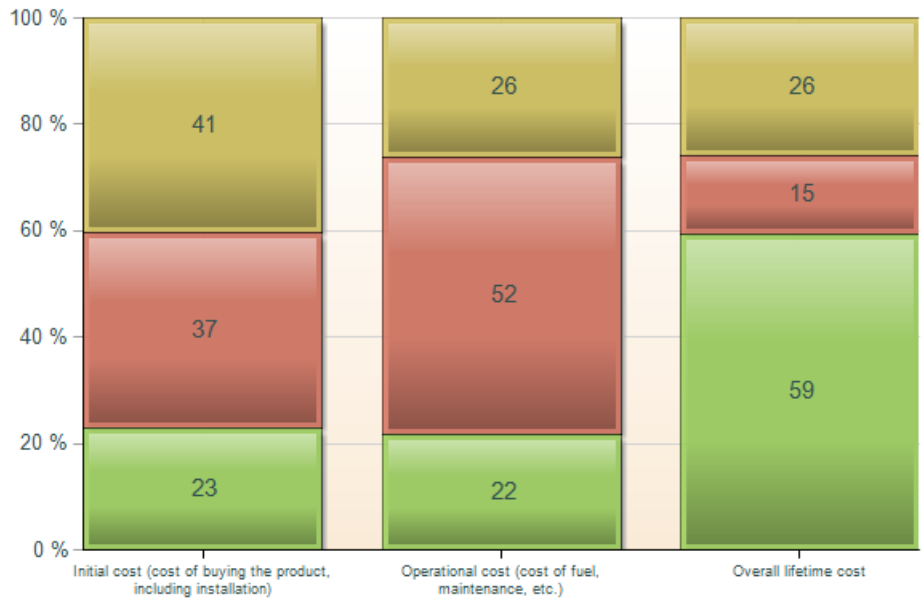


Figure C-7. Product Expenditure

How would you rate your familiarity with fuel cell technology?

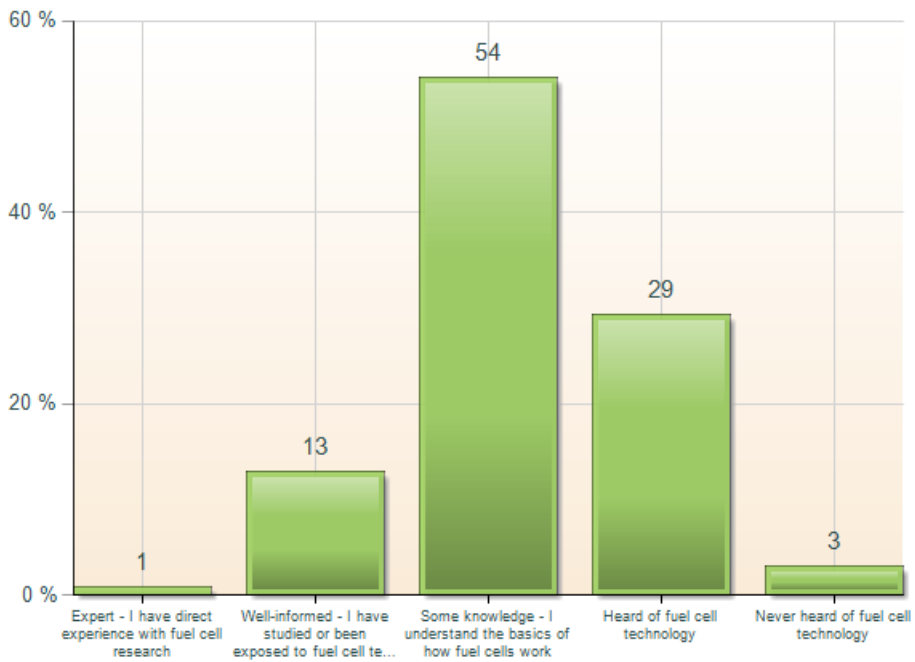


Figure C-8. Familiarity Rating

**Which application are you most interested in for fuel cell technology?  
Assume that these devices would use some form of portable fuel, such as hydrogen, which you would occasionally refill.**

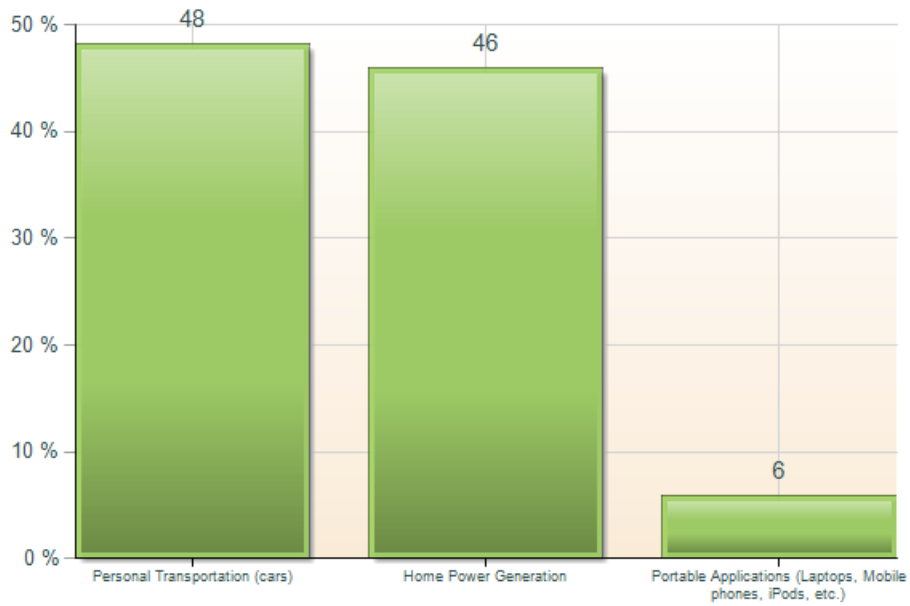


Figure C-9. Interest in Application

**How much extra would you be willing to pay per month for electricity if it were generated by a more sustainable energy source such as a fuel cell?  
The electricity generated would have greatly reduced carbon emissions and in turn leave a small carbon footprint.**

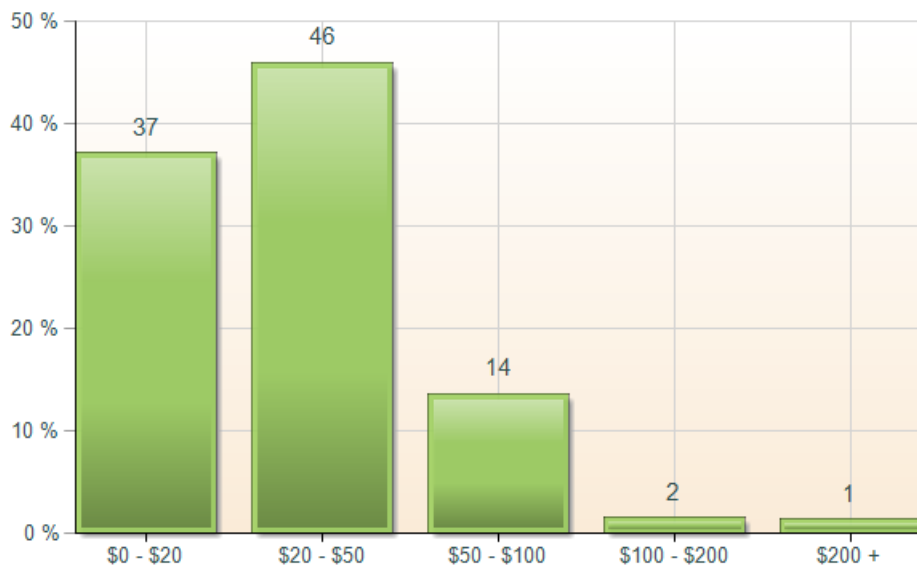


Figure C-10. Electricity Payment

**How much extra would you be willing to pay for small fuel cell powered home appliances? This would include mobile phones and portable music players. The devices would need to be recharged with hydrogen. Assume that recharging would be simple and relatively inexpensive.**

