THE ICELANDIC EXAMPLE: PLANNING FOR HYDROGEN FUELED TRANSPORTATION IN OREGON

by

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The ability to provide an adequate supply of renewable energy necessary to offset the emissions of "zero emission" vehicles is of importance for Oregon's planners and policy makers. An increase in electricity generation caused by the electricity required for zero-emissions hydrogen fuel cell vehicles will result in an increase in greenhouse gas emissions if renewable energy is not installed to meet hydrogen fuel cell needs. What are the renewable energy implications for Oregon planners to consider for meeting future fuel cell zero emission vehicle (ZEV) needs?

Work done in Iceland can serve as an example for Oregon's need for renewable energy to meet ZEV needs. Icelandic data about hydrogen generation and the renewable energy requirements necessary for ZEVs at the Grjóthåls hydrogen fueling station set a benchmark for Oregon planners to consider when figuring the impact of ZEVs.

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CHAPTER I

INTRODUCTION

The need to reduce emissions from vehicles has been recognized in Oregon for some time. At present, hydrogen fuel cell vehicles are proposed as one way to reduce vehicle emissions. If renewable energy is not available to generate the hydrogen necessary for these vehicles, the stations generating the hydrogen will use whatever electricity is available. In Oregon, a fraction of generated electricity comes from sources that produce emissions. Thus, providing adequate emissions-free energy to operate hydrogen fuel cell vehicles is necessary for such vehicles to be zero-emissions vehicles (ZEV) and is important for Oregon's planners and policy-makers.

On a regional scale, ZEVs throughout a metropolitan area could have a direct effect on the area's emissions. However, an area's electricity needs frequently extend beyond its metropolitan area, and much of this generation in non-renewably produced. While the potential exists for ZEVs to reduce one particular area's emissions, these emissions are only being externalized to somewhere else if non-renewable energy is being used. In other words, residents' energy generation needs and the resulting emissions produced are not confined to the city in which the residents live.

As the process of introducing ZEVs into the market continues, it has become imperative that planners and policy-makers address ZEVs from a regional perspective. Expanded renewable energy installations throughout a region will result in more true ZEVs and not just externalize the emissions to someplace else. Because of the growing concern over greenhouse gas emissions, their global climatic effect, and proposed emissions standards it is in a region's best interest to meet the requirements necessary for future ZEVs in order to reduce overall emissions and to promote greater regional equity by assuming responsibility for the emissions- free electricity required for ZEVs.

Background

There are many vehicles currently on the market or soon to be on the market (e.g. electric, plug-in hybrid, and fuel cell) that will require electricity to operate. Fuel cell cars are targeted to be available for mass-market sales within the next ten years. These cars are being promoted as being zero-emissions, and as emitting only water. For the purposes of the fuel cell ZEV, electricity is required to extract the hydrogen from the elements with which it is combined because Hydrogen as a gas (H_2) on earth essentially is always combined with other elements. Currently, most hydrogen in the United States, and about half of the world's hydrogen supply, is produced through the steam reforming of natural gas. In total, about 95 % of U.S. hydrogen production is produced from natural gas using steam reforming technology (U.S. Department of Energy [USDOE], 2006). Steam reformation of natural gas represents only a modest reduction in vehicle emissions as compared to emissions from current hybrid vehicles, and ultimately only exchanges oil imports for natural gas imports (Turner, 2004). Oil production peaked in the United States in 1970 (Duncan & Youngquist, 1999). Natural gas production in the U.S. peaked in 1971 (Youngquist & Duncan, 2003). The fuel cell ZEV has the potential to not produce emissions and to not require fossil fuels if the process uses electrolysis to make hydrogen, the hydrogen is electrolyzed from water with renewable energy, and the supplemental energy inputs for reformulation, transportation or compressing the fuel for on-board storage are met with renewable energy.

Fossil fuel use for transportation is not sustainable. Indeed, The Oregon Department of Transportation recognizes "Oil-based transportation is not sustainable environmentally or economically. Our dependency on increasingly scarce fossil fuels, the potential impacts of global warming, and the introduction of new carbon emission standards have pushed both automakers and consumers to find alternative solutions" (Oregon Department of Transportation [ODOT], 2009) . The U.S. Department of Energy and other market developers see a hydrogen infrastructure based on natural gas steam reformation at the service station. However, the Oregon Department of Energy recognizes "manufacturing hydrogen fuel from renewable feedstocks, with the supplemental energy from renewable resources, will prove to be the most sustainable approach" (Oregon Department of Energy [ODOE], 2009).

The State of Oregon also recognizes the importance of planning for renewable energy and fuel cells in Oregon's Renewable Energy Action Plan (ODOE, 2005):

> Fuel cell technology can play an important role in Oregon's renewable energy future. Oregon commercial and industrial sectors use approximately 30 million cubic feet of hydrogen per year. All hydrogen is imported since there are no commercial hydrogen generation plants in Oregon. If hydrogen used in Oregon were generated in Oregon using renewable resources, new jobs could be created. In the short run, most fuel cells are expected to use non-renewable fuels. However, a goal of this Plan is to foster increasing use of renewable fuels as technologies become feasible.

Furthermore, in recognition of the need for renewable energy, Oregon and 23 other states plus the District of Columbia have enacted policies that require electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date (USDOE, 2008). Transportation (34 %) and electricity (32 %) dominate Oregon's greenhouse gas footprint (State of Oregon, 2008). Installing renewable energy to offset emissions from hydrogen generation would lower both footprints for a ZEV. In essence, if a fuel cell vehicle requires only renewable energy it is contributing to neither vehicle nor power plant emissions.

The Oregon Office of Energy predicts that carbon dioxide emissions in the state will increase by 33 % from 2000 to 2025, mainly because of increased driving (ODOT, 2006). The Oregon Transportation Plan's 2006 executive summary recognizes the implications of population growth, oil supplies, and global warming as being a challenge when it states that, "Encouraging the use of hybrid, electric and other alternative-fuel engines, increasing public transit, and guiding land use and transportation choices could reduce greenhouse gas emissions" (ODOT, 2006). In 1973, Oregon established nineteen statewide planning goals as part of legislation that created a statewide land use planning system. Statewide Goals 6 (Air, Water and Land Resources Quality), 12 (Transportation), and 13 (Energy Conservation) identify the interconnected nature of Oregon's property and transportation, energy, and the environment. ZEVs in Oregon will, at the very least, have an impact on all three of these statewide goals.

Planning needs to be done for the introduction of fuel cell ZEVs in Oregon, and planners benefit from having an example to set a baseline, or a line serving as a basis for measurement and calculation to be used for comparison. In this case, the baseline is the renewable energy requirements necessary for the beginnings of fuel cell ZEVs. This baseline is necessary for Oregon's planners to map the transition to factual ZEVs. For the purposes of this thesis, a factual ZEV is defined as a situation where there is no carbon produced during the generation, transmission, or distribution of the hydrogen necessary to power the fuel cell vehicle.

There is an example for Oregon to look toward when planning to meet its future hydrogen-powered transportation needs. Iceland is an international leader in the use of hydrogen (Arnason & Sigfusson, 2000) and is the first country in the world to commit to replacing fossil fuels with hydrogen. Furthermore, Iceland uses electrolysis to make hydrogen and the hydrogen is electrolyzed from water with renewable energy (hydroelectric power) (Maack & Skulason, 2006). More specifically, Icelandic New Energy (INE), a promoter for using hydrogen as a fuel in the transportation sector in Iceland that also is responsible for the practical research on hydrogen in Iceland, has determined the hydrogen output and the renewable energy requirements necessary to power three fuel cell buses at its Grjótháls hydrogen fueling station .

