



Prospects for Hydrogen Fuel in the Early Future

05 March 2015

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Prospects for Hydrogen in the Early Future:

An Interactive Qualifying Project Report
submitted to the Faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
in cooperation with
Callaghan Innovation
Submitted on March 6, 2015

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This report represents the work of four WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review. For more information about the projects, please see <http://www.wpi.edu/Academics/Project>

Abstract

This study explores the perception of renewable energy and hydrogen energy by the public and off-grid energy users to determine where and how HyLink™ might be adopted. HyLink™ is a prototype technology that uses electricity to make hydrogen gas from water. To date, user motivations for installing hydrogen power in off-grid applications has not been studied extensively. Interviews and surveys were conducted on the general public and renewable energy system (RES) owners to understand energy habits and perceptions of hydrogen energy. Due to a lack of information about HyLink™, current RES owners were unable to express a preference either for or against the technology. Our findings will assist the development of a communication strategy targeting the interested public and current RES owners.

Acknowledgements

We would like to thank the following for their support and aid to the research and success of this project:

We would like to thank our sponsors, Robert Holt and Alister Gardiner, for setting up the project and giving us this opportunity. Additionally, we would like to thank Robert for working with us during our time in New Zealand, providing direction and support for our project.

Thank you to our WPI advisors, Professor Michael Elmes and Professor Robert Hersh for their feedback on our paper as well as pushing us to make the project what we envisioned.

Additionally, we would like to thank Callaghan Innovation for sponsoring the project and providing workspace, Internet, and hot chocolate.

Finally, we would like to thank Grae and Nancy Stevens, owners of the Beaconstone Lodge, for providing contacts for our interviews

Executive Summary

New Zealand is attempting to focus its energy production on clean, environmentally friendly electricity. The government has expressed a goal of having 90% renewably produced electricity while meeting other environmental standards. With the push towards clean energy, advances in renewably produced fuels are needed to complement the overarching goal to go green. In the typical New Zealand home, 70% of energy demand comes from heating and cooking, much of which is not satisfied by electricity. Fuels such as LPG, diesel, oil, and wood are used to fill the heating requirements of homes. In New Zealand, LPG is a common fuel for home cooking and heating, particularly amongst current renewable energy system (RES) owners. While LPG may have a smaller carbon footprint than other petroleum products, there are cleaner options available that are also renewable.

Hydrogen is a cleanly burning fuel that can be produced renewably from water. Hydrogen gas can be used in similar ways as LPG. The fuel can be used for cooking, water heating, and space heating. The only byproduct of hydrogen fuel is water, so when it is produced renewably, it is significantly better for the environment than fossil fuels. HyLink™, which is the focus of this study, is a system that converts water into hydrogen gas and stores it underground at a low pressure. The gas is then used as necessary in the home. The system is intended for off-grid homes that currently have renewable energy systems, such as solar panels or wind turbines.

Homes with an RES generally produce electricity intermittently. Solar panels work best when the sun is bright, while wind turbines work best in strong winds. Sometimes the electricity production does not meet the demand, while other times it exceeds the required production. HyLink™ is particularly useful in the off-grid application when there is excess electricity being produced. Instead of underutilizing the remaining resources from the day, the excess electricity can be used to convert water into hydrogen gas to be used at a later time.

A prototype HyLink™ system is located on Matiu/Somes Island in the Wellington Harbor. The current strategy of communicating the functionality and benefits of the system is limited to a display board at the site, which contains an infographic of the process as well as a description of hydrogen energy and the HyLink™ system. Matiu/Somes Island is a good fit for HyLink™ because it utilizes and off-grid RES that requires energy storage. However, the island

remains accessible to the Wellington area and attracts about twenty thousand visitors a year, many of whom are not aware of the system.

The goal of the project is to understand how to better inform the public about the function and benefits of the HyLink™ system and develop a means of communicating information about the technology to interested individuals. We established three objectives to reach this goal: (1) Determine the public perception of renewable energy and hydrogen as a fuel, (2) Understand the typical energy usage of off-grid users and their perception and motivations for hydrogen energy, and (3) Establish guidelines for an effective communication strategy for HyLink™, and implement these into a website to deliver information about hydrogen energy.

For Objective 1, we administered 71 surveys of the general public in Wellington. A convenience sample was used to understand the public perception of both renewable energy and hydrogen fuel.

For Objective 2, we interviewed and surveyed 10 current off-grid homeowners with open-ended questions. The idea of these conversations was to understand their motivations for going off-grid and to learn more about their energy usage needs. In particular, we were interested in whether they use LPG and if so, how much. We also assessed their perception of hydrogen energy to get an idea of how RES owners feel about utilizing a technology such as HyLink™.

For Objective 3, we used information from the public surveys and off-grid surveys/interviews to develop a communication strategy. This strategy was demonstrated in the form of a website. Additionally, we developed tools to provide an easy way to determine if HyLink™ can be a viable supplement to their system. This material was analyzed with the information from an interview with Robert Holt of Callaghan Innovation, who provided insight on what they want to communicate about HyLink™.

From our first two objectives, we have developed the following findings:

- New Zealanders believe that the development and utilization of renewable energy technology is important.
- New Zealanders accurately recognize that thermal energy (for cooking and heating) constitutes the largest percentage of their energy usage (about 70%).
- Most current RES owners use LPG in their homes, with the primary usage coming from cooking.
- People have no strong opposition nor favor towards using hydrogen as a fuel and know very little about it.
- When properly confirmed by experts, respondents do not stress safety as a concern about a hydrogen-based system.
- People have many questions about hydrogen energy centered on what hydrogen fuel is and how hydrogen fuel works.
- The primary reasons for adopting renewable energy systems include economics, environmental friendliness, and independence from the grid.
- Maintenance and reliability issues are current shortcomings of renewable energy systems.

These findings served to inform our third objective: to propose a communication strategy consisting of a series of communication recommendations for educating people on the HyLink™ system as effectively as possible. The first of these recommendations was to limit the discussion of the importance of renewable energy when educating people about HyLink™. As discussed in Finding 1, people understand the importance of renewable energy therefore arguing this point is not a necessary step in educating people about HyLink™. Instead, associating HyLink™ with renewable energy as a means of providing a familiar context for the system will be beneficial to communication efforts.

The next recommendation for communicating the advantages of HyLink™ was to prioritize a discussion about how hydrogen can be used as a fuel. Finding 4 shows that people admittedly know very little about hydrogen fuel and as a result do not hold an opinion about how suitable hydrogen is for use in a home; by providing them with information about hydrogen, we can fill this gap in knowledge and allow people to understand how they could use HyLink™.

We also suggest a significant emphasis on the ability of HyLink™ to displace LPG usage. Finding 3 explains that a majority of RES owners use LPG for cooking or heating in their home; for this reason we suggest a focus is put on the ability to displace LPG consumption with HyLink™. Finally, we advise conducting an appropriate hydrogen safety discussion. Finding 5 suggests that there is not evidence of significant preexisting oppositions to hydrogen fuel; however, hydrogen, like all fuels has some risks and dangers associated with using it. For this reason, we suggest communicating the safety procedures and regulations it fulfills, but there is not evidence of a substantial resistance to hydrogen fuel that needs to be overcome.

With these guidelines in mind, we developed a way of framing HyLink™ following Sinek's Golden Circle communication concept, which proposes that the discussion about a product starts with explaining 'why' there is a need for it, followed by 'how' it is done, and concluding with 'what' the system is. This framing is summarized below:

“When excess energy goes unused, we can be doing more by building an eco-friendly, sustainable method of independence from fossil fuels through clean, renewably produced hydrogen gas with a technology called HyLink™.”

We implemented this framing into a website and validated its effectiveness through two discussions with focus groups. The participants responded favorably to this communication strategy. Consequently, we believe that we have validated our communication recommendations as demonstrated on the website.

Based on our conversations with RES owners, we developed a list of renewable energy system and HyLink™ interest factors. We gathered the major themes that were presented in the conversations from RES owners and developed a list of criteria that would make HyLink™ appealing. Finding 7 shows that HyLink™ should be cost competitive and provide an increase in environmental benefits over the system it would replace. It also suggests it should contribute to the users' independence from external energy dependencies. Finding 8 suggests that the system's ease of maintenance and reliability would be a substantial factor in someone's decision to install the system, leading us to conclude that if HyLink™ were easier to maintain than other systems, it would be desirable. Ultimately, if HyLink™ is able to become an affordable alternative fuel system, with minimal detractions from a user's independence, while maintaining a strong

environmentally friendly image, HyLink™ will certainly have installation interest from potential users and investors.

Authorship

Christopher was the primary author of the abstract and executive summary, as well as a main contributor to the methodology. Christopher also conducted the interviews in collaboration with Nathan. Matthew was the primary author of the introduction and conclusion of the paper, as well as the lead website designer. Nathan was the primary author for the background, as well as a contributor to the findings section. Lea was a primary contributor to the background, methods, and findings section. She was the secretary for the focus groups. Each section of the report was edited by each member of the group, with various contributions from the members in every section.

Table of Contents

| | |
|--|----------|
| Abstract | iii |
| Acknowledgements..... | iv |
| Executive Summary..... | v |
| • <i>New Zealanders believe that the development and utilization of renewable energy technology is important.</i> | vii |
| • <i>New Zealanders accurately recognize that thermal energy (for cooking and heating) constitutes the largest percentage of their energy usage (about 70%).</i> | vii |
| • <i>Most current RES owners use LPG in their homes, with the primary usage coming from cooking.</i> | vii |
| • <i>People have no strong opposition nor favor towards using hydrogen as a fuel and know very little about it.</i> | vii |
| • <i>When properly confirmed by experts, respondents do not stress safety as a concern about a hydrogen-based system.</i> | vii |
| • <i>People have many questions about hydrogen energy centered on what hydrogen fuel is and how hydrogen fuel works.</i> | vii |
| • <i>The primary reasons for adopting renewable energy systems include economics, environmental friendliness, and independence from the grid.</i> | vii |
| • <i>Maintenance and reliability issues are current shortcomings of renewable energy systems.</i> | vii |
| 1.0 Introduction..... | 1 |
| 2.0 Background Chapter | 3 |
| Introduction | 3 |
| 2.1 Renewable Energy Development in New Zealand..... | 3 |
| 2.2 The HyLink™ System and Its Current Application | 5 |
| 2.3 Challenges to Expand HyLink™ Technology | 7 |
| A. <i>Ensuring HyLink™ Fulfills the Motivations Associated with Installing Renewable Energy Systems</i> | 7 |
| B. <i>Meeting public expectations on safety and ease of use and improving public perception of hydrogen as a fuel.</i> | 10 |

| | |
|---|-----------|
| C. Cost Analyses for Stand-Alone Hybrid Power Systems versus Grid Connections | 14 |
| 2.4 Communicating the HyLink™ System and the Challenges | 20 |
| 3.0 Methodology | 23 |
| Objective 1: Determine the public perception of renewable energy and hydrogen fuel | 23 |
| Objective 2: Understand the typical energy usage of current standalone users and determine their perception and potential motivation for hydrogen energy..... | 23 |
| Objective 3: Establish guidelines for an effective communication strategy for HyLink™, and implement these into a website to deliver information about hydrogen energy..... | 25 |
| Determining what Callaghan Innovation intends to communicate..... | 25 |
| Developing a Website to Provide Information on Hydrogen Energy and Evaluate the Communication Strategy | 25 |
| Developing Tools to Determine if HyLink™ is a Good Fit | 26 |
| 4.0 Findings and Analysis | 27 |
| Finding 1: People think that renewable energy is important | 27 |
| Finding 2: People understand that their thermal needs are high..... | 28 |
| Finding 3: A majority of RES owners we communicated with use LPG for their household cooking..... | 29 |
| Finding 4: People have no strong opposition nor favor towards using hydrogen as a fuel and know very little about it..... | 31 |
| Finding 5: When properly confirmed by experts, respondents do not stress safety as a concern about a hydrogen-based system. | 33 |
| Finding 6: People have many questions about hydrogen energy..... | 34 |
| Finding 7: Primary reasons for adopting renewable energy systems..... | 34 |
| Finding 8: Maintenance and reliability are considerations for installing an RES | 36 |
| Conclusions and Recommendations | 37 |
| Proposed Communication Strategy for HyLink™ | 37 |
| Communication Recommendation 1: Limit Renewable Energy Discussion | 38 |
| Communication Recommendation 2: Prioritize Hydrogen Fuel Discussion | 39 |
| Communication Recommendation 3: Stress Replacing LPG with HyLink™ | 39 |
| Communication Recommendation 4: Conduct Appropriate Hydrogen Safety Discussion | 39 |
| Proposed Communication Strategy Validation: | 40 |

| | |
|--|----|
| <i>Focus Group Findings on Website Design and Function</i> | 41 |
| RES and HyLink™ Interest Factors..... | 42 |
| <i>RES Installation Criteria</i> | 42 |
| <i>Predicted HyLink™ Installation Criteria</i> | 43 |
| Additional Recommendations | 44 |
| <i>Make HyLink™ Information Accessible</i> | 44 |
| Future Research | 45 |
| Discussion | 45 |
| Appendix A: Survey on Public Perception of Renewable Energy..... | 47 |
| Appendix B: Renewable Energy System Owner Questionnaire..... | 48 |
| Appendix C: Survey Data | 49 |
| References..... | 54 |

Table of Figures

| | |
|--|----|
| <i>Figure 1 Renewable Percentage of New Zealand (Ministry of Business & Innovation & Employment, 2013)</i> | 4 |
| <i>Figure 2 Hydrogen Fuel Flow Chart 1</i> | 7 |
| <i>Figure 3 Hydrogen vs. Gasoline; 1 minute after ignition (Swain, 2001)</i> | 13 |
| <i>Figure 4 Small LPG bottle explosion (Stawczyk, 2002)</i> | 13 |
| <i>Figure 5 Callaghan Innovation Static Display for HyLink™</i> | 20 |
| <i>Figure 6 Importance of Renewable Energy</i> | 27 |
| <i>Figure 7 Reasons for installing a renewable energy system</i> | 28 |
| <i>Figure 8 Perception of Thermal Energy Usage</i> | 29 |
| <i>Figure 9 Thermal Usage Distribution</i> | 30 |
| <i>Figure 10 Suitability of Hydrogen as a Fuel</i> | 31 |
| <i>Figure 11 Self-Reported Knowledge of Hydrogen Fuel</i> | 32 |
| <i>Figure 12 Why, How, and What Strategy</i> | 37 |

1.0 Introduction

Clean, renewable energy can guarantee power for future generations while minimizing greenhouse gas emissions and reducing the dependency on external energy resources (National Renewable Energy Laboratory, 2014). To foster these economic and environmental benefits, the New Zealand government has established a goal for 90% of its electricity usage to be generated by renewable sources by the year 2025, a significant increase from its current estimate of 77% (Energy Efficient and Conservation Authority, 2014).

Even with the push for sustainability, electricity does not meet all of the energy needs of users. Many people rely on fuels to heat their homes, water heating, and cooking. With 70% of energy in New Zealand homes being directed towards heating and cooking, a more sustainable method is needed to compliment the government's renewable electricity goal. Furthermore, renewable energy systems (RES) are intermittent in their production. They can produce more electricity than the system needs or not have enough for the day's energy demand. When a system produces excess electricity, the common practice, if the system is connected to the grid, is to sell it back to the supplier. If not, the energy can be stored in batteries or simply goes unused.