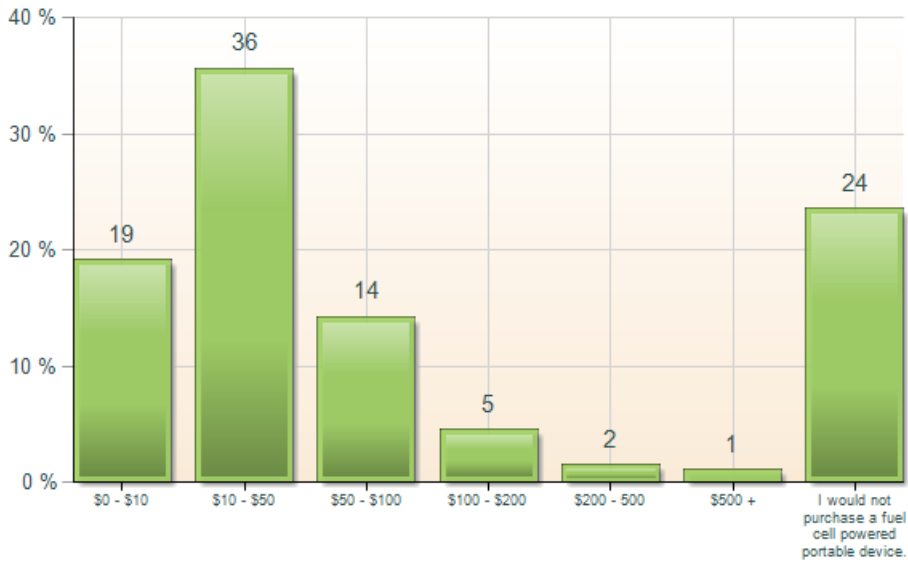


Figure C-11. Cost for Home Appliance

**How much extra would you be willing to pay for a fuel cell powered car? Imagine that the car would be run entirely by the fuel cell with many fueling stations nationwide similar to petrol stations.**

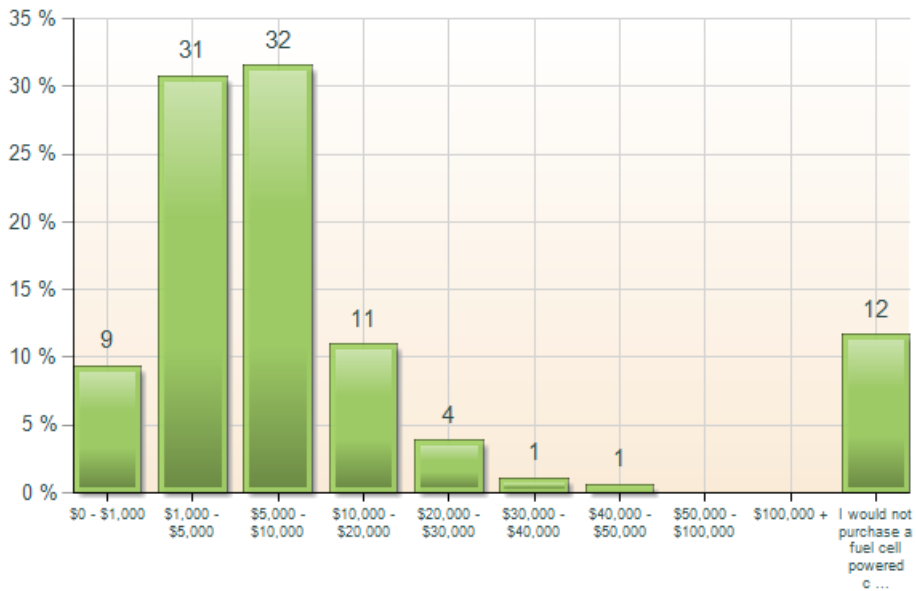


Figure C-12. Cost for Fuel Cell Car

**How much extra would you be willing to pay for a fuel cell powered laptop computer? The computer would need to be occasionally refueled with portable fuel canisters.**

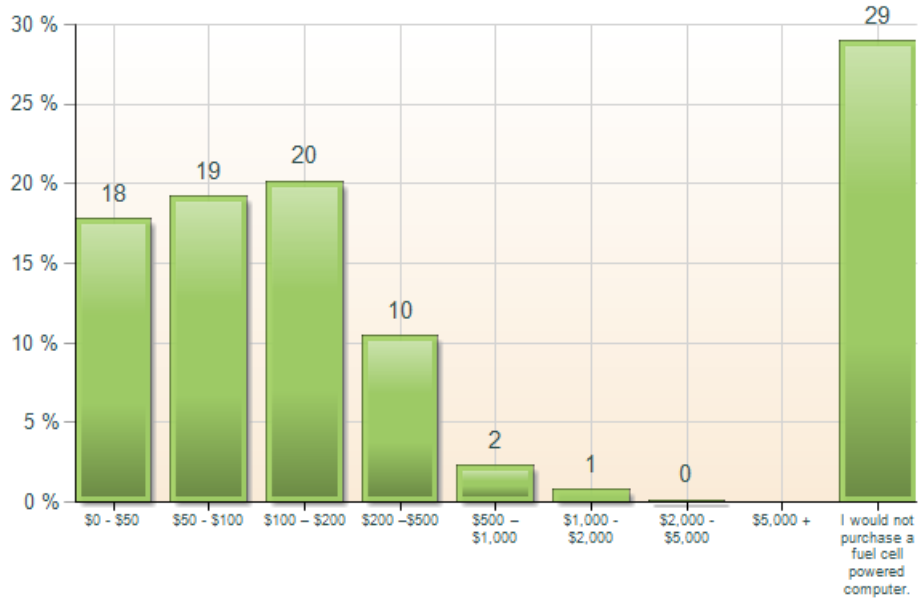


Figure C-13. Fuel Cell Computer

**How much altogether would you be willing to pay for a fuel cell powered home generator? The generator would be used to completely power your residence and take you off the electrical grid.**

