IS NEW ZEALAND’S HIGH CONTRIBUTION OF RENEWABLE RESOURCES IN ELECTRICITY GENERATION TRANSFERABLE TO THE UNITED STATES?

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SPRING 2015

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Petroleum and Natural Gas Engineering
with honors in Energy Business and Finance

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ABSTRACT

Global climate change threatens the safety of the population. Facing this threat, New Zealand has adopted renewable resource generation in a growing share of its total electricity supply. In 2013, New Zealand reached a level of 75% of electricity generation from renewable resources. With additional wind and geothermal capacity additions, the nation has set a target of 90% of electricity from renewable resources by 2025. It is examined if New Zealand’s high contribution of renewable electricity can economically and practically be applied in the United States domestic power supply. Through literature review and interviews conducted during travel, it is determined that New Zealand’s abundance of renewable resources and lack of significant fossil fuel resources, in addition to their milder climate, low energy-intensive industries, small size, and commitment to the environment, created conditions conducive to renewable electricity development. The high percentage of renewable generation in New Zealand is not transferable to the United States because of factors relating to economics, scale, resource availability, transmission, policies, social barriers, and cultural trends. Renewable generation contribution remains low in the United States, with hydropower, wind, geothermal, biomass, and solar accounting for only 13% of supply. While stricter environmental regulations in the U.S. have led to the retirement of coal-fired power plants, with coal contributing 40% of the United States electricity in 2013 compared to 50% in 2005, instead of renewable resources taking the place of coal generation, natural gas switching has occurred and is expected to continue. Thus, given the current conditions, it is unlikely the United States will experience a significant transformation away from fossil fuel generation in the near future.
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ACKNOWLEDGEMENTS

Thank you to my thesis advisor Dr. Jonathan Mathews, as well as my supervisor Dr. Andrew Kleit for agreeing to help me with the completion of a senior thesis. Thank you to the College of Earth and Mineral Sciences Center for the Advancement of Undergraduate Studies and Experience, the Schreyer Honors College, and the Presidential Leadership Academy for funding my trip to New Zealand. Lastly, thank you to the students in the CAUSE 2013 class as well as to Dr. Derek Elsworth and Dr. Semih Eser. Traveling to New Zealand with you all was a wonderful, expanding learning experience. I will always treasure the memories made and the conversations that challenged my perspectives.
Chapter 1
Introduction

1.1 Limiting Carbon Dioxide Emissions

A transformation of the world’s energy sources is an inevitable part of a sustainable future. In the last few decades, concern over climate change has grown, driving change in the world energy portfolio. As countries came together to create policies and improve motivation for change worldwide, limiting greenhouse gas emissions became of interest. The Kyoto Protocol, which became enforced in February of 2005, was the first agreement between many developed and developing nations to reduce emissions of greenhouse gases in effort to slow climate change. This agreement, which was linked to the United Nations Framework Convention on Climate Change, committed most nations to decrease emissions in order to stabilize the greenhouse gas concentration in the atmosphere.(1) The protocol implemented project-based mechanisms like the Clean Development mechanism for organizations to invest in clean development projects or the Joint Implementation mechanism which supports initiatives that decrease greenhouse gas emissions.(2) These mechanisms gave structure to organizations agreeing to limit emissions. Projects that followed the guidelines in place by the Kyoto Protocol allowed countries to earn credits for reaching targets. While Kyoto is now expired, policies from the Organization for Economic Co-Operation and Development (OECD) and the United Nations continue to help hold countries accountable for greenhouse gas emissions. These international policies provide incentives for nations to promote and develop clean energy and technology.(1)

In addition to engagement in international climate change agreements, many nations have created national reduction initiatives. Pursuing development of renewable energy has become a significant constituent of
these efforts. Most commonly, renewable energy developments have targeted electricity generation. (3) For the U.S. and most countries around the world, however, transitioning to a lower carbon electricity supply still has many challenges. There are widespread issues related to renewable electricity development including access of generated electricity to national grids, scalability and timing, infrastructure additions, material inputs, intermittency of supply, low energy density (more land required for the same amount of energy as fossil fuels), water consumption, and high cost with uncertainty in return on investment. These challenges make the case for renewables difficult at a time when fossil fuels are still abundant. (4) How could our society adapt to or meet the challenges of renewable energy development? Some nations have achieved a high success in the utilization of renewable resources for electricity generation, one of them, the South Pacific island of New Zealand.

1.2 Success of Renewables for Electricity Generation in New Zealand

A primary objective for New Zealand has been to meet the United Nations Framework Convention on Climate Change target to stabilize the concentration of greenhouse gasses in the atmosphere. Their medium term target is a 10-20% reduction in emissions from 1990 levels by year 2020 and their long term target is to reduce net greenhouse gas emissions by 50% from 1990 levels by year 2050. (2) New Zealand is unique in that the agricultural division is responsible for the largest portion of total emissions. For example, in 2008 the agriculture sector emitted 46.6% of total emissions (all greenhouse gases) with the energy sector close behind, emitting 45.3%. Because of the challenges in attempting to decrease emissions associated with agriculture, New Zealand has focused on reducing emissions from the energy sector, and in particular, from electricity generation. (2)

New Zealand has set a high standard for low carbon renewable energy, as they have pushed for development of their abundant renewable energy resources while striving to meet Kyoto targets. (2) While the first
commitment period of the Kyoto Protocol is now expired, New Zealand is prohibited from surrendering
their units until June of 2015. After, the nation will be required to surrender New Zealand units to meet
targets; this will primarily be accomplished through the New Zealand Emission Trading Scheme.(5) With
the upcoming Paris Climate Conference, a 2015 international agreement may mean more obligations for
New Zealand’s climate policy.(6)

New Zealand’s electricity supply now has one of the lowest carbon dioxide emissions compared to other
developed countries in the world.(7) In 2013, 75% of New Zealand’s electricity supply came from
renewable sources including hydro, geothermal, wind, and bioenergy. In 2013, this was the fourth highest
in the OECD.(8) In addition to the high percentage of renewables in electricity generation, 38% of New
Zealand’s total primary energy supply was renewables. This was third highest percentage of the OECD
countries, with only Iceland and Norway being higher.(8) According to data calculated from information
provided by the U.S. Energy Information Administration and the United States Census Bureau from 2013,
when comparing the United States and New Zealand and normalizing by population, New Zealand is found
to have lower electricity consumption per person as can be seen in Table 1.(9-10) This difference may be
accounted for by differences in energy costs, lifestyles and conservation efforts, as well as in efficiency.
New Zealand also has a lower electricity usage per person than the United States. Because of New Zealand’s
high level of renewable electricity, fossil fuel consumption is lower. This is evident when comparing coal
and natural gas consumption. New Zealand consumes 0.07 whereas the United States consumes 0.28
million short tons per 100,000 people. This trend is similar for natural gas consumption. Since there is less
dependence on fossil fuels, the total greenhouse gas emissions from fossil fuels is lower in New Zealand
than in the USA. The total emissions from fossil fuels in New Zealand are approximately half of that in the
United States for the same amount of people.(9-10)
In the USA, coal and natural gas together provide ~66% of the electricity supply, while nuclear power made up nearly 20% in 2013.(11) New Zealand achieved 75% of electricity from renewable resources. They plan to continue development of renewable resources without any government subsidies. They only have 25% of electricity coming from fossil fuels, with no nuclear power contributions. They power the nation, but manage to have much less emissions than the United States. A variety of factors have enabled New Zealand to develop its renewable sources, and will likely lead them to achieve their goal of 90% renewable electricity supply by 2025.(2) Could the United States ever accomplish the same?

Historically, New Zealand has had the advantage of large contributions of hydropower. Hydropower, although far from being ‘green’, emits minimal greenhouse gasses from operations alone. Emissions associated with cement production from the calcination of limestone for construction of concrete hydropower dams, while not typically associated with hydropower production, are a secondary impact of hydropower and contribute to climate change.(12) New Zealand is also naturally blessed with significant geothermal, wind, and biofuel resources, however, they lack significant oil and gas resources.(13) While the naturally available resources in New Zealand have contributed to their low carbon electricity supply, other factors have played a role. Both major political parties support renewable growth,(14) with the New Zealand Emissions Trading Scheme as one of the principal policies for supporting the management of emissions.(2)

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (million)</th>
<th>Net Electricity Consumption (billion kw hr)</th>
<th>Electricity Installed Capacity (Gwe)</th>
<th>Coal Consumption (million short tons)</th>
<th>Natural Gas Consumption (billion cubic feet)</th>
<th>Total emissions from fossil fuels (million metric tons CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>4.365</td>
<td>0.927</td>
<td>0.223</td>
<td>0.072</td>
<td>3.817</td>
<td>0.868</td>
</tr>
<tr>
<td>United Stated</td>
<td>316.438</td>
<td>1.227</td>
<td>0.333</td>
<td>0.281</td>
<td>8.228</td>
<td>1.666</td>
</tr>
</tbody>
</table>
The New Zealand Energy Strategy and the New Zealand Energy Efficiency and Conservation Strategy introduced the Emissions Trading Scheme to establish a cost for greenhouse gas emissions. This policy is expected to continue to impact energy use and development, supporting low carbon electricity expansion. New Zealand’s government promotes secure and affordable energy, environmental responsibility, efficiency and conservation, and diversity in energy sources. (13) The government policies, specifically the policies in the Resource Management Act (RMA), have stringent environmental standards that have allowed the development of renewables in a safe, and clean manner. (2) If New Zealand has been able to reach this high level of electricity generation from renewables, how transferable is that experience to other nations? Is this high level of low-carbon electricity generation with higher aspirations for growth, possible for other countries, and specifically for the United States?
Chapter 2
New Zealand’s Growth of Renewable Resources