Using this excess electricity to create fuel provides an efficient and effective way to utilize excess electricity while satisfying the thermal needs of a home, such as heating and cooking. The HyLink™ system, which is the focus of our project, offers this capability. This prototype takes excess electricity from a pre-existing RES, and produces hydrogen gas from water through a process called electrolysis. This hydrogen gas is kept at low pressure in pipelines underground until it is needed. Storing the system at low pressure alleviates safety risks and reduces costs compared to when hydrogen is pressurized or liquefied. Hydrogen burns cleanly, producing no CO₂, making it an environmentally friendly fuel. Many people who use an RES utilize liquefied petroleum gas (LPG) or other fuels for heating and cooking, which, unlike hydrogen, produces CO₂ ("Q&A," 2015). Hydrogen energy can replace these fuels, as well as reduce the need for excess battery storage.

In order to progress the HyLink™ prototype, our sponsor, Callaghan Innovation, would like to better understand the reasons people would or would not install the system in the home or workplace, what motivates people to install standalone renewable energy systems, and what aspects of HyLink™ are most attractive to prospective buyers. From the sponsor's perspective, communicating the advantages and details of this product effectively to the public is an important step in generating interest in the system. At the present time, the HyLink™ system is not yet at the marketing phase, and communication of the system has not started. Developing an engaging and informative way to convey technical information may generate more enthusiasm for the progressing transition towards communicating the system to interested investors and the public.

Our goals for this project include: examining the public's perception of renewable energy and hydrogen fuel, evaluating the typical motivations associated with installing a RES, and utilizing this information to discover an effective form of educating people about the principles behind HyLink™. The education material involves a website on the system, as well as initiating the integration of the website with social media to prepare for a marketing stage. The target audience for the website will be individuals that are interested in renewable energy technologies, especially current stand-alone system users.

2.0 Background Chapter

Introduction

This chapter provides an overview of renewable energy and the HyLink™ system in New Zealand. First, we consider the development and importance of renewable energy and power systems in New Zealand. Second, we explore the HyLink™ energy storage system and its current applications. Third, we investigate the challenges involved in expanding the HyLink™ technology for more widespread usage. Finally, we consider methods or strategies by which to communicate the HyLink™ system, including the challenges associated with the transmission of such information.

2.1 Renewable Energy Development in New Zealand

According to the Ministry of Business, Innovation, and Employment (MBIE), in 2012 New Zealand generated 73% of its electrical power from renewable resources, falling from 77% in 2011 due to low lake levels resulting in a reduction of hydropower. This accounts for 37% of the country's Total Primary Energy Supply (TPES). TPES is the total energy used by a country including the waste heat from power production. For instance, a power plant may generate 1 MW of electricity but use 2.5 MW worth of fuel due to inefficiencies; the total 2.5 MW is included in the TEPS. New Zealand has the third highest contribution of renewable energy to TPES in the Organization for Economic Cooperation and Development (OECD), behind Iceland and Norway. The increase in the renewable contribution over the last decade has been driven largely by a significant increase in geothermal electricity production in recent years. New Zealand's many tectonic features result in large amounts of geothermal resources. Geothermal accounted for approximately 15% of the electricity production while hydro accounted for 53%. A graph from the MBIE of the percentage of TPES by renewable energy source is shown below (Ministry of Business & Innovation & Employment, 2013).

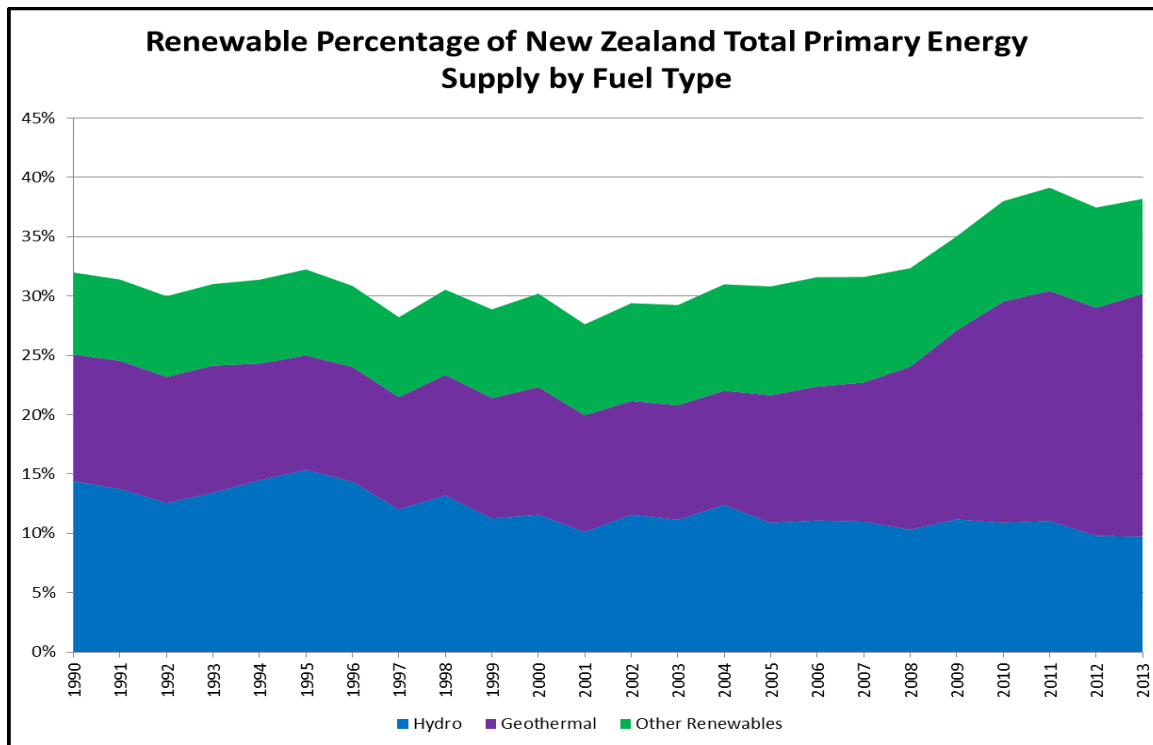


Figure 1 Renewable Percentage of New Zealand (Ministry of Business & Innovation & Employment, 2013)

The Resource Management Act 1991 (RMA) seeks to “Promote the sustainable management of natural and physical resources.” It requires local decision makers to have regard for the environment; when dealing with issues involving energy efficiency the decision makers are required to give attention to the New Zealand Energy Efficiency and Conservation Strategy (NZE ECS) prepared by the Energy Efficiency and Conservation Authority. The NZEECS has a 90% renewable electricity proportion (Energy Efficiency and Conservation Authority, 2014) among other standards and goals.

In order to work towards this goal, the contribution of other renewables will need to be increased as hydropower resources are largely exploited. New Zealand has particularly good wind resources due to its location and topography, however its current wind capacity is limited, only amounting to 2% of the relatively large renewable electricity production. (Energy in NZ 2013, Kelly) A number of proposed wind projects are progressing through a contested regulatory approval process, showing both the potential for wind production and the challenges associated with advancing the technology in New Zealand. The approval process for wind farms is long and expensive, with one project spending two years and \$120M NZD on the procedure. Factors that contribute to opposition during the approval process are landscape / construction impact and

noise. On a broad scale, wind has been shown to be competitive with other renewable generation systems such as hydro, geothermal, and solar, but its development is significantly slower, largely due to the approval process and public opposition. A potential solution to this issue is to move towards small-scale applications with 3 or fewer wind turbines. This offers the advantages of reducing the difficulties intrinsic to the approval process due to less public resistance of small-scale applications that have a smaller impact on the area. (Kelly)

Solar power in New Zealand offers less potential for large-scale power production due to less consistent sunlight compared to the rest of the world. Its growth in New Zealand has been largely supported by off-grid or standalone applications. A 2009 study indicates that large-scale solar farms will be uneconomic through the period of 2035 however small scale commercial and domestic applications will likely become economic by 2020 (Kelly). This is mainly due to the production cost of solar panels. With small-scale systems being the primary place in which wind and solar technologies will progress in New Zealand, off grid applications may become more common.

2.2 The HyLink™ System and Its Current Application

Integrating renewables into an electric system, particularly in off grid applications, generally requires the use of energy storage due to the problem of intermittency with many of these systems; the power these systems produce typically varies with time and in order to manage the more consistent energy demand requires storing excess energy and using it when power production is down (Dunn, Kamath, & Tarascon, 2011). Currently, many systems use batteries for this intermittency. However, batteries must be replaced every few years, which can be costly and inconvenient. Also, batteries cannot be left in extreme temperatures or varying conditions without lessening their working capabilities. For this reason, batteries are often a weakness of a renewable energy system.

LPG gas is another energy source that is often used alongside RESs. Many choose this form because it is known to have less greenhouse gas emissions than diesel or petrol. It is also a competitor of electricity in terms of cost ("LPG," 2015). However, this fuel does have drawbacks. When there are contaminants in the supply, it is a problem for the supplier, installer, and the consumer. There have been problems in the past in both Australia and New Zealand pertaining to contaminated gas causing system failures ("Latest News/LPG Contamination has

been an ongoing issue," 2010) . The contamination seemed to have been due to several pieces involved during the installation, and is a very costly problem to repair. With LPG, there is a chance that it can leak if the tank is not kept upright at all times. The fact that the tanks are under high-pressure means that explosions can occur if the tank is not constantly handled properly ("Safe and efficient use of LPG," 2007). Another issue is that if the tank is at temperatures that fall below freezing, low vapor pressure could cause starting failures. If there is inadequate ventilation then carbon monoxide may be created from the appliance utilizing LPG. Prices for LPG are reviewed monthly and are set internationally, rather than domestically. New Zealand has become relatively self-sufficient in terms of LPG as of 2009, yet the prices are still determined based on the international contract price. During 2008, in terms of vehicles, the price difference between petrol and LPG was an annual average of 58 cents where LPG was cheaper ("New Zealand LPG pricing,"). Another factor of the LPG price is that the international cost is set in US dollars, so the gas price is affected with the currency exchange rate. Transport costs to certain parts of the country contribute to higher LPG prices in some areas ("New Zealand LPG pricing,").

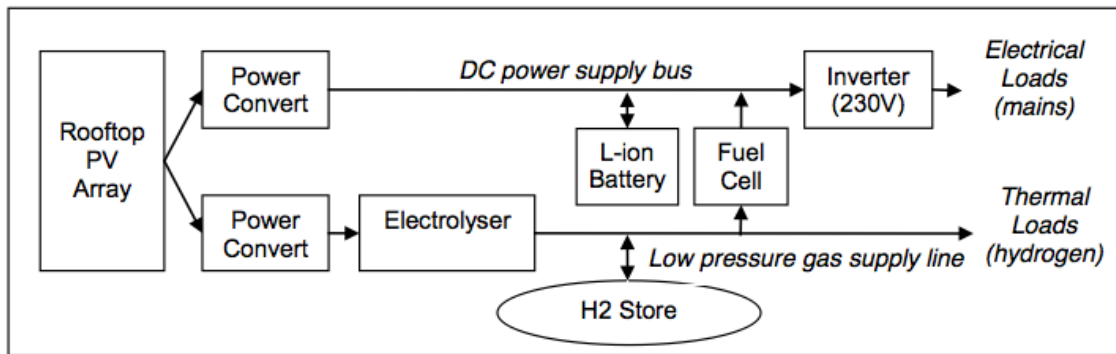


Figure 2 Hydrogen Fuel Flow Chart 1

The HyLink™ system can work to make both these current issues obsolete. The HyLink™ can be combined to work with batteries so that they do not have to be replaced so frequently. It can also replace LPG gas usage for heating and cooking in order to lessen the environmental footprint. Callaghan Innovation’s energy storage system is able to store energy by using an electrolyzer to generate hydrogen from water. The first prototype operated by producing hydrogen from a wind-electrolysis system, which was piped 2 kilometers to a farming community where it was used to provide heat and hot water. The current prototype is located on Maitu/Somes Island and provides hot water and is used for cooking on the island. The hydrogen is stored at low pressure within the piping, which mitigates risks associated with pressurized hydrogen, as well as provides a novel method of storing the gas. Due to the high cost of connecting to the grid in remote areas, utilizing a standalone energy system is often chosen as an alternative. The HyLink™ system offers a clean way to store energy from a standalone renewable energy system (Economy, 2011). The figure below illustrates the system.

2.3 Challenges to Expand HyLink™ Technology

A. Ensuring HyLink™ Fulfills the Motivations Associated with Installing Renewable Energy Systems

With Renewable Energy Systems (RES) becoming more and more mainstream, when developing a new system designed for a renewable energy application, it is important to look at what motivates people to install these systems and how your product meets these criteria.

Looking at why people invest in other renewables can help us understand what might motivate someone to invest in HyLink™. Individuals often look to install a renewable system based on how it will benefit them and sometimes in response to concerns about the environment. It may

also be independence from the grid or governmental incentives. While individuals are the ones who ultimately decide to invest in a RES, nationwide or regional factors also play a big role (Langheim, Arreola, & Reese, 2014).

While environmental considerations are important to think about, ultimately a product will only have long-term success if it makes economic sense. Studies that looked at homeowners who install RES found that generally the most important motivation for doing so was to reduce their electricity cost. A study done in California looking at people who invested in rooftop solar systems found that 74.1% of owners thought saving money on electricity was the most important factor, with 13% claiming a reduction in dependence on nonrenewable resources was most important.

Subsidies can be very effective in motivating people to use renewable resources by making expensive technologies more affordable to the consumer. These can come in the form of governmental incentives, or the manufacturer can agree to lose money on the transaction in an effort to improve interest in the system.

Governmental incentives can also have some unexpected consequences. Recently in Australia there were significant governmental incentives put in place to encourage households to install solar systems. This resulted in large amounts of rooftop solar panels being installed. Unfortunately, during peak sunlight hours there is so much electricity being produced by these panels that the power plants don't need to generate any electricity, which means the power companies aren't making any money. Because of this, the power companies have refused to buy back the excess power. Households with these systems are losing money because they aren't able to utilize the power they generate and many are searching for ways to remove themselves from the grid, which requires an energy storage device; here HyLink™ would be a good fit (Holt, 2014).

A study based in Europe sought out to find the factors driving the success stories of renewable energy. The study found that, despite the growing acceptance global warming, environmental concerns do not significantly encourage the use of RES. This supports our previous claim that while the need for renewable resources is becoming more accepted, they will only be utilized if they make financial sense. This study also found that the countries with a higher energy dependency typically have greater renewable energy development.

Complementary to this, Gross Domestic Product (GDP) was also found to have an effect on renewable development; higher GDP's give way to higher renewable development. The larger income allows countries to manage the costs associated with developing renewable technologies, including governmental policies encouraging renewable energy.

Geographic area also has a strong correlation with renewable development. This is likely due to the fact that RES tend to require large areas of land for the equipment relative to the power they produce; wind, solar, and other renewable energy farms all require large areas to produce significant power, so countries with more land have easier access to these resources. This can be applied to landowners; people with more land may be more likely to invest in these systems because they have the space to put a wind turbine, solar panel, or similar system. Another reasonable conclusion from this study was that the price of fossil fuels drives the renewable economy. Higher fossil fuel prices lead to greater RES development; expressly, as traditional energy sources become more expensive, alternative energy choices become more financially achievable. Correspondingly, greater access to coal was found to discourage the use and development of RES (Marques, Fuinhas, & Pires Manso, 2010). This is significant because New Zealand has access to coal resources, but the demand for its coal is decreasing; coal only accounts for 5% of total energy consumption. For comparison, 39.1% of electricity is generated by coal in the U.S. (Ministry of Business & Innovation & Employment, 2013). Furthermore, New Zealand still manages to produce 73% of its electricity through renewable resources (Ministry of Business & Innovation & Employment, 2013).

Table 1 summarizes the motivating factors involved in renewable ventures discussed above.