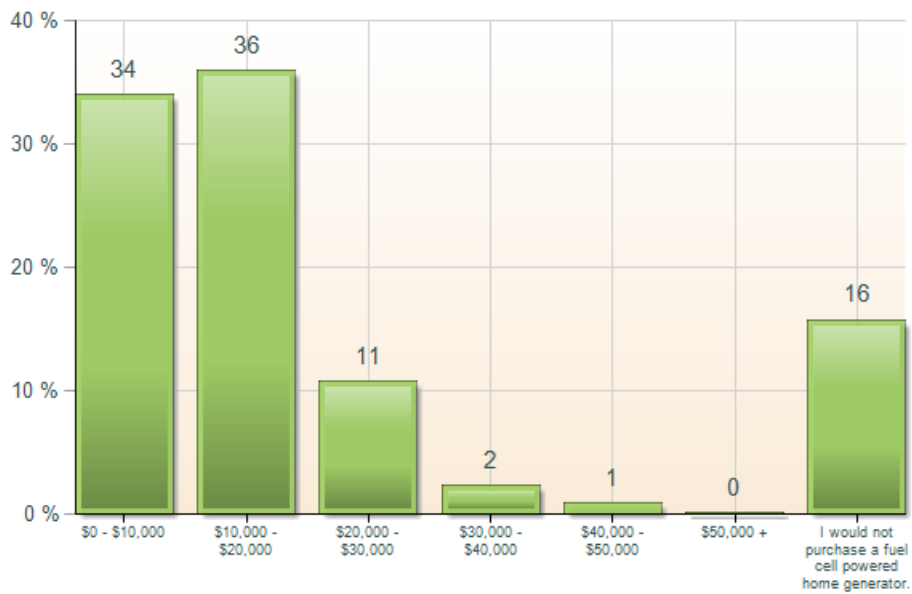
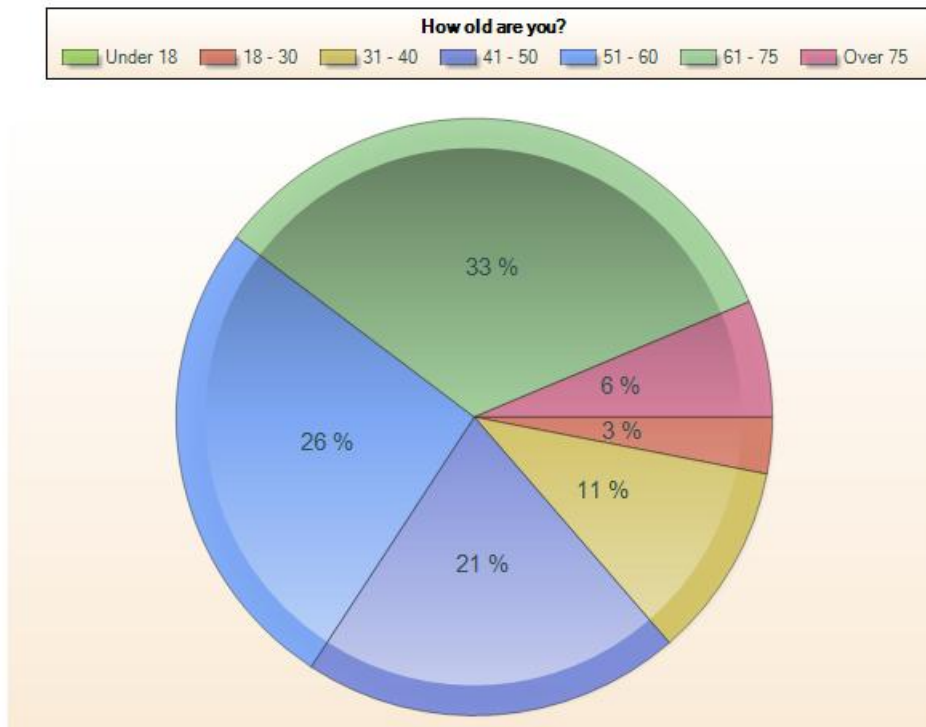