2.1 Overview of New Zealand’s Electricity System

New Zealand is a small nation consisting of two main islands, which together are just larger than the size of the United Kingdom (15) or similar to the size of Japan. (2) The country has a sparse population with about 70% of people living in just 16 cities and towns and with 75% of New Zealanders residing in the North Island. (15) The economy has a predominant export-oriented agricultural sector as well as considerable manufacturing and service sectors. (2) Farmland is thus the main natural resource, covering 40% of New Zealand’s acreage. Resources like oil and natural gas are minimal and while there are large coal reserves, they are largely, low quality lignite. (3) Lignite can be used for electricity production, but the New Zealand government has decided to phase down the last coal-fired power plants. (14) Though not used for electricity production, high quality bituminous coal mined in New Zealand, is unique in the world market because of its very low sulfur, phosphorus, and ash yield. These coking coals are exported to other countries for steelmaking and other metallurgical and industrial processes. (16)

Despite the large coal potential, with a lack of abundant natural gas resources, and the high quality hydro resources, New Zealand’s’ principal source of electricity generation became hydropower. (15) The South Island’s southern alps with 23 peaks over 3,000 m in elevation (17) combined with the south-west coast average annual rainfall between 2,000-10,000 mm, provide ideal conditions for hydropower. (18) Hydroelectric generation has been the primary source of electricity for New Zealand for the last 100 years and continues to provide the majority of electricity with over 5,000 MW of installed capacity. (8) Growth
of hydroelectric generation has slowed due to community concerns over negative environmental, aesthetic effects, and competition for water resources. (19) Nonetheless, hydropower currently provides about 55% of electricity, with geothermal providing 15%, and wind providing 5% of electricity needs. Recently, the contribution of geothermal and wind power have increased with the installed geothermal capacity increasing from about 400 MW to 750 MW and installed wind power increasing from about 40 MW to over 600 MW between the years 2000 to 2010. (15) This growth is expected to continue and by 2025 the New Zealand government has a target of 90% of electricity generation from renewable resources. (13) One of the concerns with this possible high level of renewable energy is security of supply. Exploration of energy scenario modeling has identified possible generation mixes for entirely renewable electricity systems which demonstrate security of supply over a long term period including dry years. (20) In conjunction with the increase in renewable electricity generation, the government intends to cut the CO₂ emissions by 50% from the 1990 levels by 2050. To meet these targets, the incremental growth in renewables is expected to come primarily from wind and geothermal sources. (2) The recent growth in the contribution of wind and geothermal renewable electricity to New Zealand’s supply is demonstrated in Figure 1, provided by the New Zealand Ministry of Business, Innovation, and Employment. (8) The light blue section shows growth in wind energy, while the purple section shows growth in geothermal generation between 2004 and 2014. It can also be seen that the percentage of electricity from hydropower can vary greatly, by ~20% from year to year.
In addition to renewable sources, coal and natural gas provide base, backup, and peak electricity supply. These fossil fuels currently make up about 25% of New Zealand’s overall electricity generation. Due to safety concerns, nuclear power has not had public or political support in New Zealand, and the nation will likely remain nuclear free, as electricity developments are most likely going to utilize wind and geothermal resources.

2.2 Electricity Market Structure

Prior to the 1980’s the central government of New Zealand entirely controlled electricity generation and transmission. The government set bulk supply tariffs each year, closely regulated the industry, and required consumers to purchase electricity from a supply authority which then purchased from the New Zealand Electricity Department. This structure was able to meet consumer demand, but it was not economically efficient and lacked competitive components. In the 1980’s and into the 1990’s the government enacted reforms that aimed to improve efficiency and provide more choices for consumers. It wasn’t until 1996 that an entirely competitive wholesale market was formed. The Electricity Corporation
of New Zealand (ECNZ) was initially split into two generators, Contact Energy and ECNZ. This system provided a price setting electricity pool and hedge contracts. Electricity is bought and sold in a gross half-hourly pool with all generators of over 30MW offering power into the pool and retailers submitting half-hourly. Retailers can also enter into hedges to help to decrease the volatility of the spot prices. Today about 75% of electricity is exchanged through wholesale electricity pools. Generators taking this option receive the price from the last generation unit required to meet demand. The other 25% is exchanged by financial hedge contracts between electricity generators and retailers or large industrial consumers.

In 1998, the Electricity Industry Reform Act required the ownership separation of transmission and distribution from retailing and generation. Another reform fragmented New Zealand’s electricity corporation into separate state owned entities; Contact Energy, Meridian Energy, Mighty River Power, and Genesis Power. From 1999 to 2004 the electricity industry was self-regulating, with the state owned companies in charge of generating, transmitting, and selling power, but there was disagreement on what the set of rules should be among the independent entities. So in 2003, the Electricity Commission was set up to ensure efficient, reliable, and environmentally sustainable generation and supply of electricity to New Zealand consumers. The Electricity and Gas Industries Bill was passed in 2004 and set legal framework for developments in the industry addressing the depletion of the Maui gas field, vulnerability of hydropower to dry weather, growth in demand, and energy efficiency. This bill also amended the Electricity Industry Reform Act so that transmission companies can own part of the electricity generation.

Further market restructuring has been occurring with the government selling shares in their electricity companies. More independent, and publicly owned companies have emerged as well. Today the primary generators: Meridian Energy, Contact Energy, Genesis Power, and Trust Power, still exist, but are not fully state owned. Transpower is the company that owns and operates New Zealand’s electric grid. Smaller companies are responsible for the distribution of this electricity, and even more take care of selling
the delivered electricity to consumers.(24) The Electricity Commission was taken over by the Electricity Authority, an independent crown entity, which continues to oversee operation of the electricity market in the interest of protecting consumers, promoting competition, and improving efficiency.(25) While the level of competition differs throughout the nation, all consumers have a choice in retailer, with some areas offering over 5 different options in retailers.(2)

2.3 Hydropower

New Zealand used hydropower to light up the town of Reefton in 1888. This was the first town in the southern hemisphere to experience electric lighting.(15) With New Zealand’s favorable topography and climate, an early emphasis on large schemes and the state gaining control of water use in 1896, hydropower was quickly developed, becoming the first widely used source of electricity in the country.(15) It continues to provide the majority of power to New Zealand with much of the power being supplied through the large hydropower dams Benmore, Manapouri and Clyde.(26) To take advantage of hydroelectric power, a dependable source of water is required to drive turbines. Gravity is the source of energy for hydroelectricity as water flows and turns a turbine that then drives a generator producing electricity.(26) Again, since New Zealand experiences reliable and ample rainfall, and also has a mountainous landscape with about ¾ of the land either steep hills or mountains in the South Island, early developers found hydroelectric generation an ideal option.(27) Small local operators were the first to establish hydroelectric stations, but in 1896 the government decided to prevent individuals from constructing dams without their permission.(27) As demand for electricity increased after World War II, larger hydro projects were built to try to prevent shortages in electricity. With alternating peak water flow seasons, the North island peaking in winter, and the South Island peaking in summer and spring, the nation set up a transmission system in 1965 to allow for transfer of electricity from one island to the other to guarantee electricity supply year round.(27)
Well before climate change was a concern, citizens of New Zealand protested dams because of the changes to the landscape and the alteration of water levels that can harm ecosystems. Changing the flow of water can disrupt ecosystem in a variety of ways. Some of the impacts include altered fish migration, increased velocity which prevents access to upstream habitats, damage to floodplains, changes in temperature of water that may lead to an inhabitable environment for fish and other species, and decreased water clarity that may prevent feeding. While hydropower is currently a low-cost and highly efficient option for electricity generation, many of the optimal sites for generation have already been developed. Concerns about environmental issues, have also prevented additional large-scale development. 

Despite environmental concerns with development, there are positive aspects of continuing to use the hydropower plants already in place. Hydropower emits essentially no greenhouse gasses throughout operations, effectively avoiding emissions. However, there are emissions associated with the construction of concrete dams. Electricity from a dam can be generated on short notice, so there is a secure supply. Water typically flows year-round so hydropower provides a consistent source of electricity for consumers. Storage capacity is typically a couple of months and variations in weather have a large effect on supply. Dry season can impact the supply of electricity from hydropower, so New Zealand must closely manage their hydroelectric systems. While hydropower generation has averaged about 24,000 GWh per year, with the relatively small storage capacity, the country has experienced rainfall variations, which in some cases have caused higher electricity prices. This variation is evident in Figure 1.