Table 1 Motivations associated with investment in renewable energy resources

| Individual Motivations | Regional Motivations | |
|---|---------------------------------|-------------------------------|
| - | Encouraging | Discouraging |
| <i>Decreased cost of electricity</i> | <i>Higher Energy Dependency</i> | <i>Cheaper fossil fuel</i> |
| <i>State and federal tax incentives</i> | <i>Higher GDP</i> | <i>Greater access to coal</i> |
| <i>Concerns about the environment</i> | <i>Larger geographic area</i> | |

| | | |
|---------------------------------|-----------------------------------|--|
| <i>Increased Property Value</i> | <i>More expensive fossil fuel</i> | |
|---------------------------------|-----------------------------------|--|

New Zealand perceptions of renewables are generally good, but significant opposition to renewables still exists. A survey conducted in New Zealand with over 1000 participants found that over 70% of the population was significantly concerned with energy efficiency, where their energy comes from, and climate change, showing significant public support of renewable development and environmental consideration. However when asked about various levels of wind development, 48% of people would oppose an effort for a wind farm near enough to their home that they could hear it, and 26% would oppose an effort in an area which they could see it from their home. This illustrates the concept of NIMBY (Not In My Back Yard); people are supportive of renewables until it directly affects them (Energy Efficiency and Conservation Authority, 2014).

On top of this, the system needs to be safe and easy to use; people will want to feel comfortable using the system. Without this level of comfort, people will be unwilling to purchase the system, even if it is more affordable.

B. Meeting public expectations on safety and ease of use and improving public perception of hydrogen as a fuel.

Hydrogen has often been used for manufacturing, however it has only recently started to be used domestically for transportation in cars and busses. This use of hydrogen can stir up some safety concerns by the general public. Some have argued this reluctance stemmed from the Hindenburg incident in 1937 (Banister, 2002). Hydrogen was used as the gas in the blimp which went down as it drew to its mooring and the event was memorialized in newsreels and photos and is an iconic image even today. Many have blamed the flammability of hydrogen for the disaster, but recent studies show that it was not hydrogen, but rather the iron oxides and aluminum that were used on the outer shell of the ship that started the fire (Johnston, Mayo, & Khare, 2005).

The negative connotations associated with hydrogen due to the Hindenburg seem to be waning in recent years. Several studies on public views on hydrogen as an energy source suggest that this incident is no longer a barrier for people to support the progress of hydrogen technology. One free word association survey in particular, led by Zachariah Wolff and Hemmes

in 2006 revealed that only 26% of responders linked the word “hydrogen” with something negative while another 38% related it with something neutral (Ricci, Bellaby, & Flynn, 2008).

Views on hydrogen are moving in the positive direction as more and more forms of transportation resort to using it for fueling purposes. In a driving clinic conducted in Europe, people were asked to drive cars running on hydrogen fuel cells around and then answer questions about their opinions of the vehicle. 89% of the users reported that they felt safe inside the car as it was operated. Also, 85% of the users felt that the refueling system was safe enough that they were comfortable with it (Martin, 2009). People are more likely to accept a new technology when they see it functioning properly. When researchers were first trying to implement vehicles that relied on hydrogen, they used public buses to test what the mass majority of those who use public transportation thought of the new technology. Although the researchers expected to find that people associated the product with past failures of the use of hydrogen, 77% of the riders approved and said they would support the switch to hydrogen buses (Martin, 2009).

According to Altmann and Grasel (year 1998) the public is largely uninformed about hydrogen as an energy resource. The researchers found that when asking whether people knew that the automobile industry was using hydrogen as a fuel, only 50% knew the answer to be yes. The number of total people who had ever learned about hydrogen was shown to be extremely low in another case study done by O’Garra. In a public perception review of hydrogen, several studies were discussed and every one of the studies that tried to gauge the knowledge of hydrogen found that the public knew very little. However, the perceptions of the use of hydrogen were found to be neutral on average (Ricci et al., 2008).

In reality, when looking at different types of renewable energy systems, hydrogen as a fuel is no more dangerous than substances such as oil that are widely used currently. The renewable energy system that uses hydrogen to store excess energy from any type of system, primarily either wind or solar, or most likely both, contains components that have little risk of exploding or catching flame, decreasing any chance of a hydrogen fire (Barbir, 2005). This hydrogen storing RES works in the same way as the HyLink™ system; it stores excessive energy from the already existing wind and solar power sources on the Matiu/Somes Island. Hydrogen is at the same risk for fires or explosions as petroleum products. The riskiest and most unexpected behavior of a RES that implements hydrogen would be a slow leak in a compact area (Flynn,

Bellaby, & Ricci, 2006). This has the potential to cause a fire if the hydrogen had no space to escape. Sensors can easily be developed and installed in the system to fix this issue (Flynn et al., 2006). This would allow for early detection of the signs of a leak and alert the user before this risk becomes a safety issue. Another solution could be the future development of smoke detector like systems that could sense and notify if there was a hydrogen leak. Furthermore, hydrogen fires that could occur in a fuel cell vehicle are actually less damaging than the same fire from a gasoline vehicle. You can see the results of these two events in the figure below. The gasoline fire destroys the whole car, but because hydrogen is so light, it quickly moves away from the car and just produces an intense but localized flame for a short period of time. This is a good representation of what would happen if the HyLink™ system caught fire; the hydrogen would create a centralized flame for a minimal amount of time in the vertical direction where ignition occurred. Because all components of HyLink™ can be located outside, the two scenarios are almost identical. An LPG tank experiencing a failure, however, can create a very dangerous explosion, even without igniting. A sudden release of high-pressure gas can be very hazardous (Stawczyk, 2002). The images below depict this.



Figure 3 Hydrogen vs. Gasoline; 1 minute after ignition (Swain, 2001)



Figure 4 Small LPG bottle explosion (Stawczyk, 2002)

C. Cost Analyses for Stand-Alone Hybrid Power Systems versus Grid Connections

Stand-alone power systems, or home electricity systems that do not draw power from an established grid connection, are becoming increasingly popular as a means to implement renewable energy systems on a small scale (Davidson, 2006). However, small-scale power distribution systems come with significant cost overheads. These additional costs include initial investments, maintenance costs, and component life-cycle renewal costs. Not dissimilarly, connecting to an established grid connection has expenses associated with it such as maintenance costs, grid extension costs (where applicable), and annual payments. Small-scale stand-alone power distribution systems therefore require a significant initial source of capital, while grid connections require a much smaller initial capital investment, although the grid connected power systems require continuous capital in order to pay for continuous power usage.

Implementing standalone power systems and connecting to an existing grid power system are the two main cost scenarios regarding installing a renewable energy system, which are differentiated by the status of any prior connection of the home to the grid. First, the case for a home with an existing grid connection, such that the installation cost is zero, and second, the case for a new home at a variable grid connection distance, such that installation costs exist for both the grid connection and the stand-alone power system. For both cases, the installation cost of a stand-alone power system is approximately static and independent of location. However, the grid connection installation cost varies as a function of distance from the closest connection point to the existing grid (Ekren, Ekren, & Ozerdem, 2009).

The first comparison case studies the difference in cost between implementing a new stand-alone renewable energy power system into a home with an existing grid connection and continuing to use that grid connection for power. Because the grid connection is pre-existing, the cost of installation is zero for that grid-connected system. According to the New Zealand Powerswitch organization, the median residential cost per year for electricity is about \$1781 for a medium-size household using 8492 kWh per year. This amounts to about \$0.21 per kWh (Consumer NZ, 2014). Following the cost analysis methodology of Ekren et al., the cost of implementing an optimized hybrid photovoltaic/wind stand-alone power system (similar to the one currently implemented for demonstrating the HyLink™ system on the Maitu/Somes Island) is approximately \$124,000 over a 40 year span, including system component life cycle factors

such as battery replacements (Ekren et al., 2009). This figure can be annualized to a value of \$3,100 per year for household electricity supplied by a stand-alone hybrid power system. Nelson et al. (2006) provide annual cost estimates for such stand-alone power systems, including both electrolyzer/fuel cell and battery energy storage models; the cost of energy is \$0.70 per kWh for the electrolyzer/fuel cell system, and \$0.37 per kWh for the battery storage system (Nelson, et al., 2006). Using the same 8492 kWh per year estimated energy usage for a medium household from before, the annualized costs are calculated to be \$3142 per year for the battery storage system implementation and \$5944 per year for the electrolyzer/fuel cell storage system implementation. These previous annualized estimates are significantly less expensive than the estimation from Kellogg et al. in 1998 of \$6,691 per year for a hybrid photovoltaic/wind stand-alone power system (Kellogg, Nehrir, Venkataramanan, & Gerez, 1998). The annualized energy rates for the hybrid systems as well as the grid connection systems are summarized in the table below:

Table 2 Annualized costs of grid power and hybrid photovoltaic/wind power systems

| System | Annualized Cost (USD/yr.) |
|--|---------------------------|
| Grid (Wellington) | 1781 |
| Hybrid PV/wind (Ekren et al., 2009) | 3100 |
| Hybrid PV/wind – battery storage (Nelson et al., 2006) | 3142 |
| Hybrid PV/wind – electrolyzer/FC storage (Nelson et al., 2006) | 5944 |
| Hybrid PV/wind (Kellogg et al., 1998) | 6691 |

Purchasing power from the currently connected grid is much less expensive than implementing a hybrid stand-alone power system for household usage, regardless of the grid connection region. Table 2 organizes the difference in annualized costs between the stand-alone hybrid systems and the grid connections.

Table 3 Annualized premium cost of hybrid photovoltaic/ wind power system over a currently connected grid power system

| System | Annualized Premium – Wellington (USD/yr.) |
|--|---|
| Hybrid PV/wind (Ekren et al., 2009) | 1319 |
| Hybrid PV/wind – battery storage (Nelson et al., 2006) | 1361 |
| Hybrid PV/wind – electrolyzer/FC storage (Nelson et al., 2006) | 4163 |
| Hybrid PV/wind (Kellogg et al., 1998) | 4910 |

The premium to use a hybrid power system ranges from being slightly under 100% of the grid power annualized cost to over 300% of the grid energy cost, depending on the reference location for that premium calculation and the proposed system architecture.

The second comparison case studies the difference in cost between implementing a new stand-alone renewable energy power system into a new home without an existing grid connection and paying for line extensions from the nearest point on the grid to reach the new home at a variable distance. The primary difference between this case and the previous case is that an additional cost to draw power from the grid is incurred in by way of grid line extension costs. The Central Maine Power Company charges \$12.64 per foot of overhead line extension, and the

New York State Electric and Gas Corporation charges \$12.41 per foot of overhead line extension (Central Maine Power Company, 2013) (New York State Electric and Gas Corporation, 2014). This value is roughly approximated to an empirical value of \$12.50 per foot of overhead line extension. Note that this is just a general estimation. Factors that can impact this line extension cost include specific local terrain, and the necessary voltage and power transmission levels. This cost estimate is also specific to over-ground power line extensions in order to examine the least expensive scenario for grid power system implementation, as underground line extensions are much more expensive (Vaillancourt, 2014). As a result, these general estimations do not apply well to New Zealand locales, as the terrain is not consistent not uniform, even in small regions. However, the given line extension estimations provide a lower bound on the cost of extending power lines – Maine and New York have relatively flat, uniform terrains, which allows power companies in these areas to develop fixed-rate costs that are minimal compared to a region with less uniform topography. Being stand-alone, the cost of the hybrid photovoltaic/wind power systems will not be affected by distance of the new home from the closest connection point on the established grid, since the costs of operating a stand-alone power system are independent from the distance of the system to the grid. As such, the annualized cost results from the previous case in Table 1 maintain for this case as well. Ekren, Nelson, and Kellogg all use dated line extension rates, but according to Nelson, the distance at which the stand-alone hybrid power system cost breaks even with the grid power connection cost is inversely proportional to the line extension cost, so the old line extension values can easily be replaced by the new line extension value (Nelson et al., 2006). The distances at which the stand-alone hybrid power system costs break even with the grid connection and power consumption costs can be found in Table 4:

Table 4 Break-even distances for stand-alone hybrid power system versus grid extension connection

| System | Break-even distance (miles) | Break-even distance (km) |
|--|-----------------------------|--------------------------|
| Hybrid PV/wind (Ekren et al., 2009) | 2.99 | 4.81 |
| Hybrid PV/wind – battery storage (Nelson et al., 2006) | 4.13 | 6.65 |
| Hybrid PV/wind – electrolyzer/FC storage (Nelson et al., 2006) | 8.79 | 14.15 |
| Hybrid PV/wind (Kellogg et al., 1998) | 4.36 | 7.02 |

For example, for new homes at a distance in excess of 4.81 km from the existing grid connections, it is more cost-effective to implement a hybrid photovoltaic/wind stand-alone power system, rather than paying to connect to the grid at that distance and paying monthly power dues, according to Ekren’s model. The break-even distance analysis provides a useful perspective on exactly how distant a new home needs to be from the existing grid to implement a stand-alone power system rather than connecting to the grid from purely a cost standpoint.

Next, we want to relate this cost analysis to the many other incentives for installing a renewable energy power system. The motive of the hybrid system implementation is to promote usage of renewable energy, it is important to weigh in the actual benefit of implementing such a system, in addition to just the cost information. Aside from cost factors, other incentives to invest in a stand-alone hybrid power system for a household as opposed to using grid power include thorough knowledge of these systems. In order to make these stand-alone power systems more attractive to potential investors, the information about these systems needs to be effectively displayed and communicated.

2.4 Communicating the HyLink™ System and the Challenges

The challenges and opportunities of HyLink™ must be effectively communicated in an efficient and effective manner. The incentives of the system, the public perception of hydrogen, and the motivations for installing the renewable energy system can all be utilized to convey the most important information to the target audience of current RES and stand-alone users, as well as the interested public. Using this information will allow a website and other mediums for presenting information to contain the pertinent information about HyLink™. Currently, there is a RES-HyLink™ static display to provide information on the system.



Figure 5 Callaghan Innovation Static Display for HyLink™

The current static display, Figure 3, contains text that explains why renewable energy is needed, what the HyLink™ system is and how it is stored, and information about hydrogen. It complements the textual information with an infographic showing the process of the system.

The current strategy of communicating the HyLink™ system to the public is limited to the display board located at the site on Matiu/Somes Island as shown in Figure 4. With a maximum of 250 daily visitors (Cite Emma Dunning as source), the display on Matiu/Somes Island does not have the potential to educated enough people about the HyLink™ system. While the visitors to Matiu/Somes Island is a start to the education process, the HyLink™ information needs to reach a larger population of the specified audience in order to gain momentum when the marketing begins.

Utilizing interactive displays with a website is a suitable solution for combining a static display with an added component to develop interactivity. A study by Robins and Holmes linked

the aesthetics of a website to its overall credibility. The researchers surveyed people about a website that contained the same content but presented in different levels of aesthetics, meaning the page contained the same information but was presented differently in terms of format, font, color, and layout. A study in 2008 by Michailidou, Harper, and Bechhofer links visual complexity (arrangement and amount of text, pictures, graphs, etc.) to aesthetic appearance such that the more visually complex the webpage is, the less aesthetically pleasing the website is (Michailidou, Harper, & Bechhofer). Furthermore, this study argues the aesthetics are closely related to the perception of a website's credibility, thus agreeing with Robins and Holmes' argument that more aesthetically pleasing coordinates with a user perceiving the website as more credible.

A study by Hall and Hanna researched the effects of web page text and background color combinations on readability, aesthetics, and information retention. The result of the study that had participants view two different web pages with four color combinations each determined that greater contrast leads to greater readability and that blues and chromatic colors led to higher ratings of aesthetic quality and intention to purchase (Hall & Hanna, 2004).