Figure C-14. Fuel Cell Home Generator

# Appendix D: CFCL Survey Results

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D-1. Type of Residency

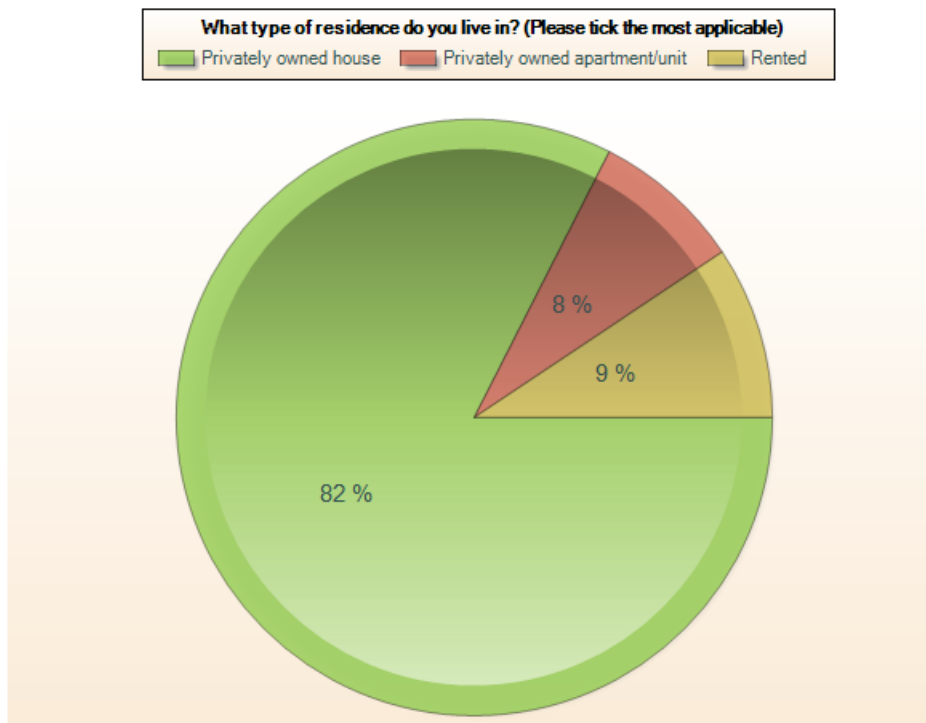


Figure D-2. Age Range

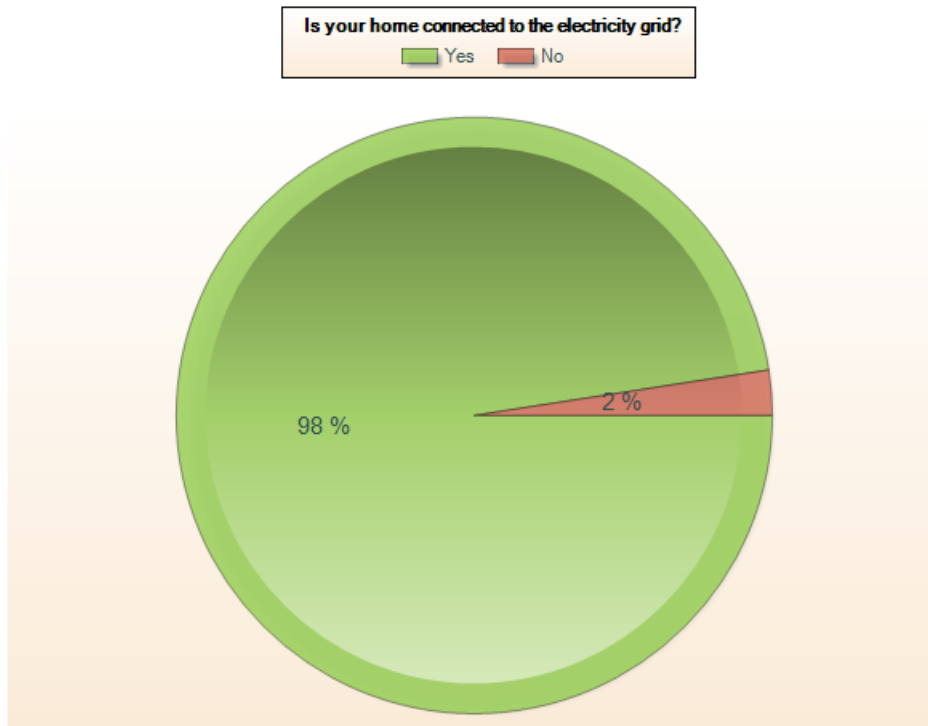


Figure D-3. On or Off Grid Connected

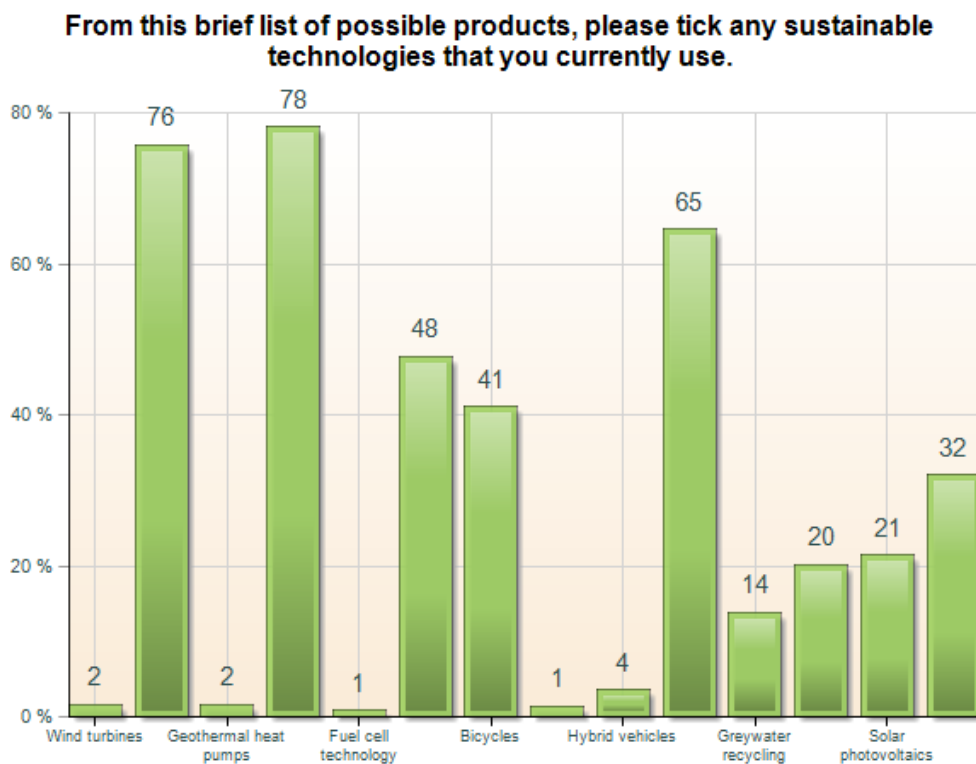
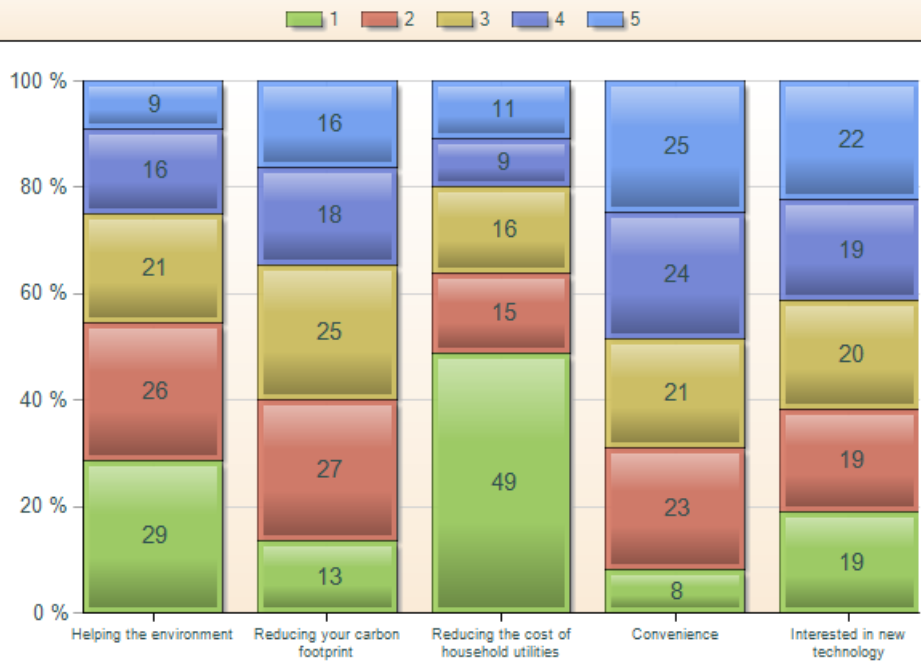


Figure D-4. Implemented Technologies

Please rank the following motivations in order of importance when you choose to purchase sustainable technology (1 = most important, 5 = least important). Please use each number only once.



FigureD-5. Product Features

Please rank the following in order of importance when you consider purchasing a product that uses sustainable technology (1 = most important, 4 = least important). Please use each number only once.

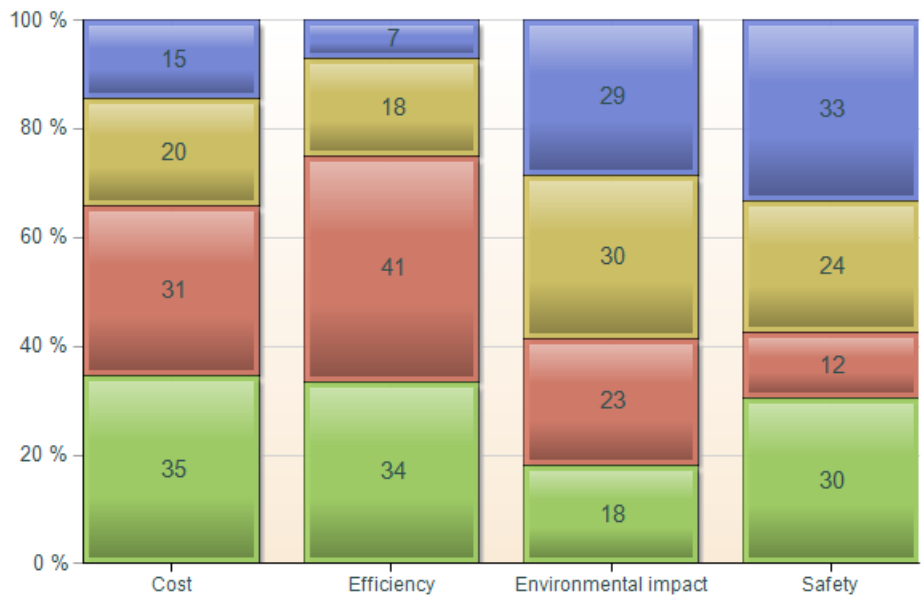


Figure D-6. Purchasing Motivations



Please rank the following in order of importance when considering the cost of sustainable technology (1 = most important, 3 = least important). Please use each number only once.