Because of the small storage capacity, and vulnerability to fluctuations in rainfall and snowmelt, climate change may have a severe impact on the nation’s hydroelectric schemes. With New Zealand’s glaciers rapidly decreasing in volume as well as the expected increase in precipitation and decrease in snow volume, the National Institute for Water and Atmospheric research estimates that with a 3°C temperature increase, there will be an increased flow of 40% in winter and a decreased flow of 13% in the summer. With
increased temperatures, demand in the summer will increase and there may be fluctuating supply of hydroelectricity. The security of supply will likely become less reliable. (29) Growing demand for water has also affected the hydropower industry with irrigation of dairy farms putting pressure on water supplies. (19) In addition to these challenges, capacity growth is not expected to be significant in the future because the optimal sites for hydropower have already been developed and new projects face increasing costs, opposition from environmentalists, and competition from those with other water interests. (19) Another challenge comes from transmission since there is critical dependence on the high voltage DC cable to transmit hydropower generated in the South Island to the demand epicenters of the North Island. Maintenance of the transmission system is required for the continual usage of hydropower in New Zealand. (15)

2.3.1 Waikato River Hydropower System

New Zealand has an extensive hydroelectric system, but the longest river contributing to electricity generation is the Waikato. More specifically, the Arapuni power station on the Waikato River was the first government funded hydropower station, commissioned in 1929. (31) This power station has eight generating units that generate about 805 GWH of energy each year. For every single megawatt of electricity generated from Arapuni, over two tons of water is needed every second. (31) Figure 2 shows the Arapuni hydropower dam.
This dam diverts water from the river into the Arapuni powerhouse at the base of the gorge pictured in Figure 3. When Arapuni first began operating, there were only four generators, but since, four additional generators have been added to the powerhouse.(31)
The last two generators were added to meet increased energy demand during the Second World War. The turbines in the powerhouse each have a capacity of about 26.7 MW and a peak efficiency of 94%. This station has the largest capacity in the Waikato River hydropower system.(31)

Mighty River Power owns and manages the Waikato hydro system. The Waikato River flows out of Lake Taupo. Although Lake Taupo is the largest storage reservoir in the Waikato hydropower scheme, only 1% of the lake’s total volume is permitted for use. This water resource must be shared between Mighty River Power for electricity generation, and agricultural businesses for irrigation.(32) The Lake Taupo levels are closely monitored to ensure that no more than 1% of the volume is used.(32) This helps to keep lake level variation close to what it would be naturally, helping to minimize environmental damage; however, management of water levels makes meeting electricity demand more difficult during dry weather spells.(26) Figure 4, provided by Mighty River Power, clearly shows the average height above sea level for each reservoir in the Waikato Hydro System. Taupo has the highest level, and as water flows down the Waikato with the topography, the height above sea level decreases.(32) These levels are closely monitored and managed with changes in weather to ensure that Lake Taupo does not have a significant water level change that could be detrimental to electricity supply, and to surrounding ecosystems.(2)
Even though the continued development of hydroelectricity is limited, given the history and large-scale development of hydropower in the past, hydroelectric generation is likely to stay a prevalent source of electricity in New Zealand moving forward. As New Zealand continues to develop wind resources, hydropower will serve as a complimentary source of electricity generation as with wind there is good long term predictability but intermittency and unpredictability in short term supply, but with hydropower there is good short term predictability and poorer long term predictability. The benefits of wind compensate for the shortfalls of hydropower and vice versa. This has reduced some of the issues relating to management of hydroelectric generation schemes because when hydropower is unable to meet demand, wind usually is able to make additional contributions.
2.4 Wind

The wind resources in New Zealand are among the best in the world with high wind velocities and consistent availability. New Zealand is situated in the Roaring 40’s, thus much of the island is positioned on the 40° latitude line that experiences the persistently strong westerly winds of the Southern Hemisphere. Due to these consistent winds, compared to the international average of 24%, New Zealand wind farms operate at 45% of maximum capacity on average. Wind farms in New Zealand typically generate double the electricity of the average international wind farm. For about 90% of the time, a windmill will produce electricity in New Zealand. While wind is much more reliable in New Zealand, there is still an element of variability that will make it impossible for wind to ever completely replace gas, coal, or hydropower stations which are more dependable and required for meeting peak demand, unless energy storage issues can be overcome.

Wind turbines generate electricity by harnessing the natural winds. As wind flows past the turbine, the blades are lifted causing a rotational force. The spinning blades turn a shaft inside the nacelle, which powers the gearbox. The gearbox uses magnets to convert this rotational energy into electrical energy. This energy goes into the wind farm’s substation and is then converted and fed into the local network or grid, transmitting electricity to houses and offices. With higher wind velocities, more energy can be generated. With wind speed doubling, energy output can increase by eight times. Although, wind is a variable source of electricity, wind speeds can be predicted accurately and the output for a particular wind farm can be forecasted days ahead. This allows management of fluctuations in supply of wind and other sources to meet demand when wind output is low. Again, hydroelectricity and wind are complementary as hydropower resources can be conserved while wind is blowing. Then water can then be saved for use another day, or used to meet daily demand peaks.
Wind turbines do not emit any greenhouse gases while operating. (37) A lifecycle analysis by the National Renewable Energy Laboratory found that wind farms, in their lifetime, which includes manufacture, construction, and transportation, contribute only 1% of the emissions compared with traditional fossil fuel generated power. (38) As New Zealand seeks to decrease CO₂ emissions, wind energy will play a crucial role. Emission reductions are one environmental benefit of wind, but there are also a few environment costs. For example, thousands of birds and bats, including endangered bird species are injured or killed by wind farms each year in the United States. (39) Fortunately, with careful consideration in choosing a wind farm location, ecological disturbances can be minimized. New Zealand is also using an advanced Avian Radar System to track the natural altitude and path of bird flocks. This allows more accurate tracking than simply having human spotters and will help determine optimal locations for new wind farms. (33)

Perhaps the most significant environmental impact of the wind industry comes from the dependence on rare earth elements neodymium and dysprosium. These elements are needed in the manufacturing of magnets, which are often used in the motors of wind turbines. (39) MIT researchers found that if growth in the wind industry continues, in the next 25 years, neodymium and dysprosium supply would need to increase by 700% and 2600% respectively. A 3.5 MW wind turbine using a synchronous motor with a permanent magnet has a rare earth element content 600 kg. (40) China accounts for 95% of rare earth element production, and has a poor record for sustainable mining practices. Mining one ton of these elements creates about one ton of radioactive waste, and between 9,600 and 12,000 cubic meters of waste gas containing acidic wastewater, sulfuric acid, hydrofluoric acid, sulfur dioxide and dust concentrate. (41) Regulations for safe storage of waste are not as stringent, and the environmental and health damages are more severe. (39) It is possible to create wind turbines without synchronous motors, although magnet technology is most commonly used today. (40)
While the New Zealand government supports growth in wind energy, now through the use of the Emissions Trading Scheme, they haven’t provided direct subsidies to wind farms like other countries developing wind capacity. Thus, in New Zealand, farms are only built if the farm is forecasted to provide enough electricity at a competitive cost.(35) Table 2 shows what it cost in 2009 to generate electricity from different sources. The range for wind was very similar to that of New Zealand’s other resources.(42)

### Table 2: 2009 Costs of Different Types of Electricity Generation (c/kWh), Provided by Meridian Energy(42)

<table>
<thead>
<tr>
<th>Resource</th>
<th>Cost of Generation (NZ c/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>7.8-10.1</td>
</tr>
<tr>
<td>Hydro</td>
<td>7.3-10.5</td>
</tr>
<tr>
<td>Gas</td>
<td>7.4-12.4</td>
</tr>
<tr>
<td>Coal</td>
<td>8.2-10.2</td>
</tr>
<tr>
<td>Geothermal</td>
<td>7.0-9.2</td>
</tr>
</tbody>
</table>

One benefit of wind energy is that the fuel for the turbines, the wind, is free. Future costs are more predictable than fossil fuel prices, particularly oil and gas, which are volatile. Additionally, wind avoids being affected by New Zealand’s carbon trading scheme, and the potential for rising costs of greenhouse gas emissions.(35) Note that in Table 2, fossil fuel costs for generation do not include the cost of emissions that gas and coal companies incur under the Emissions Trading Scheme. So even though there are some variables, like changing wind speeds, transmission costs, capital costs, other commodity costs, as well as different construction costs for roads, turbine foundations, and turbine set up, wind has a good outlook for being cost efficient now and in the future.(35) In addition, costs are expected to decrease as knowledge improves, the supply chain stabilizes, and more is invested in research and development. With New Zealand’s strong winds and the availability of complementary hydropower for additional storage and peak supply, the integration of wind power into New Zealand’s electricity system has been uniquely affordable without the aid of direct government subsidies.(35) While there isn’t currently a subsidy provided for wind energy, researchers from the University of Otago found that enacting a Feed-In-Tariff policy could
potentially accelerate wind energy development, and help overcome hurdles related to economics, consenting issues and grid connection challenges.(43)

2.4.1 Wind Farms in New Zealand

Taking a closer look at a few of New Zealand’s wind farms reveals the success of wind farms in the nation as well as the regulatory and social hurdles faced. The Te Uku wind farm is situated in the countryside of Waikato. This wind farm has 28 turbines and can generate 64.4 MW of electricity. Meridian Energy built it on a working sheep and cattle farm on a plateau that has strong winds. The farm became operational in 2010, taking about 18 months to construct.(44) The first stage of construction was focused on building 26 kilometers of roads, which were necessary to support the weight of the turbines during transportation. It then took 395 cubic meters to set each of the 28 turbine foundations before Siemens 2.3 MW wind turbines could be installed.(45) This farm, like all new energy projects in New Zealand, had to abide by the Resource Management Act. The Resource Management Act of 1991 (RMA) became the nation’s primary legislation ensuring sustainable management of the environment. The RMA requires both local and central government to take responsibility in managing issues regarding the environment.(46) According to Robin Christy, tour guide at the Te Uku wind farm, following the RMA at this site entailed a study of waterway impacts and sediment flow that could be disrupted by the wind turbines, in addition to following all of the construction protocols. While landowners and community members were not initially enthusiastic about the objective, most have had a change in attitude, as Te Uku has been successful and with noise and visual impacts kept at a minimum for the closest neighborhoods. Figure 5 shows the view from the hilltops of the Te Uku Wind Farm with one of the 2.3 MW wind turbines shown on the right. In this figure, the large scale of these turbines is easily recognized, with a major change in the landscape evident.
Figure 5: The Te Uku Wind Farm, Photo Credit: Author

Figure 6 displays the massive size of a wind turbine, with the photograph showing the hub of a turbine at the Te Uku Wind Farm. These turbines are the tallest in New Zealand at a height of 80 m and with blades 49 m in length. (45)
As was observed at Te Uku, a major challenge for wind energy development in New Zealand is social resistance. Various factors like turbine size and color, turbine noise, landscape changes, local impacts of construction, proximity to important features, and impacts of property values were found to be of concern to many locals to wind farms. (47) Unless these negative perceptions of wind farms are overcome, there may be challenges to continued growth.