A journal article by Reinecke and Bernstein furthers the argument that aesthetics affect the website's perception and usability to a view, but expands on the concept by making the argument that aesthetically pleasing web design is not universal, but dependent on cultural background. The studies revealed that users were "22% faster using a culturally adapted interface" (Reinecke & Bernstein, 2011). An example Reinecke and Bernstein give is Asian websites. They tend to be bright in color with animations. This aesthetic layout is effective in Asian culture but considered "information overload by westerners" (Reinecke & Bernstein, 2011). This can be extrapolated to cover different cultures, but the key concept is that aesthetics and user interface is affected by cultural background and is thus not universal.

The website will be designed in an approach that follows Simon Sinek's Golden Circle concept (Sinek, 2009). The idea is to follow the model of why, how, then what. Sinek argues that the successful companies, such as Apple, do not market their actual product, but market why they are providing the product. Sinek argues that organizations and consumers know what companies do. They also know how they solve a problem with a product. However, they do not understand why they are making the product. The common argument, according to Sinek, is that

the “why” is to make a profit. This, however, is the result. The “why” is the motivation for creating a solution to a problem that is linked to passion and drive. For example, Sinek uses Apple computers. If Apple were to use a traditional marketing approach, their mission would read, "We make great computers. They are beautifully designed, simple to use. Do you want to buy one?" Sinek argues that this is not as inspiring as "In everything we do, we believe in challenging the status quo and thinking differently. We do this by making our products beautifully designed and simple to use. We just happen to make great computers. Do you want to buy one?" This is especially important for a product such as HyLink™. It is not a usable device as other products such as cell phones. Since it is a product that is out of sight and not usable technology, the motivation for the product is “why it is necessary”, as opposed to “what it does”.

The website will begin with why there is a need for renewable energy and renewable energy storage. The website will transition to how the issue of energy storage can be solved. It will conclude with what the product is that will solve the energy storage needs. The idea is that this format will create a flow of the website going from the broad concept of renewable energy to the specific solution on intermittency issues. This flow, combined with utilizing information from the surveys and interviews, will allow the website to be both formatted and have the ideal information to educate the public on the HyLink™ system and allow the product to be marketed in a positive way.

3.0 Methodology

The goal of this project is to understand how to better inform the public about the function and benefits of the HyLink™ system, and develop an effective means of communicating important information about the system. In order to achieve this goal, we have developed the following research objectives:

Objective 1: Determine the public perception of renewable energy and hydrogen fuel.

Objective 2: Understand the typical energy usage of current renewable energy system users and determine their perception and potential motivation for hydrogen energy.

Objective 3: Propose a communication strategy for HyLink™, and implement these into a website to deliver information about hydrogen.

Objective 1: Determine the public perception of renewable energy and hydrogen fuel.

We conducted a survey to investigate the public's general knowledge and attitudes toward renewable energy in addition to what would motivate them to install their own system. This information was used to determine how the HyLink™ system's advantages correspond with the popular reasons for installing a RES, and what needs to be communicated about the system in order to generate interest.

We conducted our surveys using a convenience sampling strategy at two locations: Maiti/Somes Island and the Wellington Harbor region, spanning from the Te Papa museum to the Wellington train station. We conducted 71 surveys, concluding at a point that obvious patterns were established.

The survey started with a general question about the individual's opinion on the importance of renewable energy and then followed with a more specific question about whether they had previously considered RESs and what would motivate them to install one. We then asked them about their views of hydrogen as a fuel source. The survey is located in Appendix A.

Objective 2: Understand the typical energy usage of current standalone users and determine their perception and potential motivation for hydrogen energy.

The main target audience for the HyLink™ system is current stand-alone system owners such as off-grid renewable energy owners. It was important to understand the motivations of

stand-alone energy users because HyLink™ will be focused on early adopters in this demographic. We wanted to see an assessment of current systems that use various forms of energy systems, such as solar panels or wind turbines. From these assessments, we wanted to learn about the weaknesses and costs that other systems impose on the users. We identified and contacted 10 current RES owners via email, allowing them to decide if they prefer a phone interview or open-ended survey. The owners were identified based on internet research and the contacts of the RES owners that we communicated with, thus giving us a non-random sample.

The interview and open-ended survey for current RES users asks about the respondents' renewable energy systems and their motivations for installing those systems, their typical energy usage, shortcomings of the system, and which hypothetical payback scenarios would generate interest in installing a hydrogen energy system. We were hoping to understand some of the main motivations for installing or upgrading an RES. The open-ended survey is located in Appendix B. We interviewed the Department of Conservation ranger, Emma Dunning, who was one of the head rangers on Mātū/Somes Island, an eco-sanctuary where the current HyLink™ prototype system is situated. We wanted to identify her opinions on the system's current implementation and usage, as well as any future visions she may have had for it, including her impressions on the system's safety, usability, and ecological attractiveness. Additionally, we conducted interviews with two renewable energy system owners, and we received open-ended surveys from seven current RES owners. We transcribed the interviews, and then coded those and the open-ended survey responses to identify the major themes across the responses.

Our codes filtered into the overarching theme of motivations for installing a renewable energy system. For our renewable energy system owner interviews and open-ended responses, we coded based on two concepts: reasons they installed renewable energy systems and what criteria a hydrogen system would need to meet. Some of these codes included urgency and empathy, environmental concerns, and economic concerns. When talking to Marion, an RES owner, we created the code environmental concerns, with the sub-codes of peak oil and helping the environment. For codes related to economic concerns, we identified sub-codes of location, immediate cost effectiveness, and whether or not the respondent's current renewable energy system was cheaper than being connected to the grid. By utilizing this coding strategy, we were able to effectively identify and explore the key motivations behind renewable energy system

installation, with the objective of then applying these motivations to HyLink™ as a system that is analogous to a renewable energy system, thereby discerning the most important topics that a communication strategy for HyLink™ should utilize in order to maximize its effectiveness.

Objective 3: Establish guidelines for an effective communication strategy for HyLink™, and implement these into a website to deliver information about hydrogen energy.

From discussions with our sponsor, we identified core information that Callaghan Innovation wants to convey to prospective users about the HyLink™. Through our surveys and interviews, we sought to better understand the informational needs, motivations, and attractiveness of the system to prospective users. We used this information to create a communication strategy that is demonstrated in a website, in which we developed a means to educate people about HyLink™ in order to generate interest, and tools to teach anyone interested in hydrogen energy such that they can learn more and determine if it fits their needs.

Determining what Callaghan Innovation intends to communicate

To determine what information about HyLink™ that Callaghan Innovation wishes to convey, we conducted an interview with our sponsor, Robert Holt. The interview contained open-ended questions about the HyLink™ system and what aspects of the system should be part of a communication strategy to interest new users. This interview was one of the first things we did after arriving in Wellington; it also served as an opportunity for the employees at Callaghan Innovation to educate us about the system. Interview 2.0 in Appendix A shows the key questions for the interview with Callaghan Innovation.

Developing a Website to Provide Information on Hydrogen Energy and Evaluate the Communication Strategy

We developed a website to provide a way to inform the target audience about hydrogen energy and the HyLink™ product. The target audience is primarily current RES owners, especially off grid owners and Eco lodges. The information on the website was based on the findings from the public perception survey and the interviews with current RES owners (Objectives 1 and 2).

We conducted two focus groups to analyze the content and appearance of the website. The focus group was an open discussion on their impressions of the website. This included what

the group thought of the layout, color theme, and flow of the site. After the group gave their initial impressions on the website design, we explained how we envisioned the website's flow based on a broad concept of renewable energy transitioning to hydrogen energy and the HyLink™ system. This allowed us to compare how we intended others to make sense of the website and how potential users actually understood it. We discussed different components of the website, including the LPG comparison calculator, the decision tree, and the animation to understand how the different tools helped people to understand HyLink™ and how it might (or might not) fit their energy needs. Our ultimate goal of the focus groups was to determine how people perceived the communication strategy that was developed from our findings.

Developing Tools to Determine if HyLink™ is a Good Fit

We developed two tools for website users to determine if hydrogen storage is right for them. Both tools emphasized economic and environmental considerations. The first tool was a calculator that determines the economic viability of the HyLink™ and its environmental effect. The tool allows the user to input details on their LPG usage and returns a value to compare the potential hydrogen usage and cost as well as the carbon footprint comparison. In addition to providing an estimate for users, the tool allows users to create their own scenarios to see when hydrogen energy would pay off. Although hydrogen fuel can replace other fuels such as diesel, wood, oil, etc., the most common fuel for heating and cooking among RES owners in New Zealand is LPG. As a result, our tool is only for LPG comparison.

The second tool is a decision tree. It is a tool that allows the user to answer a series of questions that will reveal if hydrogen storage is the right choice or not. The development of the questions is based on the interview with Robert Holt at Callaghan Innovation, along with the results from the interviews with current standalone users. The interviews allowed us to understand and develop a pattern of the decision making process for renewable energy systems and apply that to hydrogen energy. Both tools will be located on the website for easy access by the target audience.

4.0 Findings and Analysis

We surveyed 71 people along the Wellington Harbor waterfront and Matiu/Somes area. We also interviewed ten current renewable energy system owners from various parts of New Zealand.

Finding 1: People think that renewable energy is important

The first question on the survey asks the respondents to evaluate the importance of developing and utilizing renewable energy. The scale was from 1 to 5, with 1 being not important and 5 being very important. The average response was 4.8 with 83% of respondents rating renewables as “very important” (See Figure 1). These findings are consistent with research by Nielson and the Energy Efficiency and Conservation Authority (EECA), which found that the New Zealand public also supports renewable energy; for example, 88% supported wind farms and 71% supported wind power even when it is visible from their homes. Of those surveyed, 88% believed that “climate change is important enough to think about what they can do or personally do something about” (EECA, May 2008)).

Importance of Renewables 1: Not Important; 5 Very Important

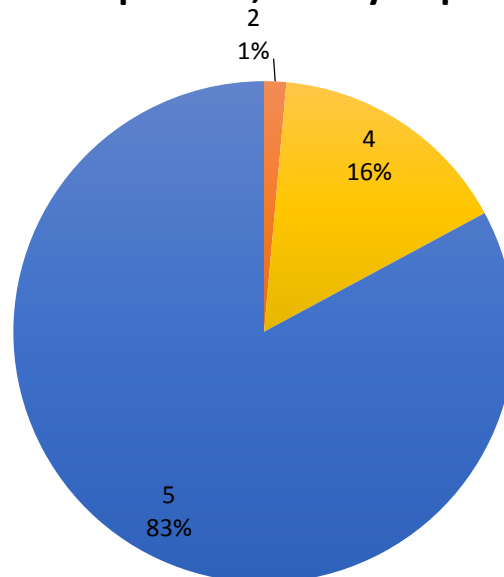


Figure 6 Importance of Renewable Energy

Furthermore, from our survey 80% of respondents have thought about installing a renewable energy system, with 39% having seriously considered it or already installed one (See Figure 2). Regarding their reasons, respondents were asked to rate various considerations for installing a renewable energy system on a scale from 1 (not important) to 5 (very important). The top three considerations, in order, were:

- 1) Environmental considerations
- 2) Decreased dependency on fossil fuels
- 3) Decreased monthly energy bill

This shows that saving money is important, but so too are concerns regarding the environment and independence from fossil fuels.

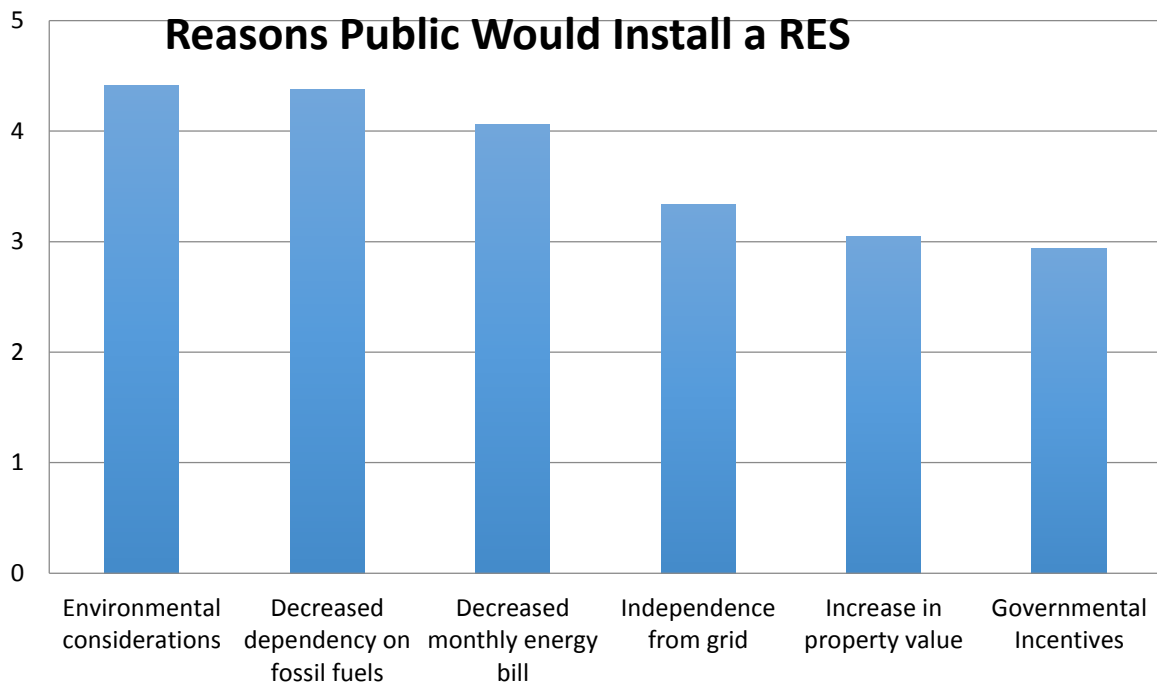


Figure 7 Reasons for installing a renewable energy system

Finding 2: People understand that their thermal needs are high

Findings from our surveys suggest that there is a good understanding in the New Zealand public about how much of their energy usage comes from thermal loads such as heating or

cooking. The correct percentage is 70%, which almost half of our respondents identified correctly. The average response was 63% (see Figure 9).

How much of an average household's energy usage do you think is used for heating and cooking?

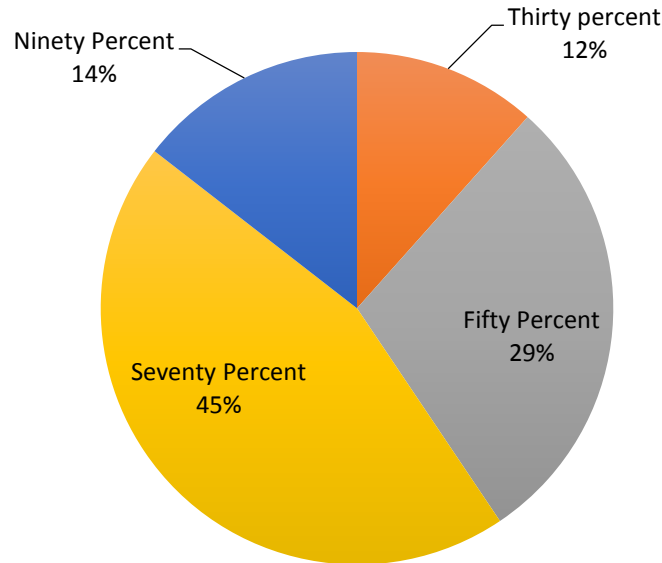


Figure 8 Perception of Thermal Energy Usage

Finding 3: A majority of RES owners we communicated with use LPG for their household cooking

During our interviews and open-ended surveys with renewable energy system owners, we found that LPG was the major type of energy in use. After conducting ten interviews with owners, we found that nine of them relied in some way on LPG for at least a portion of their fuel. Of these, 100% said they used LPG for some type of thermal application, whether it is for cooking, water heating, space heating, and, in one case, refrigeration.