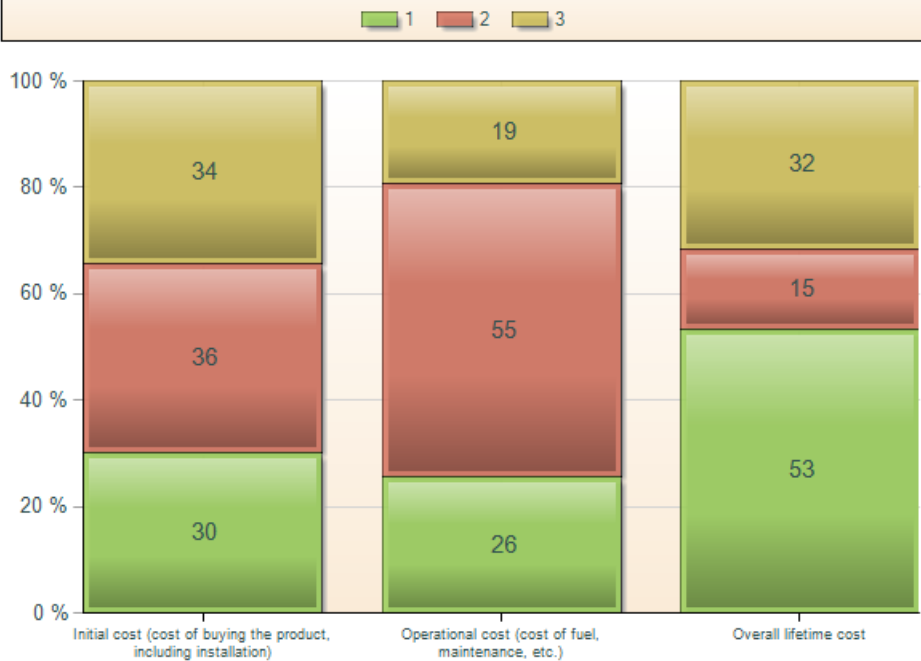


Figure D-7. Product Expenditure

How would you rate your familiarity with fuel cell technology?

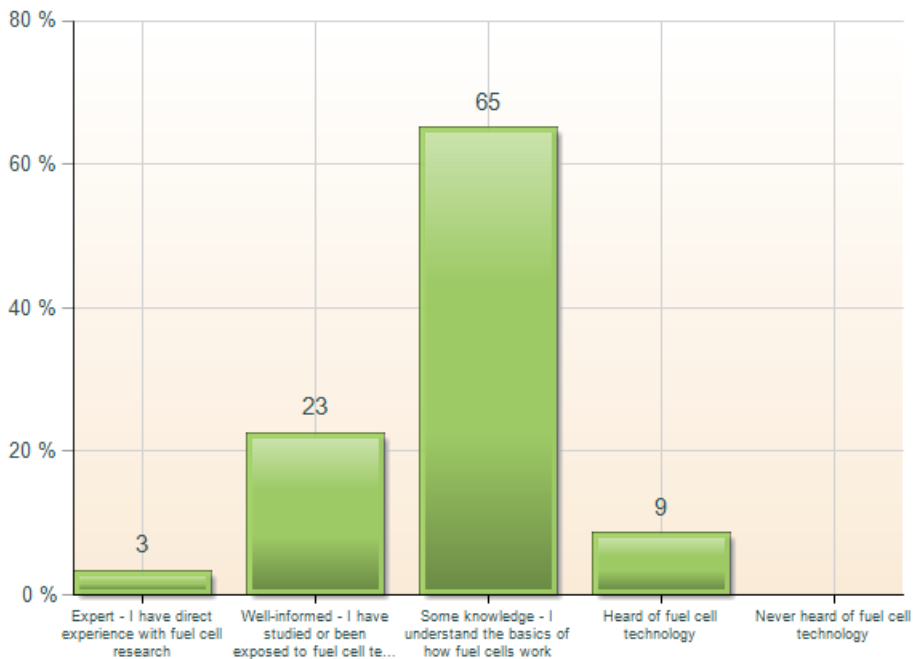


Figure D-8. Familiarity Rating

**Which application are you most interested in for fuel cell technology?  
Assume that these devices would use some form of portable fuel, such as hydrogen, which you would occasionally refill.**

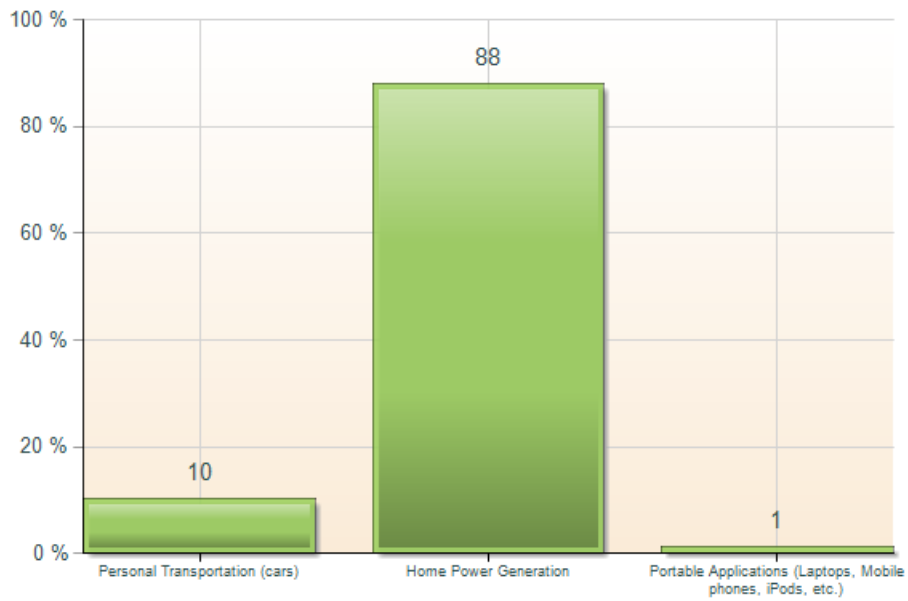


Figure D-9. Interest in Application

**How much extra would you be willing to pay per month for electricity if it were generated by a more sustainable energy source such as a fuel cell?  
The electricity generated would have greatly reduced carbon emissions and in turn leave a small carbon footprint.**

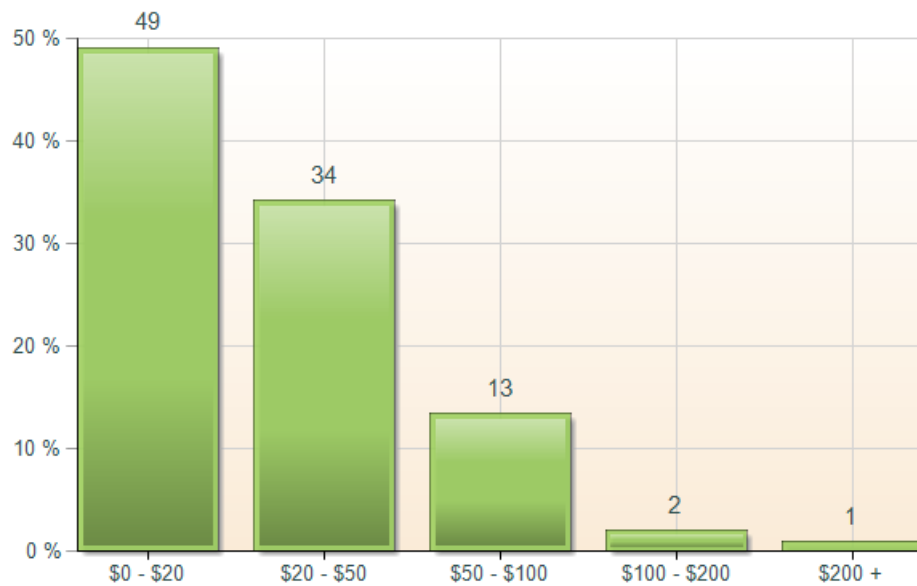


Figure D-10. Electricity Payment

**How much extra would you be willing to pay for small fuel cell powered home appliances? This would include mobile phones and portable music players. The devices would need to be recharged with hydrogen. Assume that recharging would be simple and relatively inexpensive.**