Another wind farm visited in New Zealand was the Tararua wind farm in the lower part of the North Island. Tour guide Mike Hewitt, explained that the wind farm, owned by Trust Power, is the largest in the southern hemisphere and one of the highest electricity producing farms in the world. Tararua has 134 wind turbines with a combined capacity of 161 MW, and it is located on a privately owned farm. (48) The mountainous terrain makes it so wind turbines are situated at different elevations. Because of the different elevations, which cause different wind flow velocities, efficiencies between wind turbines vary. Wind turbines at the higher elevations are about 55% efficient while windmills in lower elevation areas are only about 39%
Current research on finding the best placement for turbines continues to help optimize generation. The wind turbines at this farm spin at about 12 to 14 m/s at full power. Figure 7 shows two of the older design wind turbines at the Tararua wind farm.

Figure 7: Tararua Wind Farm, Photo Credit: Author

New Zealand currently has 19 wind farms either under construction or operating. Together the operating wind farms provide 5% of New Zealand’s electricity to about 180,000 houses a year. While there is ~623 MW of installed capacity today, there are 2500 MW of capacity consented, and developers are continuing to explore for potential sites. Figure 8, provided by the New Zealand Wind Energy Association, maps New Zealand’s wind farms, both operating and proposed, with green wind turbines indicating wind farms that are currently operating and orange turbines indicating wind farms that have been consented or that are proposed but have not yet been consented.
New Zealand’s strong and consistent wind resources along with the usability of existing transmission lines, which were historically put in place for hydropower transmission from south to north, have been integral to the success of New Zealand’s wind energy thus far. Although, success of all of New Zealand’s renewable resources for electricity generation is dependent on the long term maintenance and development of electricity transmission lines.(2) Figure 9, a map provided by the International Energy Agency, shows a map of the electricity transmission system in New Zealand.
Transmission additions have been minimal for the operating wind farms as the wind farms are located mostly along areas where there are already main transmission lines as can be seen by looking at Figures 8 and 9. Nonetheless, issues related to the differences in requirements for connection to transmission lines have resulted in difficult procedures for wind developers.(43) Moving forward, updates to the transmission systems will be required for continued wind developments to ensure electricity supplies can reach demand locations.
2.5 Geothermal

New Zealand’s large-scale development of geothermal power began in the 1950’s with the commissioning of two power stations, but for hundreds of years, the Maori have used geothermal resources directly for cooking, bathing, and heat. With the increase in hydropower developments and the discovery of the Maui gas field in New Zealand, growth decelerated between the 1970’s and 1980’s. Geothermal power development has more recently accelerated, with improvements in the market conditions, the reduced supply of gas, and the 1993 deregulation of electricity supply and generation. Geothermal power accounts for approximately 15% of the electricity supply. It is the second largest source of electricity generation behind hydropower. In addition to use for electricity generation, geothermal resources continue to be used for applications such as heating greenhouses, drying timber or other crops, and providing public bathing.

Geothermal generation uses the heat from the center of the earth. In New Zealand, fault zones are created from the subducting Pacific plate under the Australian plate. It is this tectonic system that creates magma bodies closer to the surface of the earth, and that causes fluids to heat up. Groundwater percolates towards the heat sources and then rises from buoyancy effects. This hot water may migrate to permeable rock and form a geothermal reservoir. Reservoirs are extremely hot, often reaching temperatures over 350 °C. Geothermal wells tap into these hot reservoirs, bringing steam and fluid to the surface. These fluids are then piped to a central facility and the heat is used to spin turbines generating electricity. The used hot water is re-injected into the ground and reused, or in some cases released into local rivers.

Geothermal resources are generally considered “renewable,” but heat is often removed at a much faster rate than it is replenished. Injecting waste fluids back into geothermal systems helps to replenish volume and improve imbalance, though unless this rate becomes completely balanced it is possible to run out of heat in a particular geothermal system and have to wait until that heat is replenished to continue generating
electricity. (53) Natural features of the land like hot springs, geysers, and mud pools can be irreversibly damaged by the development of geothermal resources. Countless features have disappeared in New Zealand, including many in the famous Geyser Valley. Once a tourist destination, it is now unfortunately shut down. (53) Another impact of extracting geothermal fluids is the reduction of pressure in reservoirs, which causes subsidence. This can destroy property or habitats as the ground sinks and tilts. It can also damage pipelines, roads, and natural waterways. (53) In Rotorua, unregulated development up until the 1980’s caused land subsidence of 10 m, which was the highest for subsidence from underground fluid loss. (15) Another challenge of geothermal development spawns from ownership of geothermal resources by the native Maori people. The Maori regard geothermal elements with cultural importance and are now actively involved in geothermal developments to protect the future of these resources. (15)

In addition to subsidence and loss of geothermal features, there are a few other environmental concerns with large-scale geothermal development. Geothermal generation is not emissions free. Geothermal fluids contain H$_2$S and CO$_2$ which are toxic to people and contribute to climate change. (53) Still, geothermal generation facilities emit much less greenhouse gasses than typical fossil fuel plants, approximately 85% less CO$_2$ emissions compared to natural gas plants. (54) The geothermal waste, if not properly re-injected, can cause water pollution because fluids contain high levels of arsenic, mercury, lithium, and boron. These pollutants are unsafe for drinking and irrigation water and can harm aquatic life. (53) Fortunately, pollution from geothermal development is less common now with improvements in disposal or reinjection of fluids and stricter regulations. (51)

It can be difficult and costly to find and maintain geothermal resources for the lifetime of a generation plant. There are high upfront costs associated with the development of geothermal resources. There is also a risk of depletion if resources are not managed appropriately. (51) GNS Science conducts geophysical investigations to identify contrast between rock characteristics and determine the best place to drill.
geothermal wells and to ensure that the resources are being maintained. They help to protect the resources from depletion. While there is a large initial investment required for geothermal drilling, Dr. Bishnell from GNS Science explained that the generation potential for geothermal is about 5 times higher than that of gas. With an increase in depth and ease of extraction, the initial investment needed will decrease as well.(55)

2.5.1 Nga Awa Purua Power Station and Geothermal Drilling Rig

According to tour guides from Mighty River Power, Nga Awa Purua Power Station was commissioned in 2010 and generates 140 MW nominally powering 140,000 homes. The station currently uses 9 production wells and 4 re-injection wells and has one of the largest geothermal turbines in the world. The resource consent is based on the rate of production and not the rate of reinjection. There is a limit on production of 2,500 tons liquid/day.(56) In addition there are limits on hydrogen sulfide and carbon dioxide, which are vented in the cooling tower.(56) There are a maximum of 17 people working the plant at a time and one operator working at all times. One challenge for Mighty River Power is that they are only allowed 1.6 m of elevation change in the river. With a lack of rain, production can become more dependent on the weather, similar to hydropower. With the dynamic freely traded market, New Zealand’s energy prices change on a half hour basis, but the geothermal generation is highly competitive with other sources.(56) Figure 10 shows part of the Nga Awa Purua Power Station.
Tour guide, Jim Gray, for the geothermal drilling rig, said that geothermal wells in New Zealand cost about 15 million New Zealand dollars each. Depending on the formation, the rig can drill at about 25 to 30 m/h at a maximum. Above these velocities, the drill bit is much harder to control. Jim said that when the rig is not drilling, a camera is often run into the wellbore to get some idea of the formation. In this area, there has been a high drilling success rate and many of the workers are locals coming from various backgrounds. This geothermal development has helped the local economy by providing employment opportunities to residents of the area. Again, geothermal electricity generation does not release a large volume of greenhouse gases, but Jim Gray mentioned that to drill the wells the drill engine uses about 17,000 liters of diesel a day.(56) An image of the geothermal drilling rig toured is shown in Figure 11.

Figure 10: Nga Awa Purua Power Station, Photo Credit: Author
There is potential for geothermal energy expansion in New Zealand. Taking into account environmental and regulatory restrictions, the 2012 estimate from the Energy Efficiency and Conservation Authority found over 850 MW of economic geothermal reserves. With improvements in technology or changes in market conditions this number could increase.(51)

2.6 The Future of New Zealand’s Electricity Supply

For its relatively small size, New Zealand has an expansive array of renewable energy resources. Though historic, hydroelectric and geothermal resources continue to contribute to generation along with growth in new resources.(15) The New Zealand government, which still has a large amount of control over the
electricity industry, is committed to maintaining and improving renewable electricity generation. Despite challenges, the nation has managed to develop a significant portion of their renewable resources, and have made plans to continue developments.(14) Growth in renewables will be important for the economy in New Zealand, for meeting the rising energy demand, for reducing emissions, for improving the country’s global image, and for protecting the nation from price increases and supply problems associated with fossil fuels.(13) Electricity output is expected to increase to 54.2 TWh by 2030.(2) Of all the renewable resources, wind and geothermal energy have the largest potential for growth in New Zealand.(13) Wind capacity is expected to increase by a factor of six while the share of coal decreases.(2) While the technology, capacity, and efficiency of wind turbines continues to improve, the costs should go down, which may make wind energy a more attractive option further in the future. The New Zealand Wind Energy Association expects wind power to grow from 622 MW installed capacity in 2012 to over 3500 MW in 2030. While today wind supplies 5% of New Zealand’ electricity, by 2030 it is expected to generate near 20%, and this includes keeping up with rising demand.(14) Based on energy demand projections, New Zealand will need 21% more electricity by 2030.(14) Figure 12, provided by the New Zealand Wind Energy Association, shows electricity demand versus time. Based on expected economic and population growth, the New Zealand government predicts that demand will increase by about 1 to 1.2% per year.(2) Demand will be at about 52,000 GWh by 2030 and peak demand is expected to be at 8 GW instead of the current 7 GW.(14)
Wind and geothermal developments will be needed to meet demand as the Huntly coal power plant phases out.(14). The New Zealand Wind Energy Association analyzed data from Deloitte, Bloomberg, and the Ministry of Economic Development to create an expected generation breakdown for 2030. Table 3 shows how the generation capacity for different sources is expected to change from 2012 to 2030.