The work of Iceland and INE on the beginnings of hydrogen-powered transportation can serve as a model for Oregon by examining what it would take for Oregon to imitate Iceland's current example of using renewable energy for zero emissions hydrogen generation at its Grjóthåls hydrogen fueling station. Through the evaluation of the Grjóthåls hydrogen renewable energy requirements, a baseline can be set for Oregon's renewable energy needs. The primary question for this thesis is the following: Can Oregon generate the hydrogen necessary to follow the Icelandic example of using renewable energy to generate sufficient hydrogen for zero-emission vehicles using solar and wind energies? The following sub-questions will inform the analysis:

- How much installed capacities will Oregon need to follow the Icelandic example?
- How can Iceland's information on the renewable energy requirements necessary for hydrogen ZEVs be scaled to Oregon?
- What are the suitable energy requirements of hydrogen ZEVs for solar and wind energies?
- How many units would need to be installed, and what is the area required for the installation of wind and solar energies?

Methodology

While past studies of transportation and energy issues in Oregon have evaluated various impacts, this study will evaluate the extent to which fuel cell ZEVs in the transportation sector will effectively impact the renewable energy requirements of Oregon's energy sector. The primary data sources for this study derive from Iceland and INE and by analysis of The US Department of Energy's Energy Information Administration (EIA) and The Northwest Power and Conservation Council (NPCC) data on Oregon's energy portfolio, its energy generation, and its energy use. Through this analysis, Oregon's renewable energy is separated from hydropower, and its energy use is compared with its energy generation. The EIA data for renewable energy (excluding hydropower) is not broken down by type. Therefore, this data is inclusive of all types of renewable energy generation in Oregon, which the NPCC lists as being biomass, solar, and wind. Use of the NPCC data allows for the filtering of biomass from solar and wind data.

Iceland uses hydropower and geothermal energy to electrolyze and compress the hydrogen from water because Iceland has vast amounts of geothermal and hydropower available. Analysis of Oregon's hydropower and geothermal data shows its limitations for generating hydrogen. According to the Oregon Department of Energy, Oregon's energy portfolio is 44 % hydropower (ODOE, 2008). The actual amount of Oregon's hydropower available to generate hydrogen through electrolysis depends on myriad factors including precipitation, demand, and exports out of state, but mostly from policy that directs its electricity be delivered to Oregon customers at reasonable rates. Oregon's hydroelectric availability has been impacted by the long term drought of the Western United States. This study has sized the renewable energy systems necessary to make hydrogen ZEVs from solar and wind energies and not from surplus hydropower and geothermal to best reflect local availability of generation potential and because these are two popular and familiar renewable energy sources with the potential for local involvement in the installations. Solar and wind installations also satisfy state mandated renewable resource portfolio requirements (ODOE 2005). Because the vehicles will be charged during different times during the calendar day, and the intermittent nature of solar and wind, hydropower involvement is inevitable. With this in mind, this study used historic data on hydropower generation to show how hydroelectric demand is greater than its generating capability in the context that allocating any surplus that could be used purely for hydrogen generation would result in a rate increase and not be allowed. For solar, this study used research data from a solar energy research institute at the University of Central Florida (Florida Solar Energy Center, 2007) and scaled the results up to meet the megawatt needs of the Grjóthàls hydrogen fueling station. For wind, this study used the past performance data of Oregon's average output from a 1.5 megawatt wind farm turbine (ODOE, 2007).

Purpose of This Study

The purpose of this thesis is two-fold: (1) to evaluate the supply of renewable energy necessary for zero-emissions fuel cell vehicles; and (2) to provide a baseline for planners to consider when preparing for zero-emissions fuel cell vehicles.

The rationale for this study is based on the normative planning theory and the American Institute of Certified Planners (AICP) Code of Ethics and Professional Conduct. The Code of Ethics explicitly states that planners "[s]hall always be conscious of the rights of others, [s]hall have special concern for the long-range consequences of present actions, and [s]hall promote excellence of design and endeavor to conserve and preserve the integrity and heritage of the natural and built environment" (American

Planning Association, 2005). Furthermore, normative planning theory argues that planners should be concerned with how society's limited resources are distributed.

Organization of This Thesis

The thesis is organized into six chapters. Following this introductory chapter, the second chapter will discuss a review of relevant literature including emissions and vehicles, emissions and health, hydrogen fuel cell zero-emissions vehicles, regional solutions to emission reductions, emissions reductions in a regional context, and Iceland's implementation of hydrogen and renewable energy. Chapter Three will profile the two study regions: Oregon and Iceland. Chapter Four will describe the methodology used in this study, and Chapter Five will discuss the data analysis and findings. Finally, Chapter Six will provide a summary of key findings, and discuss the implications of this study and ideas for further research.

CHAPTER II

LITERATURE REVIEW

Across the United States, jurisdictions of all levels, from city to county to state, are experiencing the need to provide community and regional planning in the context of a changing climate, emissions reductions, population growth, and energy and transportation needs. The following review of literature addresses the role of zero-emissions vehicles (ZEV) in planning for emissions reductions, and presents information on how fuel cells can be ZEVs. This chapter also reviews Oregon's plans for climate change, energy and emissions, and ZEVs. This is followed by an extended discussion on how energy and transportation emissions reductions improve the public good. This chapter concludes with an exploration of utilizing Iceland as an example for Oregon's ZEV aspirations.

Emissions and Vehicles

In Oregon, fossil fuel use for energy needs affects our percentage of greenhouse gas emissions. Transportation (34 %) and electricity (32 %) dominate Oregon's greenhouse gas (GHG) footprint (State of Oregon, 2008). Nationally, by sector and fuel type, electricity generation (41 %) and transportation (29 %) are the largest sources carbon dioxide emissions (United States Environmental Protection Agency [EPA], 2009). For many currently proposed ZEVs, transportation and electricity become interconnected because of a dependency on electricity generation. When a vehicle requires electricity generation as part of its design, the tailpipe emissions costs have been shifted upstream to whatever emissions come from non-renewable energy generation. These externalized costs are still borne by the environment and thus, society. The combustion of fossil fuels in both the transportation and electricity sectors also creates many unhealthy emissions in addition to carbon dioxide (Chu & Porcella 1995; Westerholm & Egebäck 1994).

Emissions and Health

We live on a human-dominated planet that is in the midst of an ecological crisis (Vitousek, 1997). Climate change is affecting the earth and its living systems (Parmesan & Yohe, 2003). The burning of fossil fuels contributes to climate change by increasing the amount of atmospheric carbon dioxide, a greenhouse gas (Karl & Trenberth, 2003). Increasing power generation by conventional fossil-fuel combustion further threatens human health and welfare by increasing air pollution (Cifuentes, Borja-Aburto, Gouveia, Thurston, & Davis, 2001).

The U.S. Supreme Court's decision in *Massachusetts v. EPA* found that the Clean Air Act authorizes the Environmental Protection Agency (EPA) to regulate tailpipe GHG emissions if the EPA determines they cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare (EPA, 2008). Global changes in atmospheric composition occur from anthropogenic emissions of greenhouse gases such as carbon dioxide that result from burning fossil fuels (Karl & Trenberth, 2003). Greenhouse gases trap outgoing radiation from the Earth to space, creating a warming of the planet. These gases remain in the atmosphere for a long time. Carbon dioxide's residence time in the atmosphere is 200 years. This results in an accumulation in the atmosphere, and a buildup in concentrations of greenhouse gases. Evidence for this increase in greenhouse gases can be found in instrumental observations of air samples and in bubbles of air trapped in ice cores that show carbon dioxide increasing 31 % since preindustrial times, from 280 parts per million by volume (ppmv) to more than 370 ppmv by 2003 (Karl & Trenberth, 2003). Today it continues its increase, and is now at 388 ppmv and rising. Articles, reports and recommendations on the subject of climate change have drawn a "2 degree line" (no more than a 2°C (3.6°F) increase in global mean surface temperature above preindustrial levels). Many scientists believe that anything beyond 2°C could result in a dangerous climate change with the potential to become a full-blown ecological crisis (Baer & Athanasiou, 2004), which has been defined as "a situation in which human-induced ecological disorder leads to the destruction of ecological conditions on this planet to such an extent that human life, at least, will be seriously impaired for generations, if not destroyed" (Ecological Crisis, 2008).