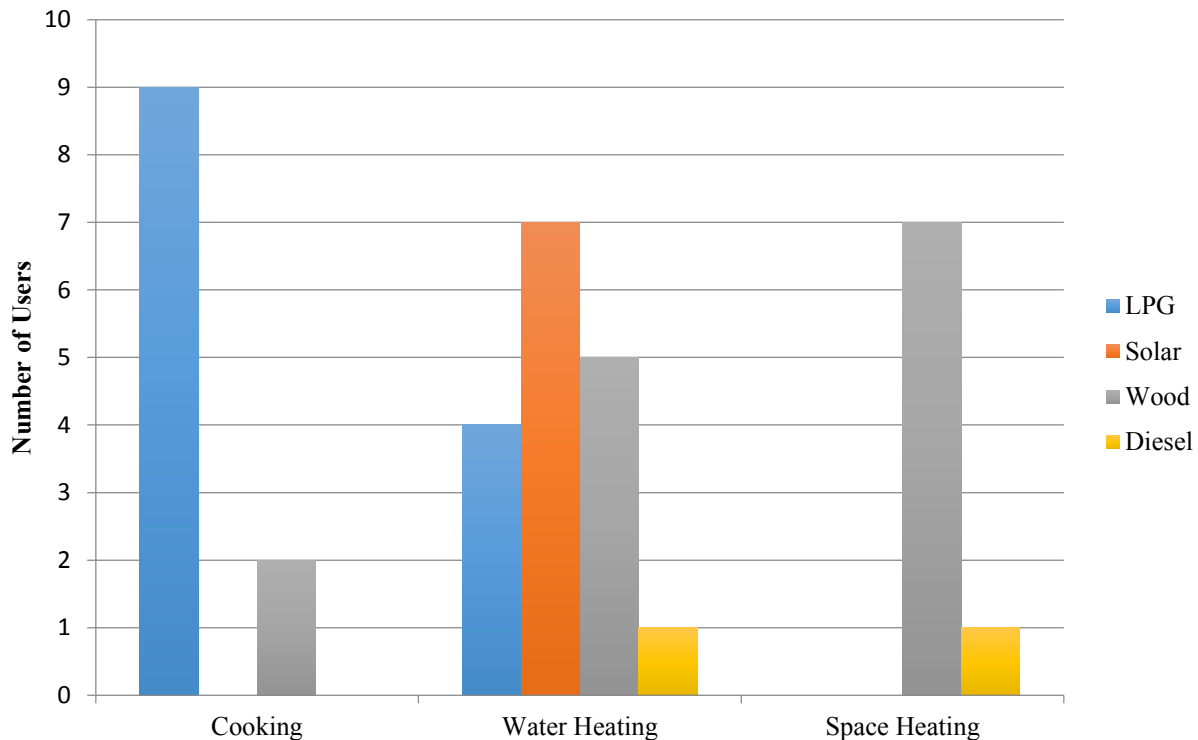


Figure 9 Thermal Usage Distribution

As you can see in Figure 10, the majority of the people we talked to said they use LPG for their cooking. Shaun Mitchell, the owner of a bed and breakfast, says he uses a “gas hob and a gas oven”. Another owner, Andre Schoneveld, explained, “Water heating in the small cabin is via an LPG fired instant water heater. Cooking is via bottled LPG gas.” He later goes on to say that gas is the main source of his cooking fuel. John Apps noted that he uses “LPG in the summer...[he] would be interested in being able to use excess power to create hydrogen fuel for cooking, if that would decrease [his] use of bottled LPG”. This owner expresses that he would happily decrease his use of LPG if it was a viable option and continued to ask for information about any systems that would help in this effort. A number of respondents indicated that they were looking for an alternative to LPG.

LPG imposes several costs on the user beyond the cost of the gas itself. Depending on how rural the household is, there can be a substantial delivery cost. Although Shaun Mitchell does not “imagine [he pays] a great deal more premium for...transportation costs”, the owner of Ruru’s Roost, Marion Edwin reported that she pays a \$125 delivery charge for every 45kg cylinder. This discrepancy is due to the fact that the cost of delivery is location dependent and

the price can vary significantly. Furthermore, there is an annual rental cost associated with the use of LPG cylinders. Marion reported that, “there’s a rental cost of about \$100 for the two cylinders for the year. And you don’t own those cylinders, they’re just rented”. Again, we found here that owners were dissatisfied with the costs and renting of LPG cylinders and were interested in alternative options.

Finding 4: People have no strong opposition nor favor towards using hydrogen as a fuel and know very little about it.

A large portion of our survey was dedicated to discovering the public’s opinions of using hydrogen as a fuel source. From the survey, we found that people neither have strong opposition nor favor towards hydrogen as a fuel source. In the question which asked how suitable the respondent thought hydrogen was as a fuel on a scale from one to five, where one was not suitable and five was very suitable, an overwhelming majority claimed they did not know enough about it to make the distinction. The significance in this response is that people admittedly do not know enough about hydrogen to make a decision on hydrogen’s suitability as a

Suitability of Hydrogen as a Fuel (1: not suitable; 5: very suitable)

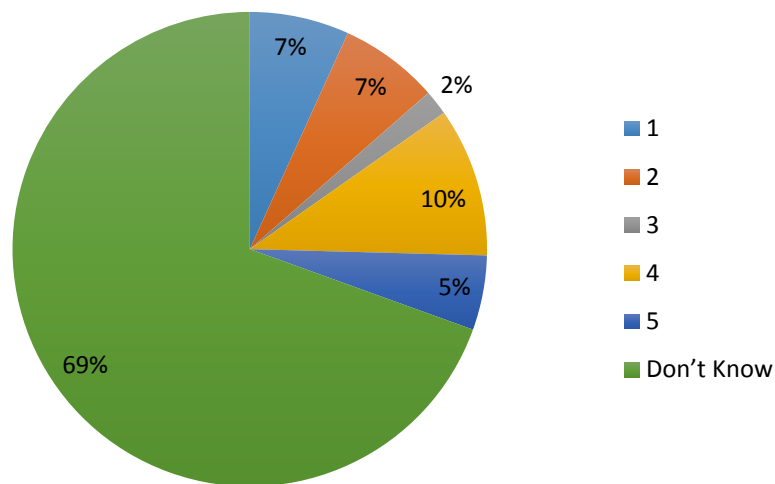


Figure 10 Suitability of Hydrogen as a Fuel

fuel. The small remainder of responses was evenly distributed between positive and negative

perceptions, although these responses are overwhelmed by the “Don’t know” response (See Figure 9). We qualify this as a neutral opinion—neither for nor against hydrogen.

Further on in the survey, we wanted to find what level of knowledge respondents had about hydrogen as a fuel on a scale from 1 (never heard of it) to 5 (very familiar). Here respondents typically admitted to knowing little or nothing about hydrogen fuel with the average response being 2.09, paralleling the “Don’t Know” response from the question discussed above. The results are shown in Figure 6 below.

**Self-Reported Knowledge of Hydrogen Fuel
(1: never heard of it; 5: very familiar)**

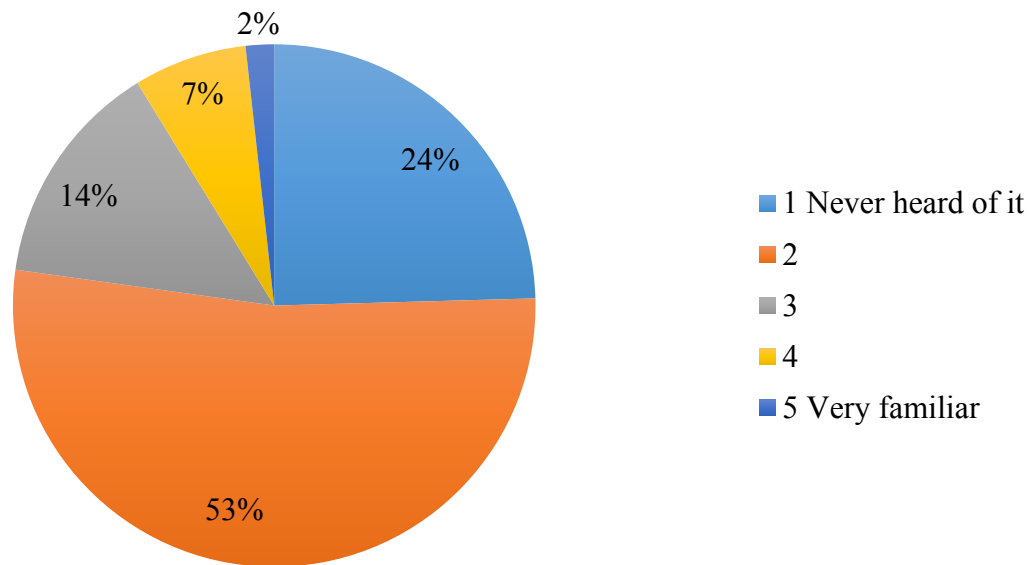


Figure 11 Self-Reported Knowledge of Hydrogen Fuel

With these two questions, we find that people do not have a solid background on utilizing hydrogen as a fuel, but do not appear to be strongly opposed to, or strongly supportive of the concept due to preexisting associations. Our background research suggested that there might be some hesitation towards its use based on significant historical disasters where hydrogen was in use; however, our data does not support this hesitation towards hydrogen.

Finding 5: When properly confirmed by experts, respondents do not stress safety as a concern about a hydrogen-based system.

Current fuel-gasses such as LPG have been around a long time and are generally accepted as being safe and reliable. In order to be implemented in homes, HyLink™ will need to uphold or exceed this level of safety. DoC ranger on Matiu/Somes Island, Emma Dunning, lives by and works with the system and said that, once the system was explained to her, she felt safe and was comfortable around it. She stated:

When you tell people that you're making hydrogen on the island, the connotations that come up are with that are quite interesting, where as you actually talk to Robert and have an idea of what's going on and that it isn't dangerous its stored at low pressure, it's like "Oh, ok, we're not going to blow up the island". (Dunning, 2015)

Understandably, people want to be able to feel comfortable around the system, as they will be in close contact with it throughout their daily lives. Marion Edwin stated, "I would assume there was some very clear risk information that would be made available with it because otherwise it wouldn't be good option." However, when asked if she had any hesitations about using hydrogen she responded with, "No. I want to know more. Tell me more, because I'm sure some guys like you are working on it."

Shaun Mitchell responded similarly saying "The safety side I'm guessing would be picked up in some sort of regulatory approvals before you even installed it or used it so I don't suppose the safety side would be a concern." He wants to be assured the system is safe, but doesn't have immediate doubts or opposition to utilizing hydrogen.

This is surprising as we thought general perceptions of hydrogen would lead people to be concerned about using it. Instead, people generally just want more information from experts – scientists and regulators – who understand and can communicate the risks of hydrogen-based fuels. The safety of the technology can be communicated as simply as providing a certification along with the system.

Finding 6: People have many questions about hydrogen energy

Rather than opposition or hesitation about hydrogen fuel, respondents typically were left with questions. These queries included a discussion of what kinds of devices would be required for the use the hydrogen gas and how much of their current system could remain the same. Shaun Mitchell asked if, “there are devices and things that, you know, make an easy transfer from that stored energy to some useful form. Obviously a gas hob would be useful to use your gas so what would you use, what sort of useful things are there for, I guess, hydrogen.” He then went on to say he would like more information on “how it would integrate with the arrangement that we’ve already got at our place.” Marion Edwin similarly asked, “How does it work? Can we use existing cylinders with the system? I just want to know the practical details about how it operates.” People wanted information about what parts of their system would have to change.

As discussed in the previous finding, people also wanted to be assured that the technology is safe; while they are not opposed to using hydrogen, they asked questions about how safe it is because it’s a new technology and safety information is not currently available.

Finding 7: Primary reasons for adopting renewable energy systems

a. Economics are always a factor in the decision process

Economics play a significant role in the decision process for installing a renewable energy system. Based on the responses from current renewable energy system owners, a primary motivation for getting an RES was always cost. When asked why she decided to install her RES, Marion Edwin said:

For us to have installed the power system that would have connected us to the national grid would have cost us more than it did to actually install our entire system... it was immediately cost effective for us to do (Edwin, 2015).

The cost to connect to the grid became a common theme among motivation to install an RES. The same is the case with renewable energy system owner, John Apps: “Connection charges to the grid were over \$30,000 and then you have bills to pay. I designed, built and installed our system for about \$12,000, so it was a no brainer!” For many cases, the decision to invest in an RES relied on it being cost effective. However, this was not always the case.

Mike Copeland, whose primary motivation for installing an RES was simply because he had no other choice, believes that an RES system does not have to be cost effective, but it does need to be affordable. Cost effectiveness means the system will save or make money while affordability is in regards to being able to pay the upfront cost of the system.

Again it is not all about pay back. Most people buy a car, which will only cost them money and depreciate throughout its life. If hydrogen were comparable, or only slightly more than petrol, I would go that way (Copeland, 2015).

Although he does not specify why he would pay more than petrol, if hydrogen power were affordable, he does reveal that there are other factors in his decision process besides economics. Even so, he says, “I would use hydrogen in a heartbeat if it were affordable”. For Mike, being able to afford the upfront cost of a system is more important than having the system save him money in the future.

b. Environmentally Friendly

An additional contribution to the decision to have an RES is the environmental impact. Although environmental considerations were not as common, nor emphasized as much as cost, it was a factor for some of the current RES owners.

And most of us are here because we want to live in an ecologically kind of friendly way and we don't want to wreck the earth so that's what we are here for. (Edwin, 2015)

Furthermore, our public surveys revealed that the top motivations for wanting to install a renewable energy system were environmental considerations, which was previously revealed in Figure 8.

c. Independence from the Grid

From the interviews with current renewable energy system owners, independence from the grid and decreased dependency on fossil fuels were factors in their decision to have an RES. Marion Edwin talked about her motivation for having a renewable energy system. “Not killing the rest of the world and realizing that peak oil and all those good things are occurring and we can't avoid it”(Edwin, 2015). In particular, she implied that it was not possible to avoid being dependent on fossil fuels without being off-grid and owning a renewable energy system. If you

are tied into the grid, she suggested, you are dependent on peak oil prices for a majority of your energy needs.

Decreased dependency on fossil fuels was the second most popular answer in the public perception survey (Appendix A). This suggests that being independent from fossil fuels is an important consideration for most people.

Finding 8: Maintenance and reliability are considerations for installing an RES

An unreliable system can be both expensive and time consuming. This is particularly true for off grid systems in rural areas where owners are likely to incur significant costs in time and travel to repair a broken RES. Gerry McSweeney of Lake Moeraki Wilderness Lodge stated, “We hate the fact that the complex systems require servicemen who charge us \$1000 just for their travel to us so we like systems that are simple and can be maintained by us.” If HyLink™ could displace some of this cost by being more reliable and easier to maintain, it would be immediately appealing to some users. However, if systems were more complex, harder to maintain, or less reliable, then users would likely be steered away.

As discussed in finding 5, Mike Copeland feels the batteries are the greatest weakness of his RES because their ability to store power can be significantly reduced by overdrawing from them. He said, “This happened once when we were on holiday and more or less cost us 5K to replace them.” A system like HyLink™ that can be filled and drained of hydrogen over many more cycles without diminished performance could be desirable to standalone owners. If HyLink™ can be demonstrated to be reliable and low maintenance, then RES users will likely be more interested.

Conclusions and Recommendations

Our conclusions are broken into two major categories:

1. Our proposed communication strategy for HyLink™
2. What the adoption of HyLink™ depends on

Proposed Communication Strategy for HyLink™

Our third objective was to propose a communication strategy for educating people on the HyLink™ system as effectively as possible. This communication strategy draws from findings resulting from our first and second objectives, which were to (1) determine the public perception of renewable energy and hydrogen energy, and (2) understand the typical energy usage of current standalone renewable energy system users and determine their perception and potential motivation for using hydrogen energy. This communication strategy is designed to follow the “why, how, what” concept from Sinek’s Golden Circle, which is discussed further in our Background Chapter.