**Table 3: New Zealand's Expected Generation Mix to 2030, Provided by New Zealand Wind Energy Association** (14)

<table>
<thead>
<tr>
<th>Generation Type</th>
<th>Generation Capacity from 2012 to 2030 (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>5.2 - 5.4</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.7 - 1.2</td>
</tr>
<tr>
<td>Gas</td>
<td>1.4 - 2.3</td>
</tr>
<tr>
<td>Coal</td>
<td>1.0 - 0.25</td>
</tr>
<tr>
<td>Wind</td>
<td>0.6 - 3.5</td>
</tr>
</tbody>
</table>

Wind energy will likely increase additional installations. Geothermal capacity is expected to nearly double, but then growth will probably be limited until the commercialization of improved geothermal technologies.
Hydropower capacity is not likely to increase significantly. This type of generation will become more geared to meeting peak demand.(14) While hydroelectric output is vulnerable to weather, variability is likely to diminish because of an increase in gas-fired plant generation as more flexible source.(2) As coal generation capacity decreases with the phase down of the Huntly power plant, gas generation is expected to increase to help meet peak supply, and fill in any gaps in generation. Storage of water in lakes will increase, with higher capacity for longer periods of time, and wind will likely be available to meet more of the electricity demand.(14)

The future will likely bring a more diversified electricity portfolio for New Zealand with a lower reliance on fossil fuels than most other developed countries in the world.(8) In addition to these predictions there are other possibilities with the continued advancement of technology. Other sources may become available and cost effective. While the world may not yet have a clear answer to the environmental problems associated with greenhouse gas emissions, New Zealand has taken steps to minimize their footprint and to ensure sustainable development moving forward.(13) As society slowly transitions into a low-carbon electricity supply, New Zealand has proven to be a leader in renewable development. For other countries, New Zealand has demonstrated that it is possible to meet electricity demand with a diverse generation mix.(57)
3.1 Renewable Resource Potential

If New Zealand can sustain its population with 75% of electricity coming from renewable resources,(8) what’s keeping the United States from achieving a similar high-level of renewable use? Differences between the United States and New Zealand have led to the utilization of various resources for electricity generation. Variations in population, geographic size, resource quality and availability, demand, market structure, culture, lifestyle, government support and policy have contributed to the differences in the generation portfolios of each country. While there are many differences between the nations, both have the resource potential to achieve a 100% renewable electricity supply. According to the National Renewable Energy Laboratory (NREL), in the United States, estimated technical capacity potential for all the renewable technologies total 212 TW and estimated generation potential total 481,800 TWh.(58) Technical potential, as defined by NREL, represents the possible energy generation given system performance, topography limitations, and environmental and land use constraints. It does not factor in economic or market assumptions that limit development potential.(58) These totals were calculated from the values listed in Table 4, provided by the NREL.
Table 4: Total Estimated United States Technical Potential Generation and Capacity by Technology, Provided by the National Renewable Energy Laboratory (58)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Generation Potential (TWh)</th>
<th>Capacity Potential (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban utility-scale PV</td>
<td>2,200</td>
<td>1,200</td>
</tr>
<tr>
<td>Rural utility-scale PV</td>
<td>260,600</td>
<td>153,000</td>
</tr>
<tr>
<td>Rooftop PV</td>
<td>800</td>
<td>664</td>
</tr>
<tr>
<td>Concentrating solar power</td>
<td>116,100</td>
<td>36,000</td>
</tr>
<tr>
<td>Onshore wind power</td>
<td>32,700</td>
<td>11,000</td>
</tr>
<tr>
<td>Offshore wind power</td>
<td>17,000</td>
<td>4,200</td>
</tr>
<tr>
<td>Biopower</td>
<td>500</td>
<td>62</td>
</tr>
<tr>
<td>Hydrothermal power systems</td>
<td>300</td>
<td>38</td>
</tr>
<tr>
<td>Enhanced geothermal systems</td>
<td>31,300</td>
<td>4,000</td>
</tr>
<tr>
<td>Hydropower</td>
<td>300</td>
<td>60</td>
</tr>
</tbody>
</table>

In 2013 the International Energy Agency estimated that the United States generated 4274.5 TWh of electricity and had a total installed capacity of 1067.9 GW. (57) Technologically, the United States has an abundance of renewable resources that could be used to supply more than enough electricity to meet national demand if economic, political, and social impediments were overcome. Similarly, New Zealand’s wealth of renewable resources could supply 100% of electricity. New Zealand’s renewable resources could potentially meet double the nation’s demand for electricity. (59)

If both countries have abundant renewable resource potential, why does only one have a high level of renewable electricity utilization with high aspirations for continued development? New Zealand has a much lower electricity demand than the United States because the population is about 73 times smaller. (10) The nation has the benefit of having abundant renewable resources within a small area, and thus, can more easily transmit the power supply to demand centers. New Zealand has a historical advantage in that the nation has its electricity foundation in hydropower generation. Even with high aspirations and strong government support, New Zealand faces hurdles in continuing to develop renewable resources, but the United States is far behind, with only an estimated 12.9% of electricity coming from renewables in 2013. (57) Figure 13
shows the difference in electricity percentage from renewable resources for different countries. The United States and New Zealand are marked with blue arrows.(57)

![Figure 13: Generation from Renewable Resources in 2013 as a Percentage of total Electricity Generation in IEA member countries, Data provided by the International Energy Agency (57)](image)

There is a large difference between these two nations in the contribution of renewable resources as a percentage of the total electricity supply. It can also be observed from figure 13 that nations with higher percentages of generation from renewables tend to utilize a more hydropower, shown in dark blue, as it is less variable than wind or solar power. This is evident in nations such as Norway, Australia, New Zealand, Canada, and Switzerland. However, looking at Denmark reveals that it is possible to achieve a high percentage of electricity generation from wind energy, shown in light blue.(57)

3.2 United States Electricity Portfolio

Though New Zealand has 75% of electricity from renewables (8) while the United States only has 12.9% coming from renewables,(57) the United States far exceeds New Zealand in installed capacity of renewable generation as can be seen in Table 5.(2-57)
Table 5: Installed Capacity of Renewable Resources in New Zealand (2) and the United States, (57) Information from the International Energy Agency

<table>
<thead>
<tr>
<th>Country</th>
<th>Wind</th>
<th>Geothermal</th>
<th>Hydropower</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>0.62</td>
<td>0.75</td>
<td>5.00</td>
</tr>
<tr>
<td>United States</td>
<td>59.60</td>
<td>3.40</td>
<td>78.00</td>
</tr>
</tbody>
</table>

In 2013 the United States generated close to 550 TWh of electricity from renewable sources. The largest amount coming from hydropower which accounted for 6.3% of electricity generation, with wind at 4%, biofuels and waste at 1.7%, geothermal at 0.4% and solar 0.4%.(57) Generation from wind has increased the most, an increase of 13-fold from 2003 to 2013. Even though the United States has a large capacity of renewable resource generation, they rank 7th from last among countries in the International Energy Agency for the share of renewables in electricity generation.(57) In 2013, coal and natural gas together generated 67% of electricity, with coal generating 40.2% and natural gas providing 26.9%.(57) As demand has increased, use of both coal and natural gas has increased, but the contribution of electricity production from coal peaked in 2005 and has been declining since, while the contribution of generation from natural gas has been increasing. Figure 14, provided by the International Energy Agency, shows the contribution of each source over time.(57)

Figure 14: U.S. Electricity Generation by Source from 1973 to 2013, Provided by the International Energy Agency (57)
The contributions of coal and oil have decreased while natural gas has increased. Concurrently, hydropower, nuclear power, and biofuels have stayed relatively constant from 2003 to present. Contributions from wind, however, have increased from nearly nothing in 2003 to about 167.7 TWh in 2013.(57)

3.3 Energy Abundance and Cultural Resistance to Renewable Technologies

New Zealand generated 43.4 TWh of electricity in 2009 compared to the United States, which generated 4274.5 TWh in 2013.(2) The scale of electricity production is about 100 times larger in the United States than in New Zealand. The United States is the world leader in consumption of electricity.(60) Nearly all the electricity generated in the U.S. is also consumed in the U.S.(57) This large supply of electricity in the United States required to meet demand, creates challenges for renewable development. Even with a high rate of renewable development and increases in installed capacity, it will take a longer period of time for alternative resources to contribute a significant portion of supply. The amount of installed capacity from renewables is higher in the United States, as is seen in Table 5.(57) But because of the larger supply, the portion of electricity coming from renewables is lower than in New Zealand where a smaller amount of renewable capacity makes up a larger portion of electricity generation.(2)