James Hansen, climate expert and Director of NASA's Goddard Space Science Center, sets a goal of no more than 1°C above present temperatures to avoid the melting of the Greenland ice sheet and he sets no more than 350 parts per million (ppm) of carbon dioxide in the atmosphere as the level necessary to avoid an ice-free planet. In 2007 we were at 383 ppmv (McKibben, 2007). As you can see, carbon dioxide in the atmosphere continues to increase from 280 ppmv in preindustrial times to 370 ppmv by 2003, 383 ppmv in 2007, and 388 ppmv today. While Hanson's work and his specifying an exact number of "allowable" carbon dioxide is contentious to many, it is a fact that the world's glaciers continue to melt while polar and sea temperatures have been increasing. Perhaps the specific number is not as consequential as the general concept discovered by Svante Arrhenius in 1896 that if you halve the amount of carbon dioxide in the atmosphere an ice age would occur and conversely, if you increase the level of carbon dioxide in the atmosphere it will raise the Earth's temperature.

Prior to the emphasis on GHG reductions to address planning for climate change, vehicle emissions reductions were desired for health benefits. Vehicle emissions are usually divided into categories of regulated and unregulated pollutants. Regulated pollutants consist of carbon monoxide, nitrogen oxides (mainly nitrogen monoxide and nitrogen dioxide), unburned fuel, or partly oxidized hydrocarbons, and particulates. These pollutants are specified by law. Unregulated pollutants are defined as compounds that are not specified by law. However, these unregulated pollutants may well belong to the group of unburned hydrocarbons, but not as individual compounds. Several of the compounds present in diesel and gasoline engine exhaust are known to be carcinogenic and/or mutagenic (Westerholm & Egebäck, 1994). Exposure to carcinogenic and/or mutagenic vehicle emissions is not limited to those produced during the combustion of fossil fuels, but also to environmental contamination of land and water due to accidental spills and releases.

Utility emissions vary by source. Of special concern for fossil fuel electricity generation is mercury (hg) emissions. The Clean Air Act regulates 188 air toxics, also known as “hazardous air pollutants.” Mercury is one of these air toxics. The Clean Air Act directs the EPA to establish standards for certain sources that emit these air toxics. Those sources also are required to obtain Clean Air Act operating permits and to comply with all applicable emission standards. The law includes special provisions for dealing with air toxics emitted from utilities, giving EPA the authority to regulate power plant mercury emissions. On March 15, 2005, EPA issued the Clean Air Mercury Rule, which creates performance standards and establishes permanent, declining caps on mercury emissions. The Clean Air Mercury Rule marks the first time EPA has ever regulated mercury emissions from coal-fired power plants (EPA, 2009). Many smokestack emissions eventually end up in the water. Under the Clean Water Act, states adopt water quality standards for their rivers, streams, lakes, and wetlands. These standards identify levels for pollutants, including mercury, which must be met in order to protect human health, fish, and wildlife. The EPA and various states issue information to the public on waters contaminated with mercury and on the harmful effects of mercury, identify the mercury sources and reductions needed to achieve water quality standards, and warn people about eating fish containing high levels of methylmercury (EPA, 2009). According to the EPA, the primary health effect of methylmercury on fetuses, infants, and children is impaired neurological development. Methylmercury exposure in the womb can adversely affect a baby's growing brain and nervous system. Impacts on cognitive thinking, memory, attention, language, and fine motor and visual spatial skills have been seen in children exposed to methylmercury in the womb. In addition, symptoms of methylmercury poisoning may include impairment of the peripheral vision, disturbances in sensations, lack of coordination of movements, impairment of speech, hearing, walking, and muscle weakness (EPA, 2009). While some studies conclude that mercury emissions are lower than previously thought (Chu & Porcella, 1995), it is a fact that mercury emissions are produced in coal-burning power plants, and burning more coal in these same plants will produce more mercury emissions.

Numerous studies have been done that document the relationship between clean air and health. A recent study says cleaner air lengthens lives. The federally funded study concluded that cleaner air over the past two decades has added nearly five months to average life expectancy in the United States. Communities that had larger reductions in air pollution on average had larger increases in life expectancies (Pope, Ezzati, & Dockery, 2009).

Scientists have long known that particulates in the air can lodge in the lungs and raise the risk of lung disease, heart attacks and strokes. The composition of these particulates is generally dust, soot, and various chemicals that come from factories, power plants and vehicles. Deaths from air pollution, including indoor and outdoor sources, have been ranked as one of the top 10 causes of disability by the World Health Organization (WHO) (Murray & Lopez, 1998). In 1995, WHO estimated that 460,000 avoidable deaths globally occur each year as a result of suspended particulate matter, largely from outdoor urban exposures (World Health Organization [WHO], 1997). Urban exposure to particulates is amplified by motor vehicles that emit particulate matter along with a variety of other pollutants. Studies in urban areas suggest that motor vehicles contribute from 25 % to 35 % of direct particulate matter emissions, and concentrations near busy roads can be 30 % higher than background levels (Buckeridge, Glazier, Harvey, Escobar, & Frank, 2002). Living in residences near busy streets results in an increased exposure to particulates and other pollutants which contribute to poorer respiratory health.

Hydrogen Fuel Cell ZEVs

One strategy for reducing greenhouse gas and air pollution emissions is to use renewable energy to meet energy needs and to support the use of hydrogen to meet future zero-emissions transportation needs (Clark et al., 2005). Currently, the United States Department of Energy Hydrogen Program is focused on advancing cost-effective, efficient production of hydrogen from renewable, fossil and nuclear energy resources (USDOE, 2009).

Hydrogen as a gas (H_2) does not exist on earth. It always is combined with other elements. Because hydrogen does not exist on earth as a gas, energy must be used to extract the hydrogen from the elements with which it is combined. Currently, most hydrogen in the United States, and about half of the world's hydrogen supply, is produced through the steam reforming of natural gas. In total, about 95 % of U.S. hydrogen production is produced from natural gas using steam reforming technology (USDOE, 2008). All of Oregon's approximately 30 million cubic feet of hydrogen used each year is imported because there are no commercial hydrogen generation plants in Oregon (ODOE,

2005) and Oregon imports 100 % of its natural gas, mainly from Canada and the Rocky Mountain states (ODOE, 2008). Steam reformation of natural gas represents only a modest reduction in overall greenhouse gas emissions as compared to emissions from current hybrid vehicles, and ultimately only exchanges oil imports for natural gas imports (Turner 2004). A dependence on imported natural gas for hydrogen generation would leave hydrogen-powered transportation vulnerable to the same price and supply issues as imported oil (Karimi, 2008). Furthermore, it does not decrease our reliance on fossil fuels to meet our energy needs, nor does a dependence on fossil fuels make hydrogen sustainable. Finally, such dependence does not produce a ZEV.

Hydrogen derived from the electrolysis of water is extremely pure hydrogen, and the production of hydrogen from renewable energy sources will free the energy system from carbon (Dunn 2002). With this form of pure hydrogen derived from electrolysis via renewable energy, a fuel cell vehicle is a true zero-emission vehicle, producing only water as byproduct. This means that no greenhouse gases are emitted in the hydrogen generation and use.