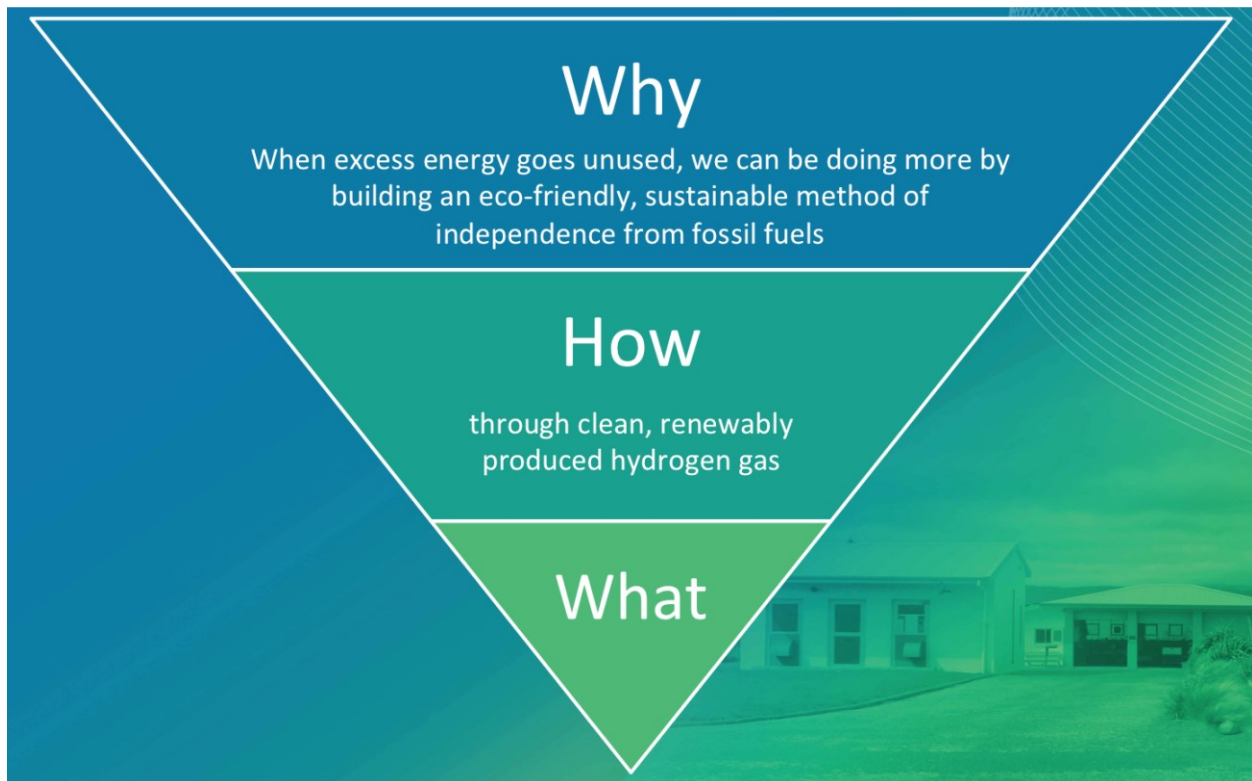


Figure 12 Why, How, and What Strategy

First, we present a problem that needs solving, or in other words, a niche that needs filling, as the “why” that needs to be answered. Then, we develop “how” to solve the problem – for example, presenting the medium or technology available through which this problem can be solved or that can fill this niche. Last, we present the “what,” which is the exact product that uses the “how” medium in order to solve the “why” problem. We validated the effectiveness of this communication strategy by conducting two focus groups using a website designed to embody the proposed communication strategy.

Communication Recommendation 1: Limit Renewable Energy Discussion

First, we determined that incorporating an in-depth discussion about the importance of renewable energy is not required. This conclusion is drawn from Finding 1, where we established that people already believe that developing and utilizing renewable sources of energy is important, which influences two major points. Since HyLink™ is a form of renewable energy system, a discussion on the importance of renewable energy would be an intuitive starting point for a communication strategy. However, people do not need to be convinced that renewable energy is important, so a discussion on the importance of renewable energy development and utilization may not be necessary or effective. The second outcome is that because people already strongly believe in the importance of renewable energy system development and utilization, an effective communication strategy engages consumers by emphasizing the association between renewable energy systems and HyLink™. Overall, a discussion emphasizing the importance of renewable energy development is unnecessary to a communication strategy; better to start with a discussion of renewable energy as a familiar foundation from which the benefits of the HyLink™ system can be launched.

This style of introduction presents itself as an effective “why” component of Sinek’s Golden Circle communication concept. To specify further, the “why” component of the Golden Circle in this renewable energy system context is developed because renewable energy systems often produce excess electricity at inconvenient or off-peak times. With thermal loads constituting a majority of actual and perceived home energy usage (according to Finding 2), there exists an evident niche where a product could satisfy both of these issues simultaneously by storing the excess energy from the renewable energy system and storing it as a fuel that can offset the high thermal energy demands from the other thermal energy source mechanisms.

Communication Recommendation 2: Prioritize Hydrogen Fuel Discussion

According to Finding 4, a communication strategy should start with in-depth information about hydrogen as a fuel source. This is because people admittedly know very little about hydrogen, and are unable or unwilling to express a preference for hydrogen as a fuel source. Essentially, the average person appears to not only know little about hydrogen, but wants to be well informed before making a decision on the suitability of hydrogen fuel. The communication strategy should seek to teach consumers about the potential usages and benefits of hydrogen as a fuel source by authorities and experts in technology, safety and regulation. This, in effect, becomes the “how” component to Sinek’s Golden Circle outline, where this clean, easily produced fuel can be easily generated with excess energy generated by these renewable energy systems (Sinek, 2009). The “how” here is that hydrogen can be made cleanly, cheaply, and safely from electricity and water, and can also be burned cleanly and safely as a fuel gas to contribute towards the thermal demands of heating and cooking. Providing consumers with information on hydrogen as a fuel source is a key step in the Golden Circle approach, because the average consumer must be convincingly informed that this previously unknown fuel is capable of accomplishing the problem presented by the “why.”

Communication Recommendation 3: Stress Replacing LPG with HyLink™

Naturally, the “what” in Sinek’s Golden Circle is the HyLink™ system. The HyLink™ system, utilizing hydrogen fuel, bridges the gap between the problem of excess electricity production from renewable energy sources, and the immense energy consumption of thermal loads such as heating and cooking. According to Finding 3, renewable energy system owners often rely on liquid petroleum gas (LPG) for thermal loads such as heating and cooking. This finding, in conjunction with the finding that many renewable energy systems consistently produce excess electricity at off-peak times, suggests the possible use of HyLink™ to displace LPG should be stressed, since this is the largest single group with both excess electricity being produced and with an established reliance on a non-renewable, non-clean, non-independent, and costly fuel source that can be readily displaced by hydrogen fuel instead.

Communication Recommendation 4: Conduct Appropriate Hydrogen Safety Discussion

Hydrogen is a fuel; there are inherently some risks and dangers associated with using it, but those risks are no more or less extreme than those of any other fuel source. Finding 4

presents that people have no strong opposition nor favor towards using hydrogen as a fuel and know very little about it, indicating that they need to learn more about the fuel before making a decision on its suitability. Finding 5 also shows that people have expressed the safety concern is satisfied with professional verification. As such, the safety of hydrogen fuel does not need to be explained in depth. This is not to say that a discussion of the safety on hydrogen fuel should be omitted from a HyLink™ communication effort, but that the strength of such a discussion should be appropriate, given that overcoming a widespread negative predisposition about the safety of hydrogen is generally not required. An appropriate discussion on the safety of HyLink™ and hydrogen fuel may be as simple as providing the certifications and safety standards of the system from a credible source, in order to show that the system has undergone the same approval procedure as would be required for any other fuel system.

Proposed Communication Strategy Validation:

Having established this proposed communication strategy for HyLink™, we implemented it into a website in order to validate that their projected effectiveness would match their actual effectiveness. The website follows the structure described by the previously mentioned communication guidelines. The website first presents renewable energy systems as the context for HyLink™, establishing that these systems often produce excess energy that effectively is lost. We then go on to provide further context that the majority of home energy usage is due to thermal loads, such as space heating, cooking, and hot water heating. These two points compose the “why” of Sinek’s Golden Circle – renewable energy systems produce excess electricity that is often wasted or lost, and significant amounts of energy are used to satisfy thermal power needs. This implements the first communication guideline.

Next, we discuss hydrogen as a fuel source, noting that hydrogen can be cleanly produced from electricity, and burned as a fuel gas to fulfill thermal demands. Due to these two key qualities, hydrogen is capable of bridging this gap between having excess electricity and having high thermal loads. Therefore, hydrogen gas forms the “what” component of Sinek’s Golden Circle concept, as it is the medium through which the “why” can be answered, recognizing the second communication guideline. Finally, the “what” is presented as the HyLink™ system, the clean energy storage solution. Having introduced HyLink™, we develop the strongest use case of the system: using excess electricity from renewable energy resources to produce clean

hydrogen fuel to displace one of the most commonly used fuels, liquid propane gas (LPG), for thermal loads such as heating or cooking.

One of the tools we created for the website allows individuals to compare the cost of HyLink™ to the cost of their current LPG usage. This fulfills a recommendation that hydrogen fuel's ability to replace LPG should be stressed. This satisfies the third communication guideline. There is one final communication guideline to fulfill – the discussion of safety of the system should be kept appropriate to the context. We believe that this is as simple as keeping resources such as safety certifications for the system available for those who seek them.

Focus Group Findings on Website Design and Function

As mentioned in our Methodology, we conducted two focus groups in order to assess the effectiveness of the proposed communication strategies. The two groups provided feedback with a range of technological familiarity, which allowed us to get a sense of how the website would work for different types of technology users. The results of our focus groups indicated that overall our communication efforts were effective, with generally positive reviews of the overall flow and organization of the website being conveyed.

The first focus group was done with five Callaghan Innovation employees. One of the five participants was very familiar with the HyLink™ project, with the remaining participants having heard of HyLink™, but not knowing much about it. We allowed participants to explore the website on their own in order to see if they ran into any confusion on how to navigate the site. The participants had a generally easy time navigating the website and although they requested small adaptations, they generally liked the way the website worked. With regard to the structure we used for portraying the information, progressing using Sinek's guidelines, participants agreed that it portrayed the information effectively. Specifically when asked about the flow of the site, participants said, "It explains it nicely". Afterwards, we explained the approach we took when setting up the Sinek-like structure and asked if it was effective. One participant said, "Yes, it was clear". In terms of navigating the website, the linear flow going down the page was appreciated because it allowed the user to go from general concepts about hydrogen energy to specific details about HyLink™ at the bottom of the page. However, the participants struggled to navigate back up the page, and requested the addition of an "up" button to go along with the "down" button that was already found on each page. Regarding the website

tools such as the calculator and the decision tree, the participants requested the ability to learn more. One participant asked, “The decision tree said “HyLink™ may be right for me”, so what next? Where do I go from here?” This led to the addition of the link to a contact form to provide information after they utilize the website tools.

The second focus group was conducted with 15 WPI peers in the Wellington Project Center. Each participant was aware of the HyLink™ system before viewing the website, but not details about how it works. The participants found the “why”, “how”, “what” design of the website to be “both interesting and engaging”, as quoted by one participant. Everyone in this group answered affirmatively when asked if they understood the flow of the site. One person in particular noted his first impressions as “the website is a great concept for portraying information about the HyLink™ system”, while another specifically said she “liked the funnel of information”. This statement refers to the order of Sinek’s structure, “why”, “how”, and “what”. Consequently, we believe that we have validated our proposed communication strategy through our demonstrative website.

RES and HyLink™ Interest Factors

By way of the methods associated with objectives 1 and 2, we identified perceptions of renewable energy and hydrogen energy, both from the perspective of those who have considered installing renewable energy systems and opted against the installation, as well as those who have opted to follow through with the renewable energy system installation. Here, we will discuss the criteria by which people may choose to accept or reject the installation of a renewable energy system, and how these qualifications could project onto the HyLink™ system as factors contributing towards or against its installation.

RES Installation Criteria

Finding 7 indicated that people who opted to install a renewable energy system did so as a result of a multi-attribute consideration, including economic, environmental, and independence factors. However, while all of these factors contributed as reasons to install a renewable energy system, Finding 7 also showed that the only one of those factors that also caused individuals to not install a renewable energy system was the economic factor. This definitively shows that an economic consideration can be the “tipping point” factor, meaning that the economic factor carries enough weight to cause people to both accept and reject the installation of a renewable

energy system. On the other hand, we have not seen any evidence that suggests that environmental factors or independence considerations have ever discouraged someone from installing a renewable energy system. From a marketing standpoint, this means that in order for someone to install a renewable energy system, it must make some degree of financial sense to that individual. Furthermore, many people live with grid-connected energy arrangements in a city region, where being grid-connected is significantly cheaper than installing a renewable energy system. The grid-connected system is less environmentally friendly and less independent than a renewable energy system, so people often default to the cheaper and more financially viable energy system option. The choice to utilize the less environmentally friendly option contradicts the result of Finding 1, which showed that people ranked environmental considerations as the most important motivation behind their potential renewable energy system installation. We attribute this result to the fact that the survey respondents had never actually installed a renewable energy system, so while it might be nice to have the sentiment of installing renewable energy systems for environmental or independence reasons, the more prominent factor contributing to such an installation seems to be cost.

Predicted HyLink™ Installation Criteria

HyLink™ is complementary to renewable energy systems. Renewable energy systems are a means by which an individual can disconnect from the electrical grid, while seeing a reduction in the environmental impact of power usage and an increase in energy independence. Similarly, HyLink™ is a means by which an individual can disconnect from external fuel sources, such as LPG shipments, reducing the environmental impact of his fuel usage and their dependence on fuel needing to be delivered from outside sources. Because of this comparability between renewable energy systems and HyLink™, we conclude that the same installation decision criteria found to apply to renewable energy systems will apply to HyLink™ as well. For example, because the financial feasibility of a renewable energy system plays such a key role in the decision to install that system, financial feasibility of HyLink™ will play a comparable role in the decision to install it as well. We also conclude that environmental friendliness and independence benefits will also impact the decision process for installing HyLink™ in a way similar to a renewable energy system.

Several of our findings have directly supported that the three factors to deciding whether or not to install a renewable energy system will also apply to the decision of whether or not to install HyLink™. There are four key findings that feed into the three investment criteria of economic, environmental, and independence factors. First, Finding 7 shows that HyLink™ would have to be cost-competitive to the systems that it would replace in order for it to be a viable installation. This directly supports that HyLink must be economically viable in order to be a success in the long-term market. Second, Finding 7 demonstrates that HyLink™ must be more environmentally friendly than the system that it would replace, which coincides directly with the environmental-friendliness installation criterion. Next, Finding 8 indicates that the system maintenance and reliability come into play as installation decision factors. The reliability of a system has roots in an independence factor, where if the user needs to make frequent service calls or perform maintenance, then the user is really not any more independent than if they depend on frequent LPG shipments. Reliability issues also can detract from economic benefits, particularly for users in very remote locations, as was the case for Finding 8. Finding 8 indicates that HyLink™ should be easy to maintain, particularly for economic reasons for remote users. Service calls can be exceptionally expensive, so a system that is simple to fix, or at least incurs required maintenance costs that are heavily mitigated by the benefits of the system, is much more preferable. Ultimately, if HyLink is able to become an economically preferable alternative fuel system, with minimal detractions from a user's independence, while maintaining a strong environmentally friendly image, HyLink™ will certainly have installation interest from potential users and investors.