In New Zealand, 37% of electricity demand comes from the industrial sector, with 32% from the residential sector, and the rest largely comes from the commercial and public service sectors.(2) The break down of consumption in the United States is essentially the opposite, with 40.2% of total demand from commercial and public service sectors, 36.9% from the residential sector, and 22.7% from the industrial sector.(57) The largest portion of consumption in New Zealand, the industrial sector, is the smallest portion of consumption in the United States. In the U.S. a larger portion of consumption comes from homes, businesses, and
government organizations.(57) whereas in New Zealand a larger portion of electricity is consumed by industries.(2)

Certain industries, like the iron, steel, cement and refining sectors, do not typically utilize renewable resources because the processes require higher energy intensity. Fossil fuels are used for 70% of the energy required for these industries.(61) While these industries exist in both New Zealand and in the United States, the scale of the United States industrial sector is much greater, with industry accounting for nearly one third of the nation’s total energy consumption.(62)

The sheer abundance of energy in the United States creates cultural impediments to the adaptation of renewable resources as well.(63) For over 50 years, Americans have linked a successful, high-tech society to reliable and cheap energy: new cars, large homes, and energy intensive appliances. The history of the nation, with 200 years of affordable electricity, abundant resources, and economic and industrial growth, has played a role in creating a culture of consumerism. Psychological elements like the desire for high social status, entitlement, comfort, and freedom also encourage an attitude of wasteful consumption and can cause social resistance to new technologies.(63)

In the United States, the cultural barriers to renewable energy and efficiency may be more difficult to overcome than in New Zealand. Only about 12% of American individuals can pass a basic electricity-literacy test, according to a study conducted by researchers from the Centre on Asia and Globalization, Lee Kuan Yew School of Public Policy, and the National University of Singapore.(63) Most of the United States electricity supply puts stress on the environment and the market. Because most power stations are away from cities and neighborhoods, the general public is largely unaware of the immediate physical impact these power stations have on their environments. Thus, because it is not part of their daily lives, most consumers do not consider the issues associated with electricity production. U.S. citizens flip the switch on to an
apparently clean, cheap, and invisible supply of energy. This segregation of production from consumption is a major hurdle for renewable electricity adoption because costs and benefits of different sources are not easily observable. (63) The public largely lacks interest in understanding the electricity system enables utility operators to keep control, maintaining profit levels. Utilities tend to bolster fossil fuel and nuclear power plants since they are able to transfer some of the external costs of pollution onto broadly unknowing consumers. (64)

In New Zealand, cultural barriers to development of new technology exist as well. For example, many locals were against the Te Uku and Tararua wind farms initially. Other wind farms have had similar social resistance to change because they don’t like the way the turbines look or sound, they don’t agree with the location they are being installed, or they dislike construction inconveniences in their neighborhood. (47) The Victory University of Wellington has conducted a case study of the Tararua Wind Farm, which shows that most of the individuals opposing wind farms initially in New Zealand change their opinions once the wind farm is completed. Individuals realize that the wind farm did not cause the expected adverse effects or did not cause them to the extent that was anticipated. (65) Since there have been many success stories in New Zealand, furthering growth in renewables becomes slightly easier. Social and institutional barriers are already being overcome, whereas in the United States a much larger population is resisting change.

3.4 Dependence on Transmission Expansion for Penetration of Renewable Electricity

In New Zealand, integration of renewables into the existing electricity transmission system may be less complex than in the United States. New Zealand has abundant renewable resources: hydropower, wind, and geothermal. The transmission system was set up historically to allow hydropower to be transferred from the South Island to demand centers in the North Island. Because the renewable sources are geographically close to existing lines, renewable electricity integration has occurred without the additional installation of
extensive transmission lines. (2) Nonetheless, there was insufficient investment in the network over the last 20 years, so significant upgrades to the national grid are required to meet demand and maintain a reliable supply of electricity. (2)

Integration of a high level of renewable energy to the United States grid is more convoluted. Conventional generation from fossil fuels allows the transport of fuels to generation facilities, whereas renewable energy is typically generated at the geographic location of the resource and then transported through transmission lines. In the United States, the majority of high quality renewable resources are located in remote areas, away from large demand centers. (66) Electricity demand is concentrated in high population density areas. It varies with climate, season, and time of day or night. (60) The interconnected electrical power network in America must instantly match supply to demand. A high penetration scenario for renewables would depend on variable generation technologies like solar and wind, which require a greater degree of management to reliably maintain the balance of supply and demand. Updated transmission infrastructure is an essential element in maintaining this balance. (66) Figure 14 shows the United States population density by county according to the United States Census Bureau. (67)
High demand coincides with the high population densities shown in red in Figure 15. (67) Maps of the United States’ potential onshore wind, photovoltaic solar, and Enhanced Geothermal System (EGS) resources, reveal the mismatch between locations of high quality renewable resources and high population demand centers. Most of the high population density areas are in the eastern and coastal cities, with lower population in the central and western parts of the country. Figure 16, provided by the National Renewable Energy Laboratory and AWS Truepower, shows the United States’ onshore wind resource potential. (68) High-speed winds, most economic for development, are located centrally, away from coastal demand centers.
Enhanced geothermal system resources have the highest potential in the west, shown in Figure 17, provided by the National Renewable Energy Laboratory. (68) Again, the highest quality resource is located away from load centers, with the most favorable locations for EGS in the non-coastal west. The only exception is the Southern California coast with high demand and high quality geothermal resources nearby. (69)
Figure 17: Enhanced Geothermal Systems Potential in the United States, Provided by the National Renewable Energy Laboratory (69)

Figure 18, provided by the National Renewable Energy Laboratory, shows the photovoltaic solar resources are again concentrated in the western part of the nation, with limited resources in the more heavily populated east. (70) The concentrating solar resources, are similarly located in the west, away from high load centers. (70)
The majority of quality renewable resources are geographically dispersed. They are remote from demand centers. The highest electricity demand comes from the urban areas of the northeast, with the highest quality resources located in the central and western states. Therefore, high penetration of renewable resources creates a need for extensive transmission expansions to connect the resources to demand centers. Extending the transmission network requires overcoming issues relating to permitting and siting lines and power plants as well as to managing variability of generation between sources. Transmission planning becomes complex with a mix of federal, state, and regional laws and policies governing development. Congress has introduced bills to help the federal government gain control over transmission planning. These bills aim to support the nation’s goals to move forward with meeting renewable energy standards. Regardless, the power to act remains mostly with the individual states. Developing renewable resources and building new transmission lines requires coordination between states, transmission companies, and local utilities. The cost-effectiveness, and thus the success of renewables in the market, is largely dependent
on transmission. But the current approach to transmission planning and siting is ineffective, therefore impeding renewable energy development.(71)

One high quality resource that is not located remotely from coastal demand centers is offshore wind. These wind resources have the potential to supply a large portion of electricity. Because these resources are available close to coastal demand centers, transmission issues are significantly reduced.(72) Offshore winds have higher velocities and are more consistent than onshore wind resources. There are currently no operating offshore wind farms in the United States although the Cape Wind project in Massachusetts’ Nantucket Sound has been proposed and approved with construction expected to begin in 2015.(73) Developing offshore wind potential will be difficult because of high costs, technology limitations, ambiguity surrounding regulations and institutional policies, and social and environmental risks. Challenges also stem from the marine environment. Wind farms must be resistant to corrosive waters, be able to withstand waves and storms, and have minimal impacts on marine life.(72) Despite challenges, the United States Department of Energy has committed the nation to strive for 20% of electricity generation from wind by 2030.(74) This goal is dependent on the success of offshore wind. (74) Offshore wind has already been developed in Denmark, Norway, Netherlands, Belgium, Great Britain, and other European countries.(75) At times when demand is low, Denmark can occasionally meet 100% of national electricity demand with wind generation. With high quality wind resources, and prominent political support, achieving remarkable levels of generation from wind becomes more realistic.(76)

In addition, there is potential for hydropower development near load centers. According to the United States Department of Energy, over 65 GW of hydropower potential still exists in the country, yet environmental and social concerns limit large-scale development in many areas.(77) It is unlikely that additional large scale hydropower projects, on undeveloped resources, will be added to the generation portfolio because of the environmental impacts on endangered aquatic species and habitats as well as industrial impacts on
fishing and tourism.(78) Hydropower is also strongly regulated, with expensive, time consuming, and often outdated requirements for planning and developing.(79) Because many of the best sites for hydropower facilities have already been developed, finding new sites with proper standards and with minimal ecological impacts is difficult; however, upgrading existing hydropower facilities could bring online a capacity of 17,000 to 30,000 MW with efficiency improvements adding an additional 4,000 to 7,000 MW.(79) Small and micro hydropower projects could also tap into this large potential with low-impact designs.(77) Figure 19 shows the hydropower potential in the United States. The highest potential is found in the western states of Washington, Idaho, Alaska, Oregon, Montana, California, and Colorado, but with many eastern states also having significant potential.(77)

Figure 19: United States Hydropower Potential, Provided by the United States Department of Energy (77)
New Zealand is able to continue operating old hydropower dams and avoid greenhouse gas emissions. The United States did not develop a large portion of their hydropower resources early on because of the availability of fossil fuel resources primarily coal, oil, and increasingly natural gas which became heavily utilized in the electricity industry well before the environmental, health, and atmospheric impacts were realized. It is not likely the nation will develop a large portion of hydropower potential in the future either. The vulnerability of hydropower generation to climate change, the negative ecological impacts of dams, the heavy regulations on the industry, and lack of proper sites for large facilities serve as substantial barriers to extensive development. (79) While New Zealand has the benefit of a large portion of existing hydropower generation, it would be challenging for the United States to develop hydropower to the point where the portion of generation increases above 6-8% of the nation’s electricity supply. (78)