Studies have shown that hydrogen fuel cell vehicles may improve air quality, health, and climate significantly, whether the hydrogen is produced by steam reforming of natural gas, wind electrolysis, or coal gasification (Jacobson, 2005). However, generating hydrogen by any method aside from renewable energy creates emission changes upstream of vehicles. The use of coal gasification in particular would damage the climate more than current fossil/electric hybrids (Jacobson, 2005). The overall emissions costs of these upstream non-renewable sources do not outweigh their localized benefits because the emissions are only externalized to some other place and will ultimately further contribute to GHG increases and downstream water and environmental issues. Moreover, there are equity issues involved when one region lowers its emissions by increasing the emissions of another area.

Emissions Reductions in a Regional Context

Emissions do not stay within a region's boundaries and they can adversely impact some people more so than others (Maantay 2002). Since a spatial relationship exists between pollution and health, what are some benefits of regional involvement in emissions reductions?

According to a recent report by Portland based Clean-edge Inc. and Climate Solutions, the Northwest can generate more than 63,000 new family supporting jobs by focusing on five clean technology areas: solar PV manufacturing, green building design, sustainable bioenergy, wind power, and "smart grid" technologies. Furthermore, the Pacific Northwest can seize a leadership role in the clean-tech economy by taking advantage of our already high percentage of renewable energy and make Oregon and Washington world-class leaders in carbon-free electricity (Wilder & Gauntlett, 2008). In a future where a competitive advantage may exist to those with the most carbon-free electricity generation, a proverbial "win-win" situation where the economy, the environment, and equity prosper because of a regional involvement in emissions reductions appears to be not only possible in the Pacific Northwest but more feasible than in most other regions in the U.S.

Regional Solutions to Emissions Reductions

The State of Oregon's "A Framework for Addressing Rapid Climate Change" (State of Oregon, 2008) embraces regional involvement in emissions reductions:

> The earth's climate is undergoing unprecedented change as a result of human activity, and this change will have significant effects on all Oregonians, their families, their communities, and their workplaces. A broad scientific consensus tells us that climate change is accelerating, and that it is happening at a speed that was unanticipated even recently. It is urgent that we act now, both to reduce the cause of this earth-transforming crisis by rapidly driving towards a low-carbon economy, and to begin to prepare for and adapt to the changes that mitigation cannot prevent. If we as Oregonians rise to this challenge and make intelligent and well-informed choices, we can minimize the most adverse impacts of changing weather patterns on our lives while producing many benefits – including economic opportunities – by leading the world to an environmentally sustainable and globally competitive state economy.

The multidisciplinary group that drafted Oregon's Renewable Action Plan (ODOE 2005), the precursor to Oregon's Renewable Energy Portfolio, concluded:

> Oregon is already making use of renewable technologies including hydro, wind, direct use of geothermal, biomass, and solar. But it can and must do better. By building on these achievements with the actions as outlined in this Renewable Energy Action Plan (the Plan), Oregon will continue to be a leader on renewable energy policy and will meet a large fraction of its energy needs with new renewables by the year 2025. The Plan also will play a central role in furthering the Governor's initiatives on sustainability and global warming. The Plan complements the state's energy efficiency programs.

Oregon has recognized a relationship between emissions reduction, technology, and gains in the economy, the environment, and equity (the triple bottom line). Oregon's greenhouse gas emissions have grown by 22 % from 1990 levels, and Oregon emissions growth has been greater than the U.S. as a whole (State of Oregon, 2008). Oregon's leaders and planners are actively seeking ways to reduce regional emissions for the public good.

Iceland's Implementation of Hydrogen and Renewable Energy

Iceland is an international leader in the use of hydrogen (Arnason & Sigfusson, 2000). Iceland is the first country in the world to commit to replacing fossil fuels with hydrogen. Since World War II, Iceland has made a rapid change from relying on imported fossil fuels to its present situation of meeting more than 70 % of its energy needs with renewable energy (Sverrisdóttir, 2006). Among the countries of the world, Iceland has the highest proportion of renewable energy in any energy portfolio (University of Iceland, 2007). Iceland lies on top of the Mid-Atlantic ridge and therefore has natural access to the magma heated steam necessary for the wide-scale development of geothermal electricity. Iceland's unique geographic location also allows for abundant hydropower. This, along with their low population makes it possible for them to have the highest proportion of renewable energy. The Icelandic research community is working hard to improve this ratio of renewable energy generation, as well as considering ways to sequester the greenhouse gases emitted from fossil fuel sources. Iceland uses electrolysis to make hydrogen and the hydrogen is electrolyzed from water with renewable energy (Maack & Skulason 2006).

Iceland recognized the need for the development of a common vision toward a transformation of the Icelandic economy into one based on hydrogen when the government of Iceland officially declared this as its goal in a statement by the Minister of Environmental Affairs, founding The Hydrogen and Fuel Cell Company on February 17, 1999 (Arnason & Sigfusson, 2000). The purpose of this company was to set up a joint venture to investigate the potential for eventually replacing the use of fossil fuels in Iceland with hydrogen. This would allow Iceland could become a pilot country for demonstration of the hydrogen economy (Arnason & Sigfusson, 2000) The Hydrogen and Fuel Cell Company soon changed its name to Icelandic New Energy (INE).

INE is the promoter for using hydrogen as a fuel in the transportation sector in Iceland and is responsible for all major practical research on hydrogen in Iceland.
INE was in charge of ECTOS, the Ecological City Transport System. This 4½-year project started on March 1, 2001 and ended August 30, 2005. The overall objective of the ECTOS project was to tackle the problem of local urban pollution by using hydrogen for powering part of the transport sector with hydrogen fuel cell buses. The purpose of the ECTOS project was to demonstrate and evaluate a hydrogen-based infrastructure for public transport vehicles and the operation of pollution-free hydrogen buses in a carbon dioxide free environment in Reykjavik, Iceland (Skulason, 2005). INE and Iceland demonstrated that three fuel cell buses could transport in a carbon dioxide free nature, i.e. the production of hydrogen and the running of the fuel cell buses add no greenhouse gases to the environment. Furthermore, through their work, INE has demonstrated the integration of the infrastructure at a conventional gasoline station.

The infrastructure preparation involved building a hydrogen refueling station integrated into a Shell facility on the outskirts of Reykjavik (Sigfusson, 2007). According to INE, this station, the Grjóthals station, has a total production capacity of 125 kg a day. "The station produces 60Nm3 every hour during operation. It was scaled to be able to fill 3 hydrogen buses daily, so that they could keep up their 150 - 200km schedule on the filling. Another way to describe the scale of the station is that it could produce enough H_2 to satisfy up to 600 personal cars in general operation. During the bus testing about 25 kg of hydrogen were filled onto the bus cylinders before they went into service. The cars that now drive in Reykjavik take about 2-4 kg of hydrogen each time" (Icelandic New Energy, 2008). "During the operation of the station in the ECTOS project the station provided the buses with 17.342 kg of hydrogen and in that sense saved the use of almost 50 tons of diesel fuel. In general the project partners are satisfied with this outcome and the valuable learning from operating the world's first commercial hydrogen station" (Skulason, 2005). Since 125 kg of hydrogen a day being dispersed in 3 kg allotments to cars would only meet the needs of 40 or so cars a day, this study assume INE is figuring on each car only needing to fill up every two weeks or so.