Additional Recommendations

Make HyLink™ Information Accessible

Currently, the information about HyLink™ is generally only communicated by word of mouth. The website could be a useful passive communication tool used for communicating information to interested individuals, but a means to access it needs to be distributed; we recommend adding a QR code or written link to it on the sign on Matiu/Somes Island. We also recommend adding pamphlets on HyLink™ to the biosecurity room on Matiu/Somes Island to potentially attract more visitors to view the HyLink™ system and its sign. We also recommend distributing a newsletter including recent advances and updates to HyLink™ to interested parties.

This recipients if this newsletter could be organized by encouraging interested parties to visit the website and add their contact details to the contact form.

Future Research

Since HyLink™ requires adapting appliances to be utilized with hydrogen fuel instead of LPG, renewable energy system owners will be required to make changes to their current setup to adapt to the hydrogen fuel. We recommend researching the public willingness to make changes in order to incorporate the HyLink™ system. What is the extent of changes that people are willing to make if they were to invest in HyLink™, and how does this compare to the other economic and social considerations for adopting renewable technology?

Next, we recommend advancing the research on the three key HyLink™ installation factors that we've identified (economic, environmental, and independence considerations) by attempting to quantify magnitude of each of their influences on whether or not an individual would install HyLink™ (or a renewable energy system). Two proposed methods for this quantitative analysis of quantitative concepts are conjoint analysis and the simple multi-attribute rating technique.

Last, we recommend analyzing the awareness of HyLink™ after the second prototype has been implemented to see if the additional prototype site provides a noticeable boost to the awareness of the existence of this technology to the public, or even to renewable energy system owners who likely pay more attention to news on technology of this sort.


Discussion

Hydrogen fuel is a progressing technology undergoing research for use in many applications from vehicles to the home to industry. HyLink™ has the intention of being used specifically for current renewable energy system owners in off-grid applications. In the meantime, HyLink™ is still in the prototype phase. However, it needs to remain adaptable to the needs and uses of potential users, since not everyone has the same energy demands. Having a system that can be used for multiple energy uses would allow it to be adaptable to different people. Mike Copeland, a current RES owner, stated, "My energy footprint is still high and the biggest reason is vehicle use. We live 20Km from Westport and I keep an office there. So I do 400km a week without trying. I would love to be able to reduce this and have long thought

hydrogen would be the way” (Copeland, 2015). While hydrogen fuel for vehicles is not the focus for HyLink™, the prospect of meeting the individual demands of the user should be looked at. As of right now, the uses of HyLink™ are limited to replacing fuel for cooking and heating, but the system should be expanded to meet the complex energy needs across the globe. Looking forward to developing an expanded form of the technology, hydrogen gas has the potential to meet the needs of more than just LPG usage. Expanding technology to meet more than just the LPG needs of off-grid owners can bring out the motivations such as independence and environmental considerations. With a system that has a limited focus in New Zealand, cost becomes very important. However, if the uses are expanded, and hydrogen fuel can be used for more than LPG, the environmental and independence considerations could have a greater influence on the decision process than they currently do for the small-scale system.

When a technology such as HyLink™ becomes a commercial product worldwide, it will have different impacts depending on the location. As we found in New Zealand, hydrogen fuel would significantly impact cooking since LPG is most commonly used for cooking. In the United States, hydrogen fuel would have a different impact due to the different climate. In the northeastern part of America, HyLink™ would have to be adapted to be utilized for heating in the cold winters and cooling in the warm summers, which adds a versatile challenge to the system. Even so, it is not as simple as adapting to the location; based on the U.S. Energy Information Administration, the percentage of energy used for heating and cooling is declining due to the increase in electrical demand. With changing energy demands, technologies need to be adaptable to changing energy usage. While the distribution of energy is shifting in America, the availability of energy is declining in sub-Saharan Africa. Less than 25% of the population has access to clean cooking (World Energy Outlook, 2014). This represents a different set of considerations for hydrogen fuel—instead of replacing harmful, expensive fuels, it is providing a fuel to an area that would otherwise not have access to one. Technology such as HyLink™ needs to be adaptable to meet the changing needs of a culturally dynamic world, because HyLink™, as it is, faces a tremendous hurdle of finding the right investors in its selective niche that are willing to overcome the upfront costs of the technology to reap the benefits of producing sustainable hydrogen fuel.

Appendix A: Survey on Public Perception of Renewable Energy

Where do you live?  Age: 18-25 26-35 36-60 60+

1. How would you rate the importance of developing each of the following energy sources based on their utilization of renewable sources of energy such as wind and solar? environmental impact. (1 is low impact, 5 is high impact)

| | 1 | 2 | 3 | 4 | 5 |
|------------------------------------|---|---|---|---|---|
| Natural Gas | ? | ? | ? | ? | ? |
| Non-Renewably Produced Electricity | ? | ? | ? | ? | ? |
| Renewably Produced Hydrogen | ? | ? | ? | ? | ? |
| Geothermal | ? | ? | ? | ? | ? |
| Renewably Produced Electricity | ? | ? | ? | ? | ? |
| Wood | ? | ? | ? | ? | ? |

2. Please indicate how much thought you have given to installing a renewable energy system in your home or workplace.

I haven't considered installing a renewable energy system

I have thought about the concept, but I have not considered investing in a renewable energy system

I have seriously considered investing in a renewable energy system but did not install one.

I have installed a renewable energy system.

_____ (type of system)

2A. If you have considered a renewable system, please elaborate on your answer. (For example, type of system considered, why you did or did not install it, and any comments on the use of energy storage with the system)

3. Rate each of the following reasons for installing your own renewable energy system, such as solar panels or a wind turbine, based on how important they are to you. (1 is not important, 5 is very important)

| | 1 | 2 | 3 | 4 | 5 |
|--------------------------------|---|---|---|---|---|
| Independence from the grid | ? | ? | ? | ? | ? |
| Environmental considerations | ? | ? | ? | ? | ? |
| Decreased monthly energy bill | ? | ? | ? | ? | ? |
| Decreased dependency on fossil | ? | ? | ? | ? | ? |
| Increase in property value | ? | ? | ? | ? | ? |
| Governmental incentive | ? | ? | ? | ? | ? |
| Other | ? | ? | ? | ? | ? |

4. How many 24-hour long power outages per year would it take for you to consider investing in an alternative power source? (i.e. generator)

1-3 times per year

3-12 times per year

12 or more times per year

Would never invest for this reason

5. How much of an average household's energy usage do you think is used for heating and cooking? (this includes both space heating and water heating)

10% 30% 50% 70% 90%

7. Please select your primary heating fuel.

Natural Gas Geothermal Wood Oil

Hydrogen Electricity LPG/Propane

Other: _____

7A. Please mark any fuels you would not consider using in your home. (select all that apply)

Natural Gas Geothermal Wood Oil

Hydrogen Electricity LPG/Propane

Other: _____

7B. Please mark the reasons you would not consider these fuels. (select all that apply)

Cost Safety Environmental concerns

Availability Other: _____

8. How much do you know about hydrogen fuel?

1 2 3 4 5

Never Very familiar

Heard of it

8A. How suitable do you think hydrogen is for cooking/heating in your home?

1

Not suitable _____

Don't know

Please briefly explain your response.

8B. Does hydrogen fuel produce greenhouse gases?

Yes Sometimes

No Don't know

8C. What's the earliest you can see hydrogen being used as a fuel gas in New Zealand homes?

2-10 yrs. 10-25 yrs. 25-50 yrs.

50-100 yrs. Never

9. Have you heard about the EY Link™ system located on Matiu/Somes Island?

Yes No

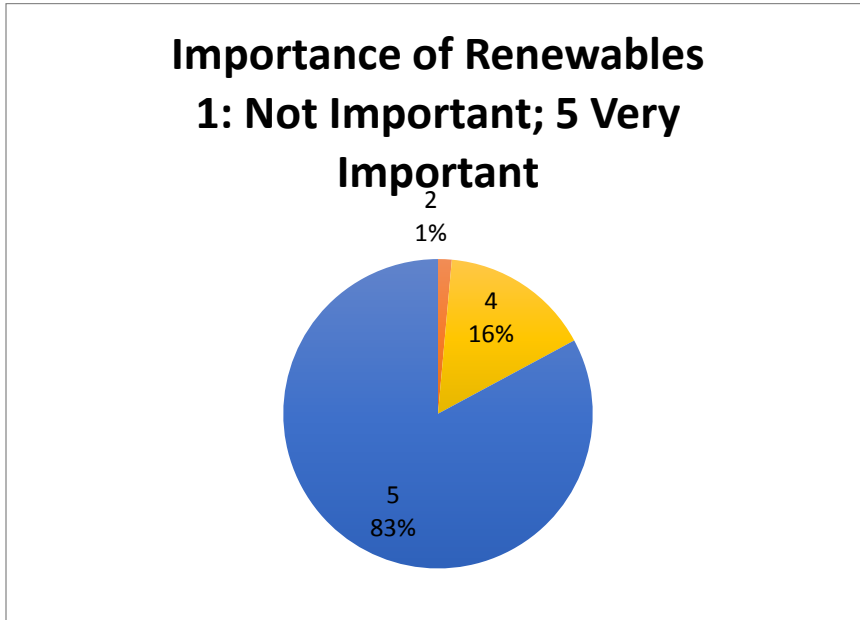
9A. If so, how?

Appendix B: Renewable Energy System Owner Questionnaire

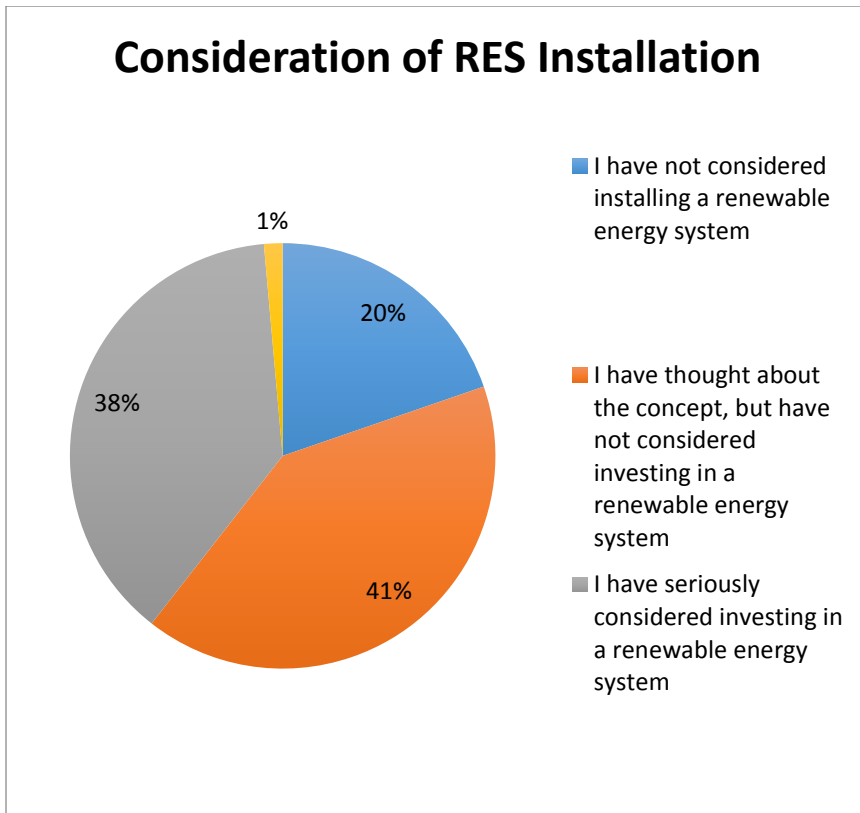
1. What type of renewable energy system do you own? (E.g. Solar panels, Wind turbine, etc.)
2. Please explain your reasons for installing the system
3. Where is the system located? (General region, City/Suburb)
4. How long did it take the system to pay for itself or how long do you expect it to take? (I.e. payback period)
5. Does your system meet all of your energy needs? Please explain (Electricity, space heating, hot water heating, cooking, etc.)
6. Have you or have you considered upgrading/ adding to your system?
7. Are you off the grid? (Are you tied into the local power system?)
8. What is the greatest weakness in your energy system?
9. If you use energy storage, are you satisfied with the system? (I.e. Batteries)
10. How would you feel about using hydrogen as a fuel? (See below for brief explanation, or check this website that is under development for more info)
11. What would the payback period need to be for you to consider it? (Leave blank if you would not consider it. If payback period is not a factor, state payback is not a factor)
12. Please state any questions or comments you may have about hydrogen storage

Appendix C: Survey Data

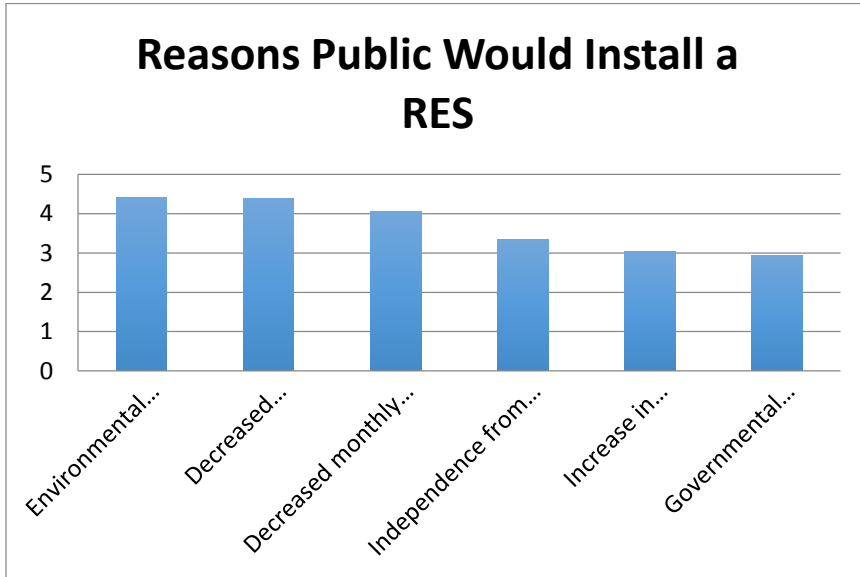
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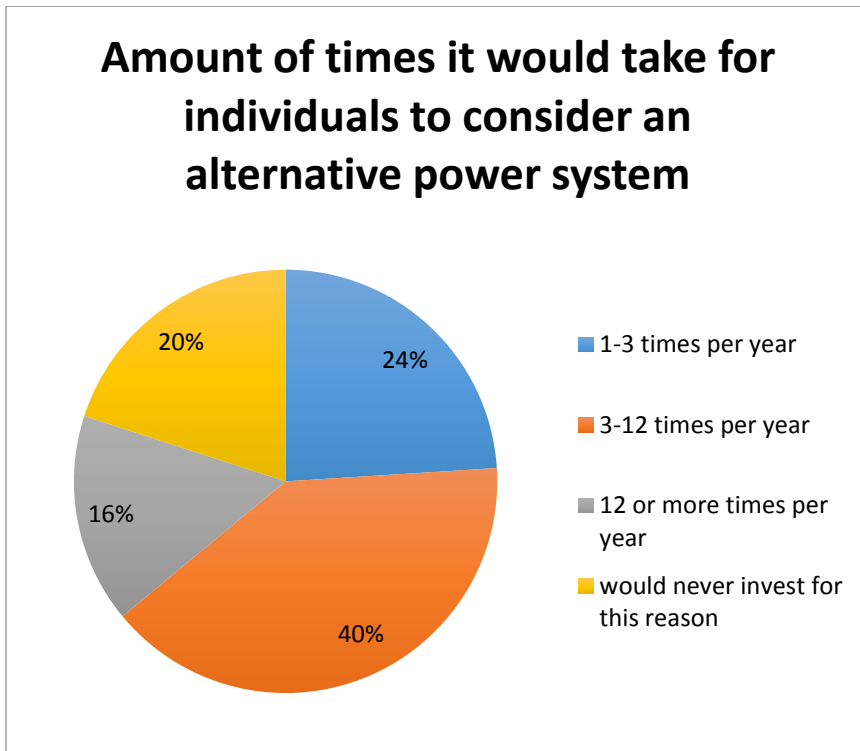
Question 2:



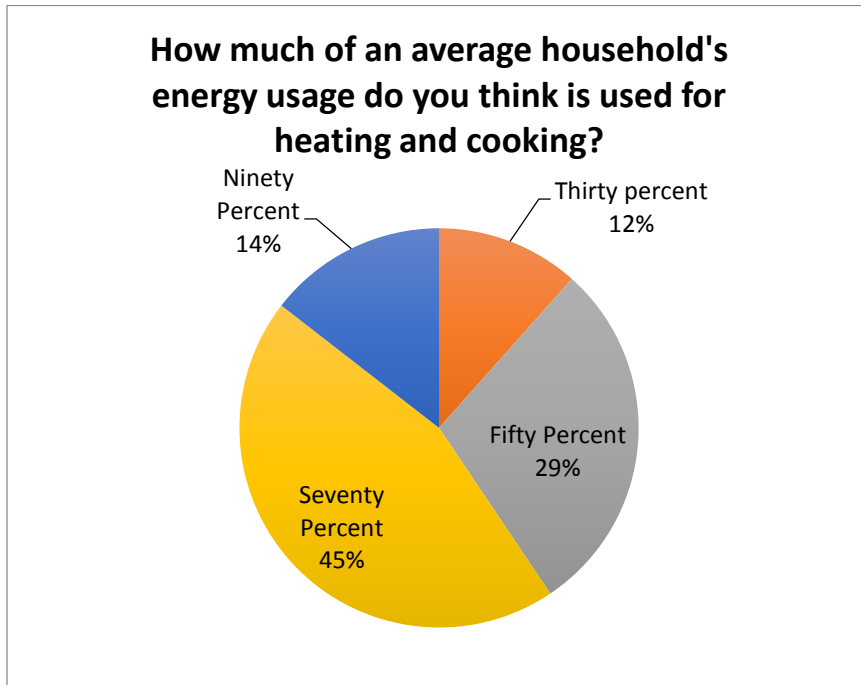
Question 3:



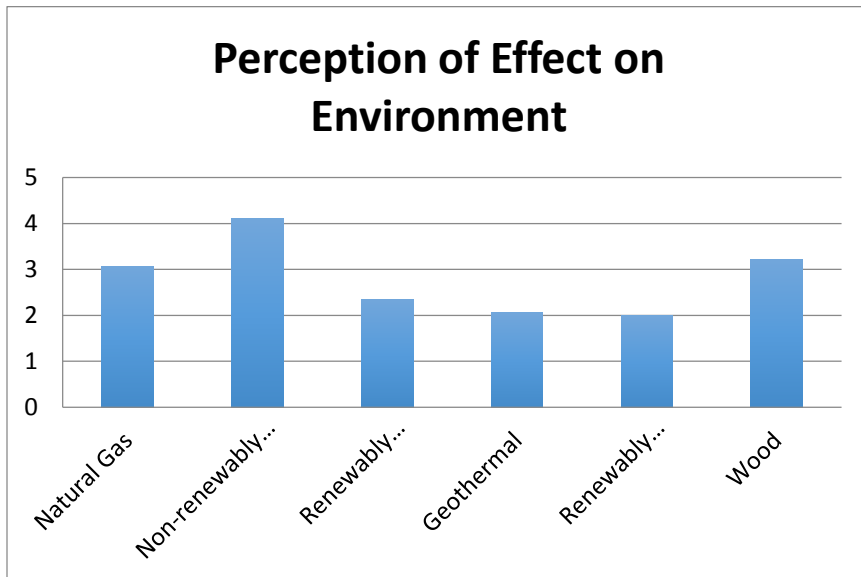
Question 4:



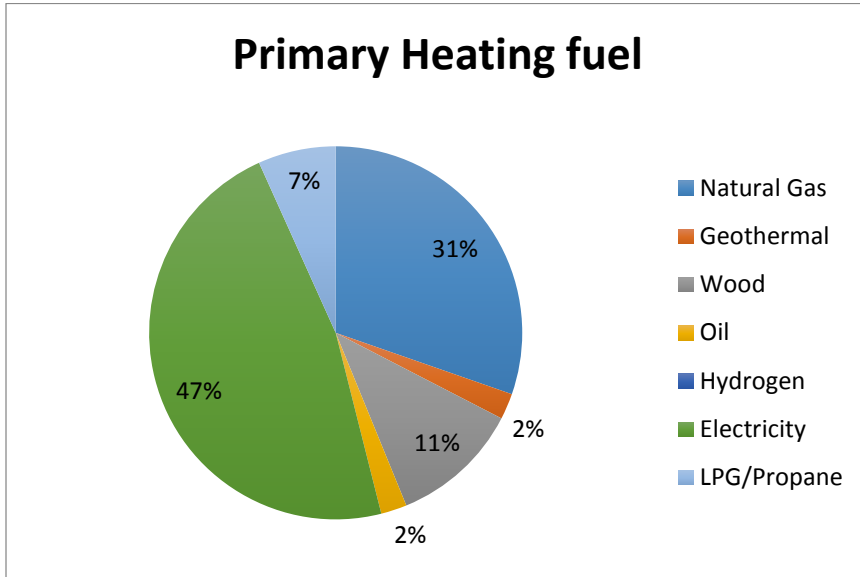
Question 5:



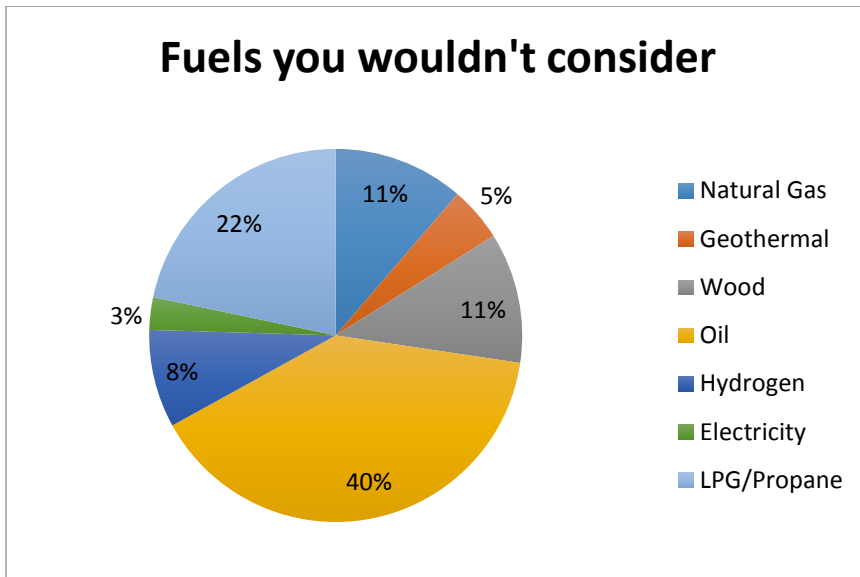
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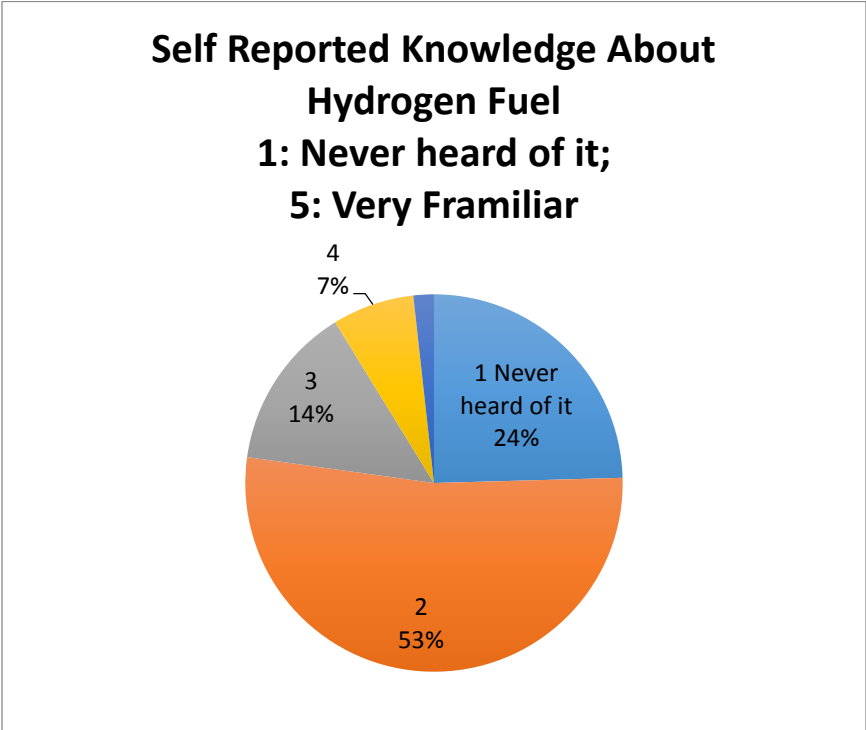
Question 7:



Question 7A:



Question 8:



References

- Banister, D. (2002). In Support of Hydrogen. *Built Environment*, 28(2), 165-167.
- Barbir, F. (2005). PEM electrolysis for production of hydrogen from renewable energy sources. *Solar Energy*, 78(5), 661-669.
- Central Maine Power Company. (2013, April 2013). Retrieved 17 November, 2014, from [https://http://www.cmpco.com/MediaLibrary/3/6/Content/Management/YourAccount/PDFs and Docs/LineExtPricing.pdf](https://http://www.cmpco.com/MediaLibrary/3/6/Content/Management/YourAccount/PDFs%20and%20Docs/LineExtPricing.pdf)
- Consumer NZ. (2014, November 2014). Price Trend Graphs. Retrieved 17 November, 2014, from <https://http://www.powerswitch.org.nz/powerswitch/price-trends/graphs>
- Davidson, P. (2006, April 13, 2006). Off the grid or on, solar and wind power gain; Incentives, savings push more families to renewable energy. *USA Today*. Retrieved from [http://pqasb.pqarchiver.com/USAToday/doc/408991125.html?FMT=ABS&FMTS=ABS:FT&type=current&date=Apr 13, 2006&author=Paul Davidson&pub=USA TODAY&edition=&startpage=B.1&desc=Off the grid or on, solar and wind power gain : Incentives, savings push more families to renewable energy](http://pqasb.pqarchiver.com/USAToday/doc/408991125.html?FMT=ABS&FMTS=ABS:FT&type=current&date=Apr%2013,%202006&author=Paul%20Davidson&pub=USA%20TODAY&edition=&startpage=B.1&desc=Off%20the%20grid%20or%20on,%20solar%20and%20wind%20power%20gain%20:Incentives,%20savings%20push%20more%20families%20to%20renewable%20energy)
- Dunn, B., Kamath, H., & Tarascon, J.-M. (2011). Electrical Energy Storage for the Grid: A Battery of Choices. *Science*, 334(6058), 928-935. doi: 10.2307/41351734
- Economy, I. P. f. H. a. F. C. i. t. (2011). HYLINK: Distributed Hydrogen Energy System for Remote Areas. *IPHE Renewable Hydrogen Report*.
- Ekren, O., Ekren, B. Y., & Ozerdem, B. (2009). Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage – A case study. *Applied Energy*, 86(7–8), 1043-1054. doi: <http://dx.doi.org/10.1016/j.apenergy.2008.09.024>
- Energy Efficiency and Conservation Authority. (2014). Energy Policy and Strategy. Retrieved 12/5, 2014, from <http://www.eeca.govt.nz/central-and-local-government/local-government>
- Energy Efficient and Conservation Authority. (2014). Generating your own renewable energy. Retrieved 17 November, 2014
- Flynn, R., Bellaby, P., & Ricci, M. (2006, 2006). *Risk perception of an emergent technology: the case of hydrogen energy*.

- Hall, R. H., & Hanna, P. (2004). The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention. *Behaviour & Information Technology*, 23(3), 183-195. doi: 10.1080/01449290410001669932
- Holt, R. (2014). In L. Dighello, M. Beardsley, C. Flanagan & N. Varney (Eds.).
- Johnston, B., Mayo, M. C., & Khare, A. (2005). Hydrogen: the energy source for the 21st century. *Technovation*, 25(6), 569-585. doi:
<http://dx.doi.org/10.1016/j.technovation.2003.11.005>
- Kellogg, W. D., Nehrir, M. H., Venkataramanan, G., & Gerez, V. (1998). Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems. *Energy conversion, iee transactions on*, 13(1), 70-75.
- Langheim, R., Arreola, G., & Reese, C. (2014). Energy Efficiency Motivations and Actions of California Solar Homeowners.
- Latest News/LPG Contamination has been an ongoing issue. (2010). *Auckland Master Plumbers, Gasfitters and Drainlayers Association*. from
<http://www.aucklandmasterplumbers.co.nz/news/details/lpg-contamination-has-been-an-on.html>
- LPG. (2015). *BOC A member of the Linde group*. from http://www.boc-gas.co.nz/en/products_and_supply/gas-products/lpg/index.html
- Marques, A. C., Fuinhas, J. A., & Pires Manso, J. R. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy*, 38(11), 6877-6885. doi: <http://dx.doi.org/10.1016/j.enpol.2010.07.003>
- Martin, E. (2009). Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics. *International Journal of Hydrogen Energy*, 34(20), 8670-8680.
- Michailidou, E., Harper, S., & Bechhofer, S. (2008). *Visual complexity and aesthetic perception of web pages*.
- Ministry of Business, & Innovation & Employment. (2013). Energy in New Zealand 2013.
- National Renewable Energy Laboratory. (2014). Learning About Renewable Energy. Retrieved 09 December, 2014, from <http://www.nrel.gov/learning/>
- New York State Electric and Gas Corporation. (2014). Line Extensions. Retrieved 17 November, 2014, from
<http://www.nyseg.com/YourHome/services/buildingandremodeling/lineextensions.html>

- New Zealand LPG pricing. *AA Motoring: The New Zealand Automobile Association Inc.*, from <http://www.aa.co.nz/cars/maintenance/fuel-prices-and-types/new-zealand-lpg-pricing/>
- Q&A. (2015). *LPG Exceptional Energy*. from http://www.exceptionalenergy.com/en_GB/media-room/q-a
- Reinecke, K., & Bernstein, A. (2011). Improving performance, perceived usability, and aesthetics with culturally adaptive user interfaces. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 18(2), 8.
- Ricci, M., Bellaby, P., & Flynn, R. (2008). What do we know about public perceptions and acceptance of hydrogen? A critical review and new case study evidence. *International Journal of Hydrogen Energy*, 33(21), 5868-5880. doi: <http://dx.doi.org/10.1016/j.ijhydene.2008.07.106>
- Safe and efficient use of LPG. (2007). from <http://www.lpga.co.nz/infoSafety.php>
- Sinek, S. (2009). Start with why. Retrieved December, 5, 2012.
- Vaillancourt, K. (2014). Electricity Transmission and Distribution. Retrieved 10 September, 2014, from [http://iea-etsap.org/web/Highlights PDF/E12_el-t&d_KV_Apr2014_GSOK1.pdf](http://iea-etsap.org/web/Highlights%20PDF/E12_el-t&d_KV_Apr2014_GSOK1.pdf)