3.5 Economic and Political Landscapes

In New Zealand, renewable energies receive meager support schemes from the government. Renewable technologies are already cost competitive with fossil fuels. Thus, most renewable electricity projects depend solely on current market mechanisms. (2) Though, with the high initial cost of wind energy and other renewable technologies, as well as challenges with delays during the consenting period, there are still substantial economic barriers to steady development. (43) New Zealand’s government does supports a competitive electricity market by aiming to continually improve older policies like the Resource Management Act to make the consenting process smoother, by addressing market failures and system constraints, and by promoting consumer choice. (13) Yet, fossil fuel generators receive government subsidies while renewable technologies do not. (43) To help meet Kyoto targets and reduce emissions, the nation introduced the emissions trading scheme to putting a price on carbon for businesses in the forestry, energy, transport, and industry sectors. (80) This scheme is expected to help level the playing field for renewable technology development by increasing the price of fossil fuels. (81)
In the United States, the cost of renewable electricity is higher, because electricity prices are kept artificially low. Despite the fact that most renewably generated electricity has a stable price, which is not subject to fuel volatility, high capital costs often make renewable energy projects uneconomic. Certain technologies that utilize resources like biomass, wind, and conventional hydropower and geothermal, are in some cases able to compete with fossil fuels and nuclear power on a cost per unit basis. Other resources like enhanced geothermal systems, and solar power cannot typically compete with traditional electricity generation sources.(60) Unlike New Zealand, renewable energy must be subsidized to be competitive with conventional fuels; however, the government also heavily subsidizes conventional fuels. Fossil fuel and nuclear power plants have received 90% of all subsidies in the last 60 years. More recently, in 2004, fossil fuels received 86% of subsidies, with nuclear receiving 8% and renewable energy and energy efficiency together receiving just 6%. For research and development funding, fossil fuel energies received 27% of subsidies with renewable technologies receiving 12%.(82) Furthering this uneven distribution of benefits, conventional fuels were given 75% of all energy related tax credits, while renewable technologies were given only 15%.(82) Subsidies have distorted the electricity market, allowing consumers to avoid paying for the true cost of energy extraction, generation, distribution, use, and environmental and social damages.(64) External costs associated with nuclear and fossil fuel plants include transportation, air pollution, water contamination, and land use. These costs are not reflected in electricity prices. For example, in 2007 if these external costs were included in the electricity price, consumers would pay an additional 19.14 ¢/kWh for coal generation, 12.00 ¢/kWh for natural gas generation, and 11.10 ¢/kWh for nuclear power.(64) The average residential electricity price in 2007 was 10 ¢/kWh, so including externalities, the price would more than double for all three types of non-renewable generation.(64)

Utilities have also made it a priority to maximize profits and keep prices low. With the deregulation of the electric utility market, providers have focused more on maintaining a competitive position in the market
and less with expanding renewable generation.(64) In addition, price caps, which keep electricity prices artificially low can cause excess consumption, impede investments and exploration, and prevent consumers from making rational choices based on cost.(82) By eliminating subsidies, price caps, and by internalizing externalities, electricity could be accurately priced, albeit priced higher. By incorporating more of the external costs into electricity prices, renewables could have more of an economic advantage; however, the existing market structure in the United States does little to incentivize deployment of renewable electricity technology. Instead, it encourages consumption by keeping prices artificially low, and passes external costs on to society.(64)

The nation does, however, have a few policy tools aimed at making the production price of renewables more cost competitive. These include the Federal Production Tax Credit (PTC), the Investment Tax Credit (ITC), and the Modified Accelerated Cost-Recovery System (MACRS).(83) Though, the history of political support in the United States has been intermittent. In the 1980’s when fossil fuel prices dropped and fossil fuel generators became more efficient, renewable technologies could not economically compete. Renewable technologies were contending against other renewables for funding and political support. When the renewable market eventually collapsed, failing to meet high expectations promised from the government in the 70’s, the majority of American people became disinterested in the adoption of alternative energy. The federal government has failed to enact a consistent long-term policy supporting renewable technologies since.(64) The uncertainty associated with short-term policies has hindered development, but a few individual states have taken the lead. While these states, in particular Colorado, California, New York and Nevada, have helped progress renewable development, inconsistencies between states lead to complications in planning and implementation. These inconsistencies combined with intermittent federal policies discourage investment and make renewable projects more difficult.(64)

An example of how short term policies can affect growth is demonstrated by the sporadic renewals of the Production Tax Credit on the wind industry (PTC). Although the PTC effectively promotes wind
development, uncertainty of whether the policy will be renewed and for how long have inhibited production and deployment of wind energy projects. While wind is still economically viable without the PTC, the ramp up and ramp down costs are high. Also, the uncertainty over return and the negotiations over power purchase agreements generate investment volatility. The intermittency of policy creates a boom-bust cycle in wind technology investments. Thus, this cycle of political uncertainty is damaging to the industry. Lessening uncertainty is critical in developing renewable energy public policy. In the United States, renewable energy investors may face more risk than in New Zealand where the government strongly supports renewable development and most technologies are cost competitive without subsidies.

3.5 Climate Differences

Climate is an important factor in accounting for differences in electricity usage between the United States and New Zealand. New Zealand has a mild climate with average daily temperatures between 50°F and 70°F year round. Weather varies from northern to southern areas of the country with average temperatures decreasing further south. According to the National Institute of Water and Atmospheric Research, the average monthly rainfall is approximately 100 mm. In the United States, the climate is mostly temperate, but with large variation by region. Florida and Hawaii are tropical, while Alaska is arctic, and the Great Basin is arid. Thus, a wide range of temperatures exists across the nation. In Washington D.C. the average monthly rainfall is approximately 81.5 mm. New Zealand has higher annual rainfall and higher wind velocities within a smaller area than the United States. This contributes to the larger portion of renewable technology in New Zealand’s electricity supply.

Because of climate differences, on average, it takes significantly more energy to maintain comfortable indoor temperatures year round in the United States, than in New Zealand. The University of Greifswald compared heating and cooling degree-days between different nations from 1960 to 2006. The
degree-days shown for New Zealand come from New Plymouth and Christchurch climate station averages. Because the climate varies widely in the United States, data from 22 different climate stations was compiled to calculate adequate averages for the entire country. Data for New Zealand and the United States is summarized in Table 6. The United States has far more heating and cooling degree-days than New Zealand and thus, must use more electricity to maintain comfortable conditions in buildings. (90)

Table 6: Heating and Cooling Degree Months from 1960 to 2005, Provided by the University of Greifswald (90)

<table>
<thead>
<tr>
<th>Country</th>
<th>Heating Degree Months from 1960 to 2005 (&gt;15°C)</th>
<th>Cooling Degree Months from 1960 to 2005 (&lt;18°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Minimum</td>
</tr>
<tr>
<td>New Zealand</td>
<td>31.20</td>
<td>24.81</td>
</tr>
<tr>
<td>United States</td>
<td>50.72</td>
<td>38.67</td>
</tr>
</tbody>
</table>

New Zealand does not rely as heavily on electricity for heating and cooling homes and buildings. The average size of a new home in the United States is 201.5 m² whereas in New Zealand the average is 196.2 m². (91) Home sizes, while slightly larger in the United States, are relatively comparable between the two countries. Since there is less electricity necessary for heating and cooling of homes in New Zealand, the demand for electricity is lower per household than in the United States. (9) In one study, it was found that the more energy needed for heating and cooling, the fewer individuals are willing to pay for renewable electricity because the incremental expenditure is larger. (92) Thus, because it takes more electricity in the United States for heating and cooling homes, (90) individuals may be less willing to pay for more expensive renewable technologies. (92)
3.7 Efficiency and Cost of Residential Electricity

However, since New Zealand’s temperatures are mild, there has been less incentive for efficiency investment. Compared to OECD standards, New Zealand homes are large, poorly constructed, and poorly heated. (93) New Zealand homes tend to be older and have less insulation than other nations with similar climates. The average indoor temperature of New Zealand homes has decreased from the 1970’s to 2000 by almost 1°C, while the price of residential electricity, the most common heating fuel, increased at a rate faster than inflation. (93) These conditions have made heat more difficult for New Zealander’s to afford.