Jon Björn Skulason, Icelandic New Energy, concludes in his, "ECTOS, Ecological City Transport System," final public report (Skulason, 2005):

> Setting out goals and objectives of a project of this size and nature was a difficult thing 4½ years ago. However the project partners agree that a successful demonstration has taken place, proving that the current stage of technology can be integrated into the modern society of today. In Iceland it has also been demonstrated that this has been done in a CO_2 free nature, i.e. the production of hydrogen and the running of the fuel cell buses add no greenhouse gases to the environment. Integrating the infrastructure has also been successfully proven at a conventional gasoline station, in a pre-commercial way. The strategic goal was also to show in what way the future society might benefit in social, economic and environmental terms by using hydrogen as a fuel instead of conventional fossil fuels.

> Throughout the project it has been shown that social and environmental benefits are very visible. However, the current stage of technology does not yet make it commercially economical. Indications are though that the cost of the new technology will come down in the near future and therefore not far into the future the city of tomorrow will benefit in social, economical and environmental way by using hydrogen instead of fossil fuels.

At the moment, Iceland is reeling from its economic collapse which began in 2008. It is quite possible this collapse will delay Iceland from meeting its immediate energy goals of replacing fossil fuels with hydrogen. It is unclear at this time how Iceland's ultimate goal of replacing fossil fuels with hydrogen around the year 2050 (Sigfusson, 2007) will be affected by their recent economic problems.

Summary

Seventeen years ago the Union of Concerned Scientists issued a statement that put us all on notice (Union of Concerned Scientists, 1992):

> We the undersigned, senior members of the world's scientific community, hereby warn all humanity of what lies ahead. A great change in our stewardship of the earth and the life on it is required if vast human misery is to be avoided and our global home on this planet is not to be irretrievably mutilated.

Today, environmental issues as they relate to GHG emissions and climate change are even more pressing. For planners, ZEVs pose a wicked problem with no definitive formulation. Every problem can be considered a symptom of another problem and can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution and this study has attempted to explain this problem in terms of using technology for overall emissions reductions because of the potential of future transportation to impact future electricity generation and its accompanying emissions. The consensus of scientists about the ramifications of a continued increase in GHG emissions and the accompanying changes in the global climate creates a situation where the planner has no right to be wrong (Rittel & Webber, 1984). This literature review has listed many of the dangers involved with increased vehicle emissions while showing an alternative for planners to consider when implementing future transportation plans. If zero emissions are the desired end goal of the planner, then the Icelandic example of the Grjóthâls station and its renewable electricity needs for the generation of 125 kg of hydrogen a day is a good model for Oregon's transportation and energy planners.

CHAPTER III

REGIONAL PROFILES

Comparison of Oregon and Iceland

In evaluating the renewable energy needs of the Grjóthåls hydrogen fueling station in Reykjavik, Iceland, this thesis refers to the "Icelandic Example." Briefly stated, this example is to use renewable energy to generate and compress the hydrogen necessary for the Grjóthåls hydrogen fueling station in Reykjavik, and to do so onsite to avoid transmitting the hydrogen from its generating facility to its distribution facility. If the hydrogen is made on site, then transmission (pipeline, trucking) is not necessary. What is necessary is renewable electricity for electrolysis being fed into the grid upstream of the fueling station. As long as the necessary amount of renewable energy generation is ending up at the proper distributor, then onsite hydrogen through electrolysis (in that distributor's region) is zero-emissions hydrogen. Under this scenario, the cost of hydrogen is determined by the cost of electricity and not the cost of generation plus the pipelines and/or trucking. Since this study used Iceland's Grjóthåls hydrogen fueling station as a model for Oregon, it was important to first understand some of the similarities and differences between the two regions. The comparison between Iceland's and Oregon's renewable energy potential is not novel. Ormat Technologies, Inc, a company active in the design, engineering, supply, installation, support and operation of renewable and sustainable energy products, in a July 23, 2007 presentation in Portland, Oregon on *Getting Geothermal Electricity Projects On Line*, which is posted on the State of Oregon's website,[1] assessed Oregon's geothermal potential. During their presentation, the spokesman for Ormat wondered, "Could Oregon become another Iceland? Could Oregon's existing resources, wind, tidal, biomass, solar, and geothermal resources make Oregon perhaps the most sustainable/carbon neutral state in the U.S." (Fleishman, 2007)?

External factors related to historical, demographic, and energy portfolio characteristics presented in this chapter assist in revealing the potential for Oregon to follow the Icelandic example of hydrogen generation at its Grjóthåls hydrogen fueling station. This chapter summarizes both key similarities and differences relevant to this study.

Settlement and Growth

A geographical context of Iceland and Oregon shows Iceland as having an area of 39,756 square miles and an estimated population of 276,365 in 2000. The Icelandic government reports that 99 % of the population lives in urban areas and 60 % of the people reside in the republic's capital, Reykjavík, or in suburban areas directly outside of the city (Icelandic Foreign Service, 2008). While Oregon has an area of 97,074 square

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[1] http://www.oregon.gov/ENERGY/RENEW/Geothermal/docs/OGWG8_ORMAT

miles and a 2000 census estimated population of 3,421,399, 70 % of Oregon 's population lives in the Willamette Valley (Kline, Azuma, & Alig, 2004) and 54 % of the population resides in the greater Portland area.[2] Iceland's 2008 estimated population growth rate is 0.783 % and its net migration rate is 1.13 migrants per 1000 population (Central Intelligence Agency [CIA], 2008). Oregon's population growth rate is currently declining, possibly due to economic conditions. Its 2006-07 population growth rate was 1.5 % (down from 1.6 % the previous fiscal year) (Oregon Labor Market Information System, 2008) and its 2007-08 population growth rate is 1.2 % (Portland State University Population Research Center [PSU], 2008). According to Portland State University, "Between April 1, 2000 and July 1, 2007, net migration (people moving into Oregon minus people leaving) is estimated to be 212,062 and accounts for 65 % of the total population growth. Between 1990 and 2000 that percentage was 73 %, but in the early 2000s, it dropped to 56 %. Migration primarily is driven by the state of the economy. When Oregon's economy is strong, net migration increases as people move here to take advantage of employment opportunities. When the economy goes into recession, in-migration flows slow down (PSU, 2009). Oregon's 2007 net migration rate is 3 migrants per 1000 population.[3]

While Iceland and Oregon are both experiencing a slowdown in their economies, Iceland is an island nation and Oregon is not. This has a profound effect on the ability of

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[2] Assumption: Metropolitan Area Residents (PMSA) *2000:* 1,874,449 divided by Oregon's 2000 census population

[3] Assumptions based on PSU *2007 Oregon population report* statistics and a 2007 Oregon population of 3,745,455 with a net migration of 37,752

people to move into and out of Iceland in comparison to the ability of people to move into and out of Oregon from other states in the U.S.

Energy Use

Iceland has the highest electricity consumption, per capita, of any country in the world with 31,147.292 kWh (NationMaster, 2009).[4] The United States has the ninth highest electricity consumption, per capita, of any country in the world with 12,924.224 kWh per capita (NationMaster, 2009). Aluminum smelters require vast amounts of electricity. There are currently three aluminum smelters in Iceland, with a fourth under construction and others planned. Because of this, electricity consumption has more than doubled in recent years creating the situation where Iceland now uses more power per person than any other country in the world (Economist, 2008).

Residential Electricity Consumption Per Capita in Oregon's homes has stayed relatively flat since 1981. Its 2005 per capita consumption of electricity in Oregon homes was 5,052 kWh, ranking it 25 out of the 50 U.S. states (USDOE, 2008). During the 1990s, industrial per capita use declined 24 %. This was largely due to plant closures or reduced output from mills and aluminum smelters. By the end of 2002, both of Oregon's aluminum smelters were closed, one permanently (ODOE, 2007). Affordable and available electricity is a need for aluminum smelters. Hydropower is, and has been, a source of such electricity. Oregon purchases the electricity from the aluminum companies who have long-term contracts from the Bonneville Power Administration because this is

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[4] NationMaster is a vast compilation of data from such sources as the CIA World Factbook, UN, and OECD.

cheaper than building new generation facilities. The smelters sell their electricity rights because they make a profit in doing so without the need for production of aluminum and they can foresee future need and rate increases. Smelters have relocated to Iceland to capitalize off of Iceland's low-priced and abundant hydropower. This process has lowered Oregon's per capita energy consumption while raising Iceland's per capita energy consumption.