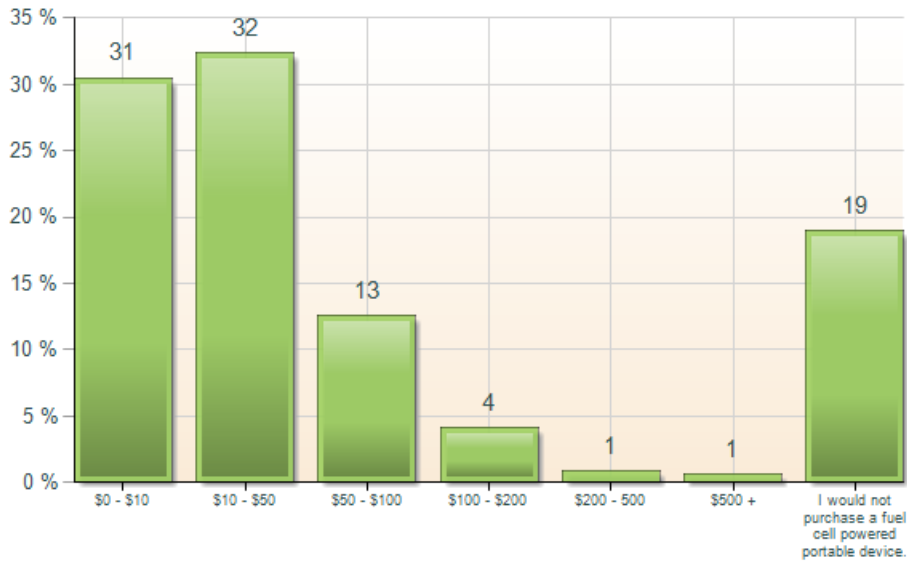


Figure D-11. Cost for Home Appliance

**How much extra would you be willing to pay for a fuel cell powered car? Imagine that the car would be run entirely by the fuel cell with many fueling stations nationwide similar to petrol stations.**

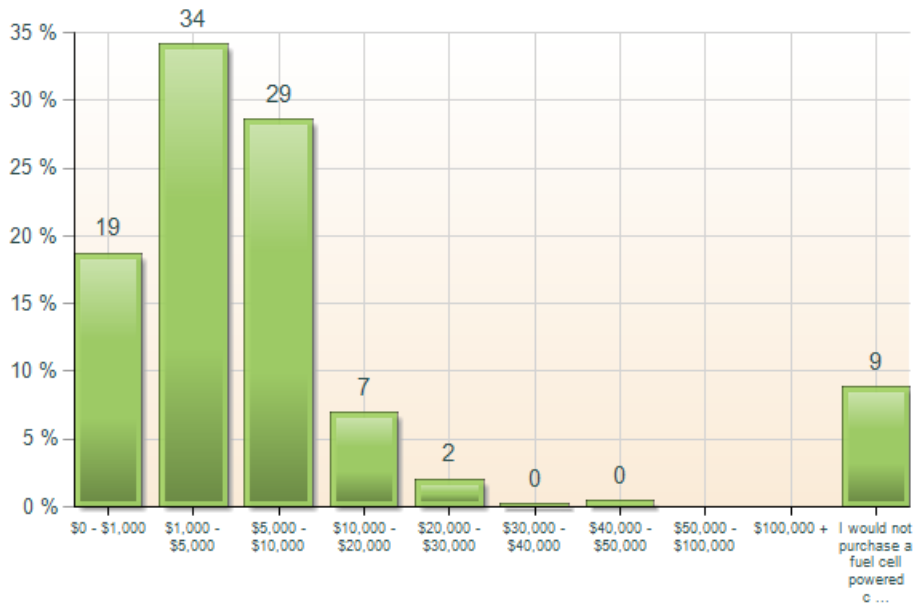


Figure D-12. Cost for Fuel Cell Car

**How much extra would you be willing to pay for a fuel cell powered laptop computer? The computer would need to be occasionally refueled with portable fuel canisters.**

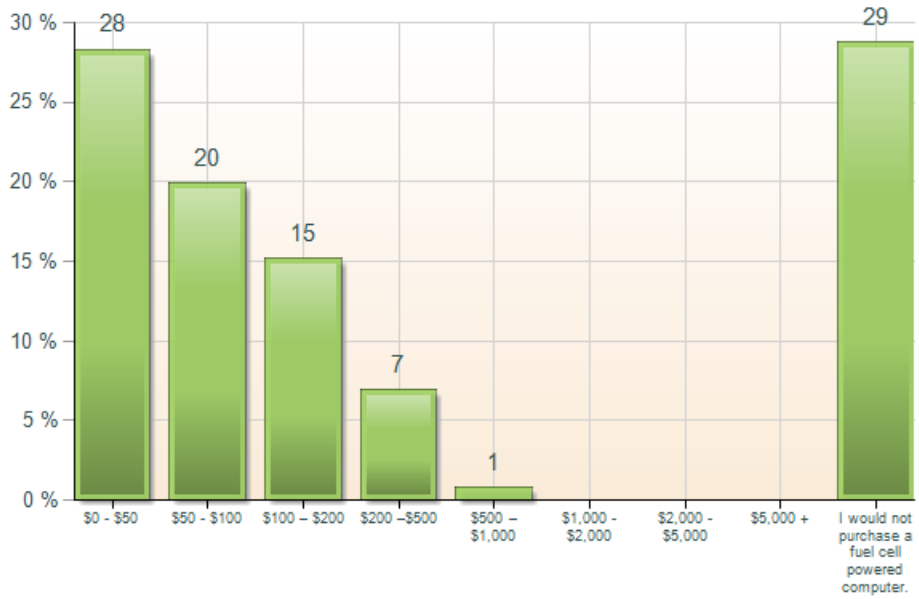


Figure D-13. Fuel Cell Computer

**How much altogether would you be willing to pay for a fuel cell powered home generator? The generator would be used to completely power your residence and take you off the electrical grid.**