While the government is now helping to fund efficiency improvements in New Zealand homes, (13) the high cost of electricity in proportion to the average income of residents continues to incentivize less electricity usage. (93) Table 7 shows the difference in GDP/Capita (94) between New Zealand and the United States and the difference in average electricity cost. The data is shown in US dollars. A conversion rate of 1 US dollar equals 0.75 NZ dollars was used to convert the cost of electricity. (94-95)

Table 7: Electricity Cost Compared to Average GDP/Capita, Data Provided by The World Bank, (94) The Energy Information Administration, (95) and the New Zealand Ministry of Business, Innovation, and Employment (96)

<table>
<thead>
<tr>
<th>Country</th>
<th>2013 GDP/Capita (US$)</th>
<th>2014 Average Cost of Residential Electricity (US¢/kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>34,825.70</td>
<td>20.69</td>
</tr>
<tr>
<td>United States</td>
<td>53,042.00</td>
<td>12.46</td>
</tr>
</tbody>
</table>

New Zealander’s on average have lower economic performance than the U. S and also pay more per unit of electricity. While differences in purchasing power between the nations also affect the true cost of electricity as compared to the average income, it is clear from table 7 that the cost of electricity for a household, on average, is a larger percentage of gross income for New Zealander’s (96) than for residents of the United States. (95) The higher cost of electricity not only makes it easier for renewable technology implementation, but also encourages electricity conservation because of the greater burden placed on consumers. (2)
3.9 Growth in Natural Gas in America has Increased Fossil Fuel Contributions

New Zealand does not have significant natural gas resources. This is evident when looking at Table 1. New Zealand consumes 3.817 compared to the United States 8.228 billion cubic feet of natural gas per 100,000 people. The United States has recently experienced a revolution in shale gas development. Combining the new technologies of horizontal drilling and hydraulic fracturing has enabled the nation to extract previously uneconomic hydrocarbons. (97) In less than 10 years, the United States transitioned from being a net importer of natural gas to being entirely independent. (97) With approval from the Department of Energy, the United States may become a liquefied natural gas (LNG) exporter. (57) Despite controversies over environmental impacts, the changeover from coal to natural gas between 2006 and 2011 accounted for a decrease in emissions of approximately 430 million ton CO₂ due to higher efficiencies. (97) This changeover accounted for a 10% decrease in emissions in the power sector from 2005. (57) The increase in natural gas production from shale has contributed to energy independence for the United States, has decreased gas prices for domestic consumers, and has provided over 600,000 jobs effectively stimulating the national economy. (97)

This surge in gas production has changed the electricity portfolio of the United States. Along with decreasing the use of coal, the increase in natural gas generation is also expected to decrease the use of renewable technologies in the United States. (98) The abundant supply of natural gas will likely defer usage of renewable resources for electricity generation. It will take more time for these renewable technologies to become cost competitive assuming policies stay the same. (98) In the long term, where gas competes with renewables, CO₂ emission reductions from shale development are less significant, especially if methane leakages occur. (98) Because of the high quantity of affordable natural gas available for electricity generation, it may take more time for the United States to have a similar level of renewable electricity contribution to New Zealand.
3.9 Feasibility of Renewable Electricity Growth in the United States

Is it possible for the United States to experience the same level of renewable electricity supply as New Zealand? There are significant challenges that the United States must overcome to have a high penetration of renewable generation. Besides renewable technologies not being cost competitive with fossil fuel counterparts,(64) there are challenges with transmission, policies, and social resistance.(82) Despite having high quality renewable resources, the feasibility of renewable penetration depends on future cost of electricity, taxes on emissions and security of supply (99) as well as advances in the utilization of smart grids, and in electricity storage.(60) Improving existing polices to be less uncertain and potentially adding new policies to improve efficiency and create a structured environment for growth would likely improve the feasibility of renewable adaptation in the United States.(59)

According to the United States Energy Information Administration, demand for electricity is projected to increase at a constant rate of 0.9% per year, but these projections change with changes in economic growth, advances in technology, and changes in the price.(100) Coal-fired plants continue to retire due to the challenges and high cost of updating older plants to meet more stringent environmental regulations. With this decrease in coal capacity, there is an opportunity for other generation sources to increase contribution in the United States electricity portfolio.(66) Renewable generation could increase, but cheap and widely available natural gas is more apt to continue being the fuel of choice to replace coal-fired generation.(57)

Chapter 4

Summary

In the face of surmounting environmental concerns over global climate change, New Zealand and the United States have taken steps to increase renewable energy contributions in electricity supply and decrease
CO\textsubscript{2} emissions from fossil fuels. Both nations have high quality renewable resource potential; however, New Zealand currently has a higher percentage share of renewable generation compared to total generation. They had 75\% of their electricity generated by renewable resources in 2013, and have high aspirations for continued growth in renewable electricity supply.(8) The United States, while it has a larger renewable capacity, generated only 12.9\% of total electricity supply from renewable resources.(57) In the United States, 86\% of the electricity generated comes from coal, natural gas, and nuclear power.(2) For a given number of people, New Zealand is able to meet electricity demand with half of the CO\textsubscript{2} emissions than the United States, and with no nuclear waste produced.(95) Although, the United States has a more energy intensive economy compared to New Zealand’s economy driven by tourism and agriculture. The differences in economies have, in part, been responsible for driving growth in varied energy sources, as the energy demand for the two nations is drastically different.(15-57)

While differences in electricity generation sources between New Zealand and the United States have developed over time, they are largely attributed to the differences in available resources, namely fossil fuels, as well as New Zealand’s stance on nuclear power.(15) Additional contributing factors are New Zealand’s smaller size with high quality renewable resources within a smaller area, and lower electricity demand due to their milder climate, less energy intensive economy, and lower population. Having high quality resources within a local area has made connecting renewable capacity to the grid, a simpler task.(2) Whereas, in the United States, renewable resources are more dispersed from population centers and therefore, transmission challenges are more significant.(101) Because of the varying policies between states, construction of transmission lines is also a complex endeavor. New Zealand’s early development of hydropower capacity is another advantage for the nation in terms of renewable generation. Dams continue to supply a large portion of electricity, even as additional developments are not expected.(27) As New Zealand’s coal fired power plant phases down, wind and geothermal additions will most likely make up the increase in electricity
supply to meet growing demand. (14) As coal capacity decreases, New Zealand’s share of renewable resources in the electricity supply will increase. (2)

In the United States, coal plants are also phasing down as environmental regulations make operations more expensive and as cheaper natural gas is abundantly available. Instead of renewable resource contributions increasing, the natural gas share of total electricity supply is expected to grow. (57) This will create further competition for renewable technologies, as the cost to generate electricity by natural gas is less in the current market environment than for renewable technologies. (98) Inconsistent policies for renewable resources cause uncertainty over investments, while long term support from the government for fossil fuel research and exploration remains unchanged. (64) This continues to cultivate an uneven playing field for alternative electricity sources. While in New Zealand, the higher cost of electricity makes renewable development economically competitive with traditional fuels. (2)

A degree of public opposition of climate change causation continues to challenge progress in the transition to low carbon electricity even as empirical evidence supporting such change gains increasing traction among the mainstream scientific community. (63) In the United States, a culture of abundance and entitlement to affordable electricity discourages conservation. Consumers are less willing to pay for ‘cleaner’ electricity sources as the severity of climate change effects are still unclear. (63) In New Zealand, the success stories of wind farms and other renewable resources have already begun to break social and institutional barriers (47) while the higher cost of electricity for consumers discourages excessive use. (93)

Because of the various factors explored, it is not likely that New Zealand’s high contribution of renewables to electricity supply is transferable to the United States. The differences in scale and availability of resources, in economies, policies, and social and cultural attitudes, make it more difficult for the United States to have a large share of renewable resource generation compared to total electricity supply. Moving
forward, in the United States, it seems more likely for the percentage of generation from natural gas fired plants to increase with the retirement of coal plants. While in New Zealand, it is likely for the contribution of renewable resource generation to increase further.
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The Pennsylvania State University
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Reservoir Engineering Intern, ConocoPhillips
May 2014 – August 2014 in Houston, Texas
- Analyzed water and hydrocarbon production trends in the Eagle Ford using Fekete Harmony, Spotfire, and OFM
- Projected water rates using type curves for water
- Ran multiple economic case scenarios for water transportation and disposal strategies using economic software PEEP
- Proposed a facilities strategy for salt water disposal with estimated savings of 7 million dollars

Production Engineering Intern, ConocoPhillips
June 2013 – August 2013 in Billings, Montana
- Conducted a study on the performance of naturally flowing wells in the Bakken
- Performed statistical analyses on historical data for flow time, flowing pressure and production rate
- Created a regression model correlating flow time to reservoir properties and used results to improve the Bakken Operations Center and the Bakken Integrated Schedule
- Enhanced communication skills and gained teamwork insight while working with a cross-functional group
- Gained exposure to daily field operations and best practices for operations excellence

Research Assistant, Penn State Energy Institute
June 2012 – September 2013 in University Park, Pennsylvania
- Examined microemulsion phase behavior to refine surfactant floods for enhanced oil recovery
- Organized and prepared laboratory for experiments
- Assisted professors by developing more organized notes for Petroleum Engineering courses

LEADERSHIP EXPERIENCE

Vice President, Penn State Society of Petroleum Engineers
April 2014 – Present in University Park, Pennsylvania
• Worked with different companies to organize technical elective courses for Penn State Students including Wild Well Control, Reserve Estimation, and Hydraulic Fracture Analysis using FracPro software

**Junior Class Representative**, Society of Petroleum Engineers  
April 2013 – April 2014 in University Park, Pennsylvania

• Reached out to underclassmen at orientation events to increase membership of younger students
• Answered questions from underclassmen about the Petroleum Engineering major and SPE in general
• Helped to plan SPE events for the Penn State Chapter such as the Annual Technical Conference and Exhibition

**ACADEMIC INVOLVEMENT**

Center for the Advancement of Undergraduate Studies and Experience

• Explored energy choices in society and trends in the connection of energy availability to economic development
• Toured a geothermal power plant and drilling rig, coal power plant, wind farm, hydropower dam and sustainability trust in New Zealand
• Conducted an independent study leading to a senior thesis on New Zealand’s path to a high level of renewable electricity

Presidential Leadership Academy

• Improved critical thinking abilities through participation in class activities and debates
• Attended various regional conferences and gained perspective on different leadership styles

**AWARDS AND SCHOLARSHIP**

• Penn State’s Petroleum Engineering Design Project Award for Reservoir Characterization
• Career Development Program Mentor
• President’s Freshman Award
• Pittsburgh Petroleum Section Society of Petroleum Engineers Scholarship
• Girl Scout Aid, Girl Scouts in the Heart of PA