Iceland has seven energy companies, Akureyri Municipal Water and Power Company (Norðurorka), Hitaveita Suðurnesja, Húsavík Energy (Orkuveita Húsavíkur), Iceland State Electricity (RARIK), Landsvirkjun, Westfjord Power Company (Orkubú Vestfjarða), and Reykjavík Energy (Orkuveita Reykjavíkur) (Orkustofnun - National Energy Authority of Iceland [NEAI], 2007). Reykjavik Energy is Iceland's largest utility, providing almost 70 % of the country's population with electric power (ABB Group, 2008).

The three main providers of electricity in Oregon are the investor-owned utilities Portland General Electric (PGE) and Pacific Power (a PacifiCorp company), and the Bonneville Power Administration (BPA), a federal power marketing agency. Pacific Power serves 31 % of Oregon's electric utility load, providing power to more than 486,000 customers. PGE serves 40 % of Oregon's electric utility load, providing power to about 733,000 customers. Idaho Power, another investor-owned utility, serves about 1 % of Oregon's electric load (ODOE, 2007). Together, these three investor-owned utilities account for almost three-quarters of Oregon's electricity supply. The Bonneville Power Administration provides power to Oregon's 36 consumer-owned utilities as well as to direct-service industrial customers, such as aluminum smelters. Consumer-owned utilities include people's utility districts, municipally owned utilities and electric cooperatives (ODOE, 2007).

Energy Portfolios

According to Orkustofnun, the National Energy Authority of Iceland, "only 20 to 25 % of the technically and environmentally feasible hydropower, and only 20 % of the conventional geothermal potential available for electricity production in Iceland, have been harnessed" (NEAI, 2007). This leaves Iceland with considerable room to develop renewable energy sources for end use. Iceland's aluminum industry uses more Gigawatt Hours[5] each year then all of Iceland's other electricity consumers combined (NEAI, 2007). In sum, Iceland's installed capacity and generation of geothermal and hydropower electricity continues to rise to meet an increasing demand, while fossil fuel for electricity generation continues to diminish. Data from Orkustofnun, the National Energy Authority of Iceland on Iceland's Energy Portfolios for the years 2005 and 2006 is used in Figures 3-1 through 3-9 to illustrate this trend.

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[5] A unit of electrical energy equal to one billion watt hours.

Figure 3-1. Installed Capacity in Iceland, 2006

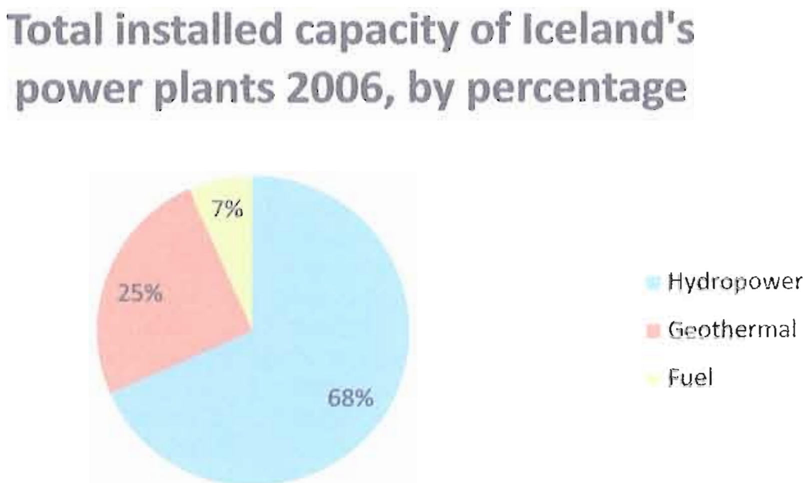


Figure 3-2. Installed Capacity in Iceland, 2006

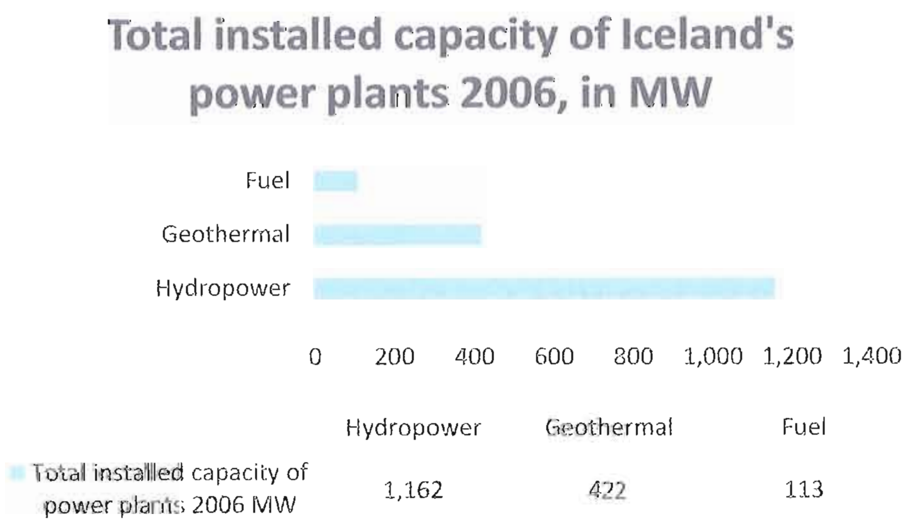


Figure 3-3. Installed Capacity in Iceland, 2005

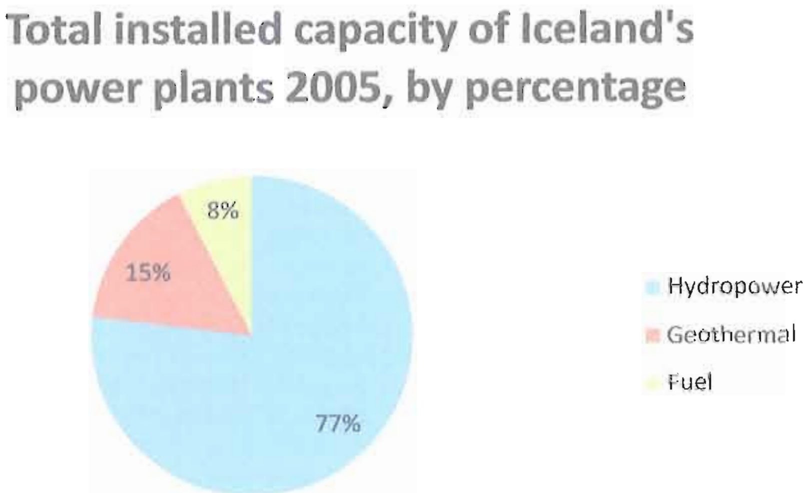
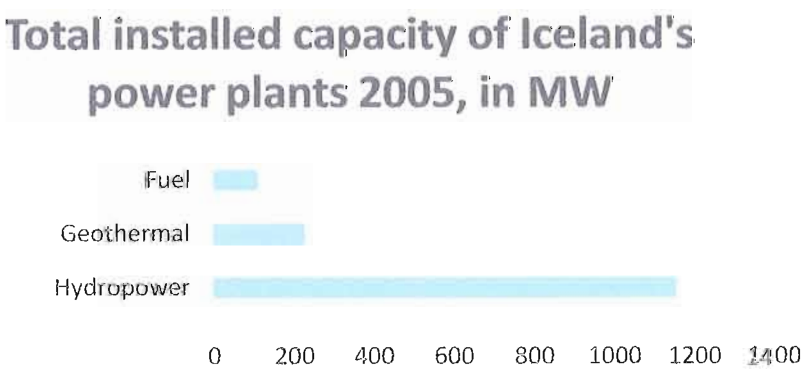


Figure 3-4. Installed Capacity in Iceland, 2005



	Hydropower	Geothermal	Fuel
Total installed capacity of power plants 2005 MW	1159	232	115

Figure 3-5. Electricity Generation in Iceland, 2006

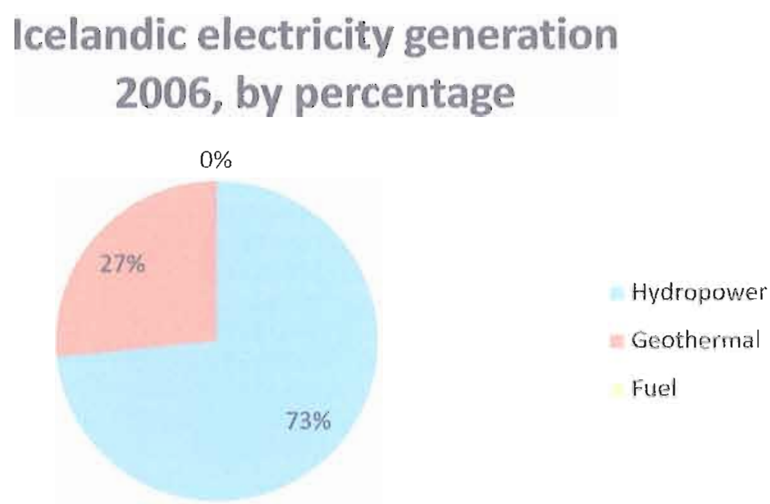


Figure 3-6 Electricity Generation in Iceland, 2006

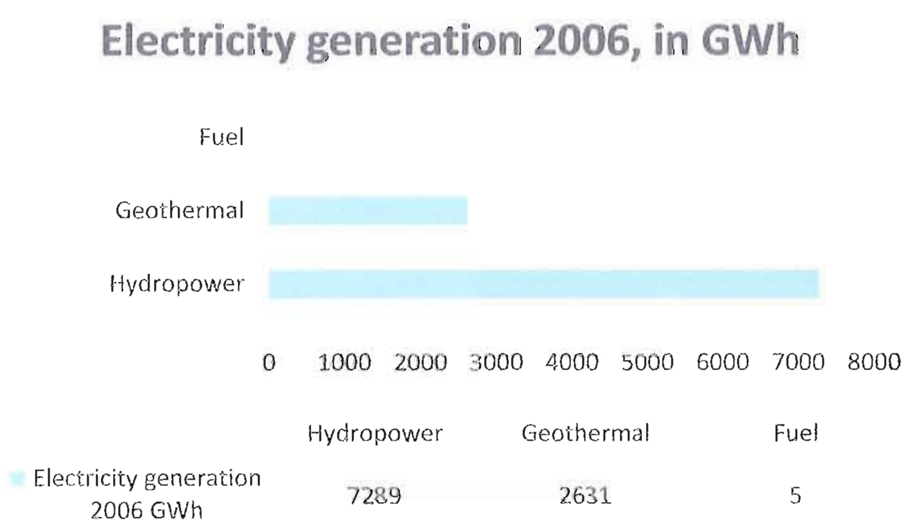


Figure 3-7. Electricity Generation in Iceland, 2005

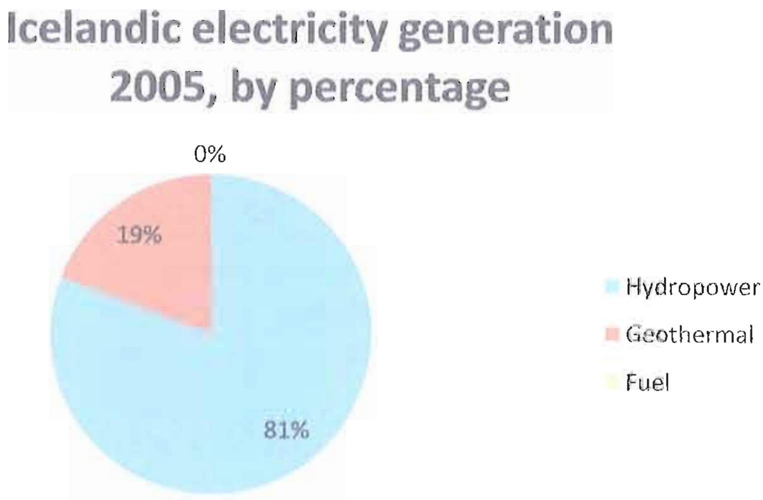


Figure 3-8. Electricity Generation in Iceland, 2005

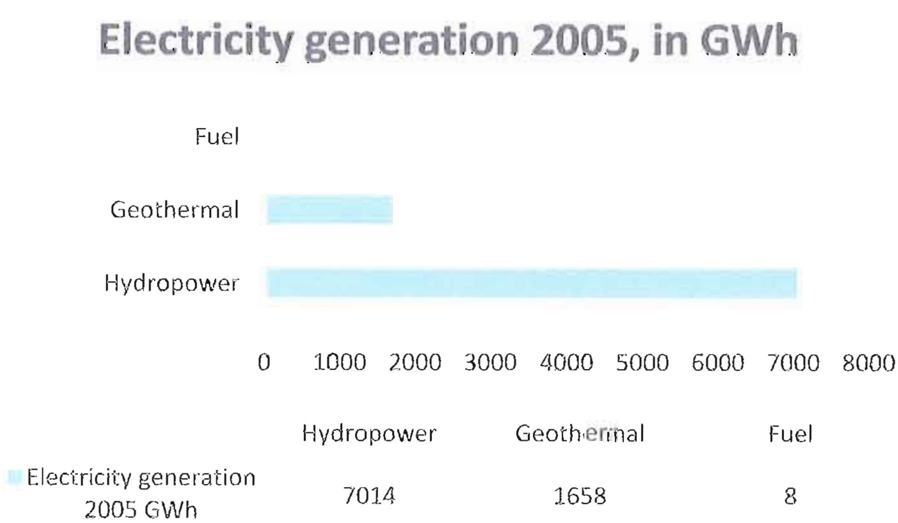
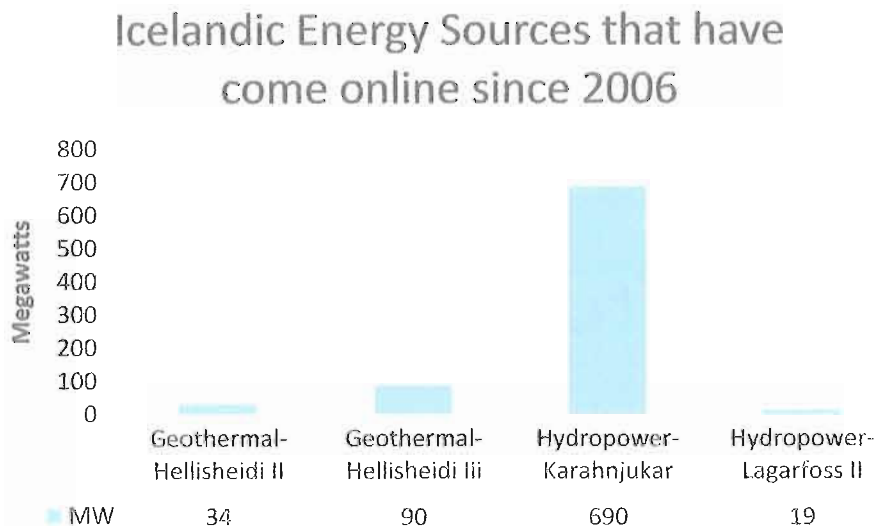


Figure 3-9. New Electricity Generation in Iceland



Energy conservation is the foundation of Oregon's energy policy (ODOE, 2008). Because of energy conservation and the electricity made available due to plant closures or reduced output from mills and aluminum smelters, Oregon's energy portfolios have not experienced the rapid change that Iceland's have the last 20 years. The average annual increase in Oregon electricity consumption 1980–2005 was only 0.8 % (USDOE, 2008). Oregon's hydroelectric system is considered to be built, meaning the addition of more dams in Oregon is not considered to be feasible. There is variability in any dam's electricity generation depending on the hydrology, and other factors, during the year. The mean average for the 16 year period 1990-2006 is 39,709,412 MWh.[6] This creates the need for Oregon to install other means of generation to meet the energy requirements above and beyond conservation and redistribution, and to compensate for the fluctuations inherent in Oregon's hydrology. Oregon currently generates no geothermal electricity. It has about a dozen areas that are known to be able to produce geothermal electricity. Oregon's high-temperature geothermal areas have the potential for about 2,200 MW of electric power (USDOE, 2005). Oregon's only nuclear power plant went offline in 1993

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[6] A unit of electrical energy equal to one million watt hours.

and natural gas, coal, and renewable energies have increased to compensate for this and to meet an increase in demand due to population growth. Data from the US Department of Energy's Energy Information Administration on Oregon's energy portfolios is used in Figures 3-10 through 3-15 to illustrate Oregon's energy consumption and generation.

Figure 3-10. Oregon Electricity Consumption, 2005

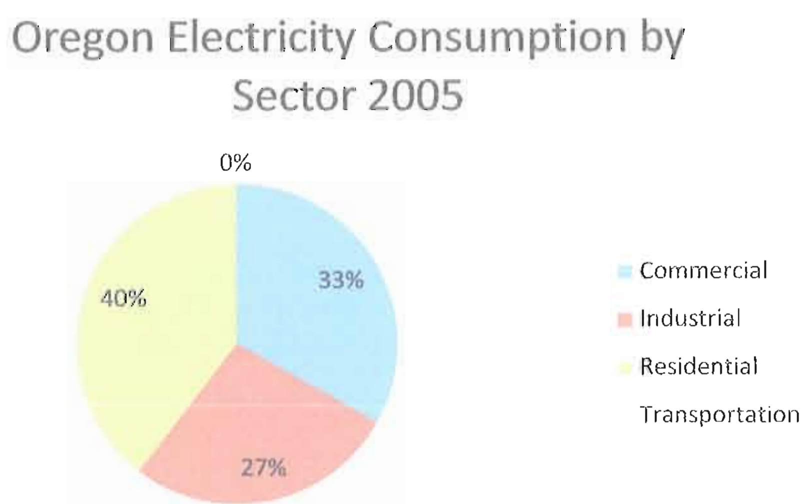


Figure 3-11. Oregon Electricity Consumption, 2005

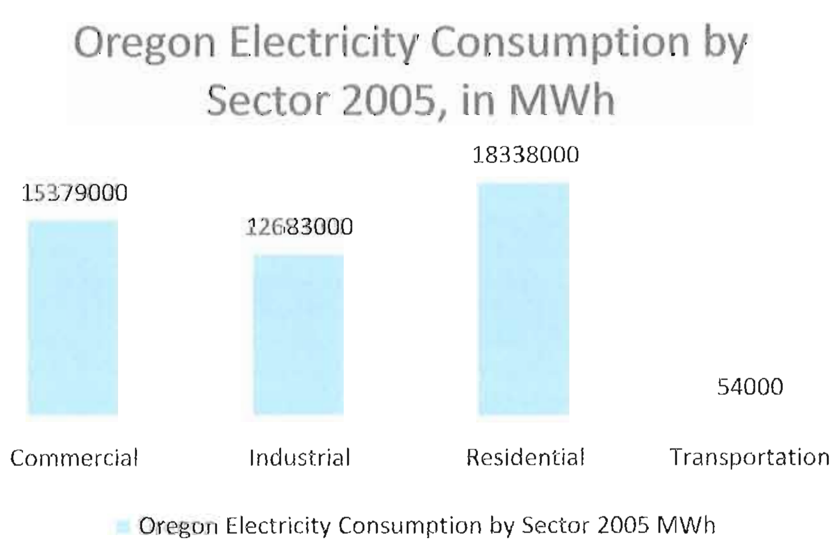
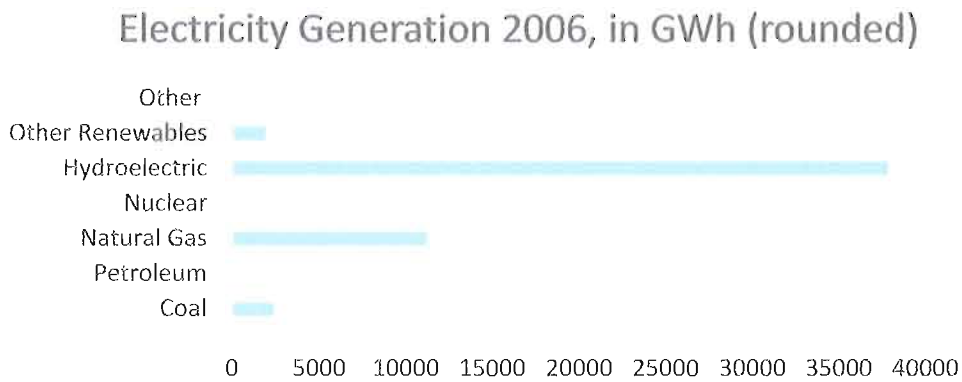
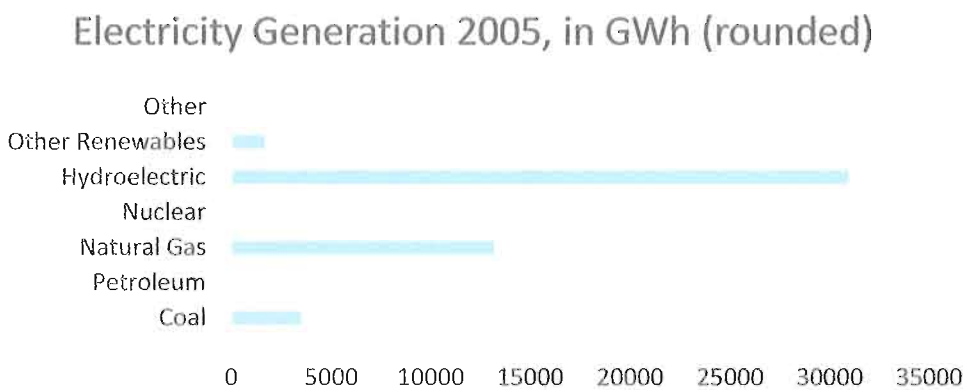


Figure 3-12. Electricity Generation in Oregon, 2006



	Coal	Petroleum	Natural Gas	Nuclear	Hydroelectric	Other Renewables	Other
GWh	2371	12	11198	0	37850	1870	40

Figure 3-13. Electricity Generation in Oregon, 2005



	Coal	Petroleum	Natural Gas	Nuclear	Hydroelectric	Other Renewables	Other
GWh	3467	78	13150	0	30948	1642	40

Figure 3-14. Sixteen-Year Oregon Hydroelectric Generation