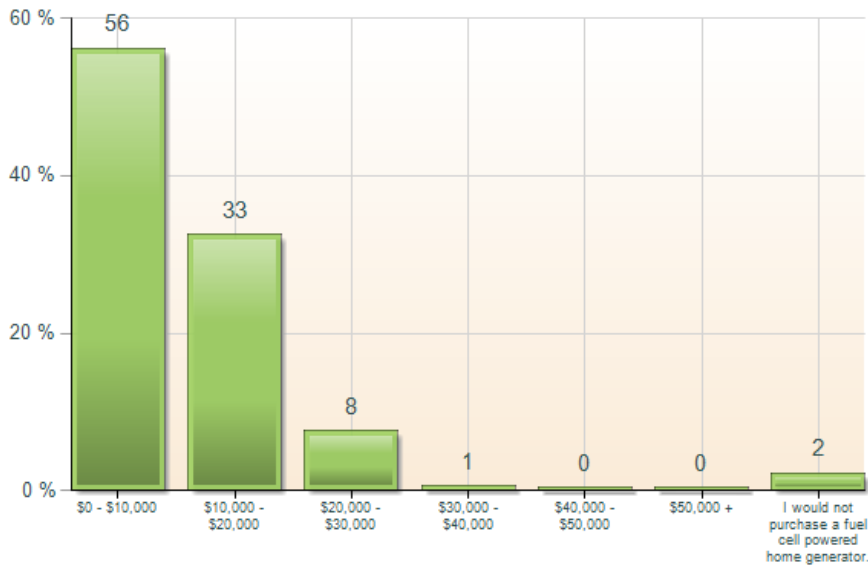


Figure D-14. Fuel Cell Home Generator

# Appendix E: Significant Comments

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1. Will fuel cells attract the feed in tariff that PV currently attracts?
2. Since I already provide my home energy needs with a small PV + wind system, this influences my responses to some of your questions. The cost of PV panels seems to be halving every 3 or 4 years so this makes PV more and more attractive. However access energy from PVs may one day go into generating hydrogen for personal fuel cell recharge.
3. Would use fuel cell mainly to run air conditioning for small area of the house, if our PV system could not keep up.
4. Blue Gen Fuel cells are available now for approximately \$50,000. They are designed to return power to the grid and run on Natural Gas. Their heat output might be useful to harness in the winter but a large PV system is better value in Australia with some kind of demand management in place. Distributed power is a good idea though to avoid transmission losses.
5. Currently have 2 KW grid connected PV @ home. Heat with wood, hot water/cook with gas. Diesel vehicles are hybrid diesel / LPG. Project to convert one to vege oil - have 4,000 liters stored. Don't need a fuel cell yet . . .
6. As I'm renting, it seems unlikely that it be easy for me to use this technology, hence my leaving some sections blank. I know more about PV panels and think it more practical at this stage to consider portable PV panels in my situation than fuel cells, but don't know enough. I do not own a car, or a 'personal player' or a laptop - I use a desktop computer and appliances at home. Hope that makes sense of my answers to your survey.
7. Have solar pv electrics so no need for fuel cells. A lot of questions meaningless because it really comes down to overall environmental efficiency and the cost over the life of the device.
8. I currently have a solar pv system providing all my good power so no need for fuel cell there.
9. I would not buy a fuel cell fuelled appliance as I can recharge batteries during the day with my household PV installation. Similarly, I get 4.5L/100km with my 100 year old diesel technology. The fuel cell only becomes attractive if it is better than my 4.2kW PV/battery system for peak power output and lifetime cost.

10. the survey was well designed. However, domestic fuel cell power plants are pretty low on my priority list right now, having just committed to a \$6000 PV system for our home.
11. I would not be willing to pay extra for fuel cell generated power because I currently buy renewable electricity (GreenPower) and have grid-connected PV panels. Using a natural gas powered fuel cell for my electricity would increase my carbon emissions. Using renewables to make hydrogen to then make electricity in a fuel cell introduces a lot of inefficiencies such that it is best to use the original renewable energy directly. Where I can see an application for fuel cells is for long-range electric vehicles, until battery technology improves dramatically anyway.
12. as our house is at least 50%+ self-sufficient, i am not interested in spending more on another technology. If anything, I would add to my pv system. Very interested in an electric car(plug in charge) supported by fuel cell engine as backup to charge batteries on the go.
13. Much of my domestic power needs are met by PV, so I would not be considering purchasing a fuel-cell to provide the (small) extra amount required. I do not want to go off the grid; I live in the city and export power to it. However, if I had no PV installed, and a fuel-cell generator was price competitive with a 'house sized' PV system over time, I would certainly consider one.
14. Not interested in home fuel cells b/c my PV system provides all required electricity to power home appliances; if PV wasn't practical I'd consider a fuel cell, but only if similar pay-back to PV.

# Appendix F: Fuel Cell Technology

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## **Alkaline Fuel Cell (AFC)**

The Alkaline Fuel Cell is one of the oldest types of fuel cells. The AFC was first utilised industrially in a space exploration program and continues to be utilised by NASA's shuttle program. When operated at temperatures below 100 degrees Celsius, the AFC has recorded efficiencies around 60%. When allowed to operate at a higher temperature, such as in the space exploration programs, the fuel cell is able to reach efficiencies close to 75%. Although this fuel cell showed incredible promise with commercial applications, there is hardly any research currently being done with the AFC. The reason for this lack of research is the infamous "carbon dioxide" syndrome. More specifically, for the AFC to operate at any capacity, pure hydrogen and pure oxygen must be fed to the fuel cell. There is absolutely no tolerance for any carbon dioxide in the system. Any such infiltration would cause a failure in the cell. Because of the extreme measures that need to be taken to remove the carbon from the oxygen there is very little promise for present applicability of the AFC. This will continue to be the case until there is an economical method of ridding the oxygen of all carbon dioxide (Principles of Fuel Cells, 2006).

## **Phosphoric Acid Fuel Cell (PAFC)**

Often regarded as the most complex fuel cell, the phosphoric acid fuel cell was developed as a way to utilise the technology from the AFC without having a zero tolerance for carbon dioxide. The result of this compromise was a bigger, more expensive and less efficient fuel cell. Although this fuel cell is commercially available as a power source ranging around 200 kW, the actual commercial viability is very low. Although the PAFC is able to tolerate high amounts of carbon dioxide, The PAFC is quite expensive, as well as very inefficient. Because of the slow rate of oxidation in the cell, efficiencies peak around 45% at best. For there to be any future application with the PAFC, a much less expensive material must be used (Principles of Fuel Cells, 2006).

## **Polymer Electrolyte Membrane Fuel Cell (PEMFC)**

Polymer electrolyte membrane fuel cells have been gaining popularity in the science community due to their increasing promise for commercial applicability. The solid electrolyte substance in the centre of the device sets the PEMFC apart from its peers. Unlike most fuel

cells, which have a liquid electrolyte, the PEMFC's use of a solid allows for greater portability. This characteristic makes the PEMFC the fuel cell with the greatest potential for transportation applications. Furthermore, the incredibly small size of the fuel cell is allowing scientists to implement it in portable devices such as cell phones, computers, etc. Operating at around 200 degrees Celsius, the biggest disadvantage of a PEMFC is the cost. The cell utilises platinum, one of the most expensive metals on the planet. Similarly to the PAFC, if there is to be any future commercial application the PEMFC would need to implement a cheaper material (Principles of Fuel Cells, 2006).

## **Molten Carbonate Fuel Cell (MCFC)**

What was thought by some to be the second-generation fuel cell, the molten carbonate fuel cell has yet to make any commercial or industrial appearances. Still in its stages of research and development, the MCFC operates at around 650 degrees Celsius. The efficiency is recorded to be around 52%. While this fuel cell is considered to be a high temperature fuel cell, the MCFC operates at a far lower temperature than its counterpart (the SOFC). Once again, this cell is currently too expensive to be practical for commercial applications (Principles of Fuel Cells, 2006)

## **Solid Oxide Fuel Cell (SOFC)**

Operating at the highest temperature (around 1000 degrees Celsius) the SOFC is commonly thought to be the best choice when using coal as a fuel. In reality, however, it is far more likely that natural gas will be the source of fuel for the cell. One of the great advantages of operating at a high temperature is the increased efficiency, around 70%. Although efficient, portable and effective, the fuel cell is relatively inapplicable due to the high temperatures. There has been much research conducted on how to lower the operating temperature, but so far there is little promise for any commercial use (Principles of Fuel Cells, 2006).

## **Direct Methanol Fuel Cell (DMFC)**

The sixth type, and currently the most researched fuel cell, is the direct methanol fuel cell. This cell is a hybrid of the other cells. The general premise is that a methanol off-stream from other fuel cells or discharging units (exhaust from a car) is what is used to fuel the DMFC. Considerable research has gone into implementing a type of hybrid fuel cells in vehicles. Unfortunately, for any further implementation to occur, there must be a way to store



the hydrogen in a safe and efficient manner. At the present time, because of hydrogen storage, the units are either too heavy or too large to be implemented in any commercial transportation machine (Principles of Fuel Cells, 2006).

# Appendix G: Sample Interview Questions

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## **For Technical Experts:**

1. What are currently the most practical applications for fuel cells?
2. What is the current cost of producing a fuel cell, and how do you expect that to change in the future?
3. A source of hydrogen is critical to the use of fuel cells. What different methods exist for producing hydrogen and how viable is each one in terms of efficiency, cost, and environmental impact?
4. Would you say there are any major safety concerns with the use of fuel cells? If so, what are they?
5. Do you foresee a time when fuel cells will be widely used and if so when and in what application?

## **For ATA staff members:**

1. What measures does the Australian government currently have in place to promote the use of alternative energy technology?
2. How likely would the current government be to vote in favour of a measure that encouraged the use of such technology with tax exemptions or direct funding?
3. How might the political mood of the government change in the future, and how would that impact such a measure?
4. What are the specific advantages and disadvantages of the technology you promote?
5. How do you envision the future of Australia's energy market?
6. Specifically long-term, over the next several hundred years?
7. Do you think that fuel cells will ever have a significant place in the energy market?
8. Why, or why not?

# Appendix H: Calculations

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## Weighted Averages

When we analysed certain questions in our survey, we found that in order to convey a clear message a weighted average would be necessary. The questions that we performed this calculation on were specifically questions concerning an individual's ranking priority. This weighted average depended on the number of choices the participant was given. For example if the respondent had a total of 5 choices to rank, the weighted average had a maximum value of 5 and a minimum value of 1.

In order to calculate this average we took the percentage of each choice for each ranking. With this percentage we multiplied that number by a specific weight. The value of the weight was dependent on the number of choices. Please refer to the example below for the exact formula.

For this example the participant was asked to rank their favourite from a list of three options. Their choices were either A, B or C. They had the option to rank each letter with either a 1 (favourite), 2 (middle) or 3 (least favourite). We will specifically look at the calculation method for ascertaining the weight percentage for letter A. In our example, 50% said A was their favourite (1), 30% said that A was their second favourite (2) and 20 per cent said that A was their least favourite (3). We gave the favourite rank a weight of 3, due to three total choices, the middle rank a weight of 2 and the least favourite rank a weight of one. The calculation for the weighted average then becomes:

$$0.50 * 3 + 0.30 * 2 + 0.20 * 1 = 1.5 + 0.6 + 0.2 = \mathbf{2.3}$$

The weighted average for the sample's opinion for the letter A is a 2.3 out of a possible 3. We repeated this calculation for all choices for each of the questions.

# Appendix I: Economic Data

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To produce our economic predictions in section 5.1, we assumed the following data to be correct. These assumptions were based upon evidence provided either by CFCL or other reputable sources. However, as with any prediction of future events, small changes in the assumptions can produce drastic effects in the outcome of the study. For this reason, we have provided a list of all data used in these predictions, so that the reader can make his or her own judgement on whether this study is applicable to a particular situation.

## Assumptions for Figure 24.

<b>Name</b>	<b>Value</b>
Electricity Maintenance Charge (\$/year)	200
House Consumption of Energy (kWh/day)	18
Increase of Electricity cost (%/year)	5%
Cost of Electricity (\$/kWh)	0.17

## Assumptions for Figure 25 and 26.

<b>Name</b>	<b>Value</b>
Electricity Maintenance Charge (\$)	200
House Consumption of Energy (kWh/day)	18
Increase of Electricity cost (%/year)	5%
Cost of Electricity (\$/kWh)	0.17
Cost of CFCL Fuel Cell (\$)	25000
Government Subsidies for Fuel Cells (\$)	0
Cost of Scrubber (\$)	700

Lifetime of Scrubber (years)	2
Cost of Air Filter (\$)	300
Air Filter Lifetime (years)	1
Cost of Fuel Cell Stack Replacement (\$)	6000
Lifetime of Fuel Cell Stack (years)	3
Other Maintenance Charges (\$)	0
Frequency of Other Maintenance (years)	1
Warranty Cost (\$)	7000
Warranty Lifetime (years)	3
Length of Warranty Included with Purchase (years)	2
Change in warranty cost (%/year)	-5%
Thermal Output for heating water (W)	700
Gas Consumption (MJ/hr)	12.6
Electrical Output (kWh/day)	36
Cost of Gas (\$/MJ)	0.004121
Gas Cost Increase rate (%/year)	4%
Average Hot Water Tank Capacity (L)	200
Average Hot Water Temperature (°C)	42
Average Tap Water Temperature (°C)	9
Hot Water Gas consumption (MJ/year)	29119

NPV Discount rate (%/year)	7%
Cost of Solar PV System (\$)	6000
Cost of Installation (\$)	4000
Kwh Rating (kW)	0.075
Peak Sun hours (h/day)	4.6
Government Subsidies for Solar Panels (\$)	4000
Feed in Tariff in dollars per kWh	0.6

### **Assumptions for Figure 27.**

<b>Name</b>	<b>Value</b>
Electricity Maintenance Charge (\$/year)	200
House Consumption of Energy (kWh/day)	18
Increase of Electricity cost (%/year)	5%
Cost of Electricity (\$/kWh)	0.17
Cost of CFCL Fuel Cell(\$)	10000
Government Subsidies for Fuel Cells (\$)	3000
Cost of Scrubber (\$)	700
Lifetime of Scrubber (years)	2
Cost of Air Filter (\$)	300
Air Filter Lifetime (years)	1
Cost of Fuel Cell Stack Replacement (\$)	3800
Lifetime of Fuel Cell Stack (years)	5

Other Maintenance Charges (\$)	0
Frequency of other maintenance (years)	1
Warranty Cost (\$)	5000
Warranty Lifetime (years)	3
Length of Warranty Included with Purchase (years)	2
Change in warranty cost (%/year)	-1%
Thermal Output for hot water (W)	700
Gas Consumption (MJ/hr)	12.6
Electrical Output (kWh/day)	36
Cost of Gas (\$/MJ)	0.004121
Gas Cost Increase rate (%/year)	4%
Average Hot Water Tank Capacity (L)	200
Average Hot Water Temperature (°C)	42
Average Tap Water Temperature (°C)	9
Hot Water Gas consumption (MJ/year)	29119
NPV Discount rate (%/year)	7%
Cost of Solar PV System (\$)	6000
Cost of Installation (\$)	4000
Kwh Rating (kW)	0.075
Peak Sun hours (h/day)	4.6

Government Subsidies for Solar Panels (\$)	4000
Feed in Tariff (\$/kWh)	0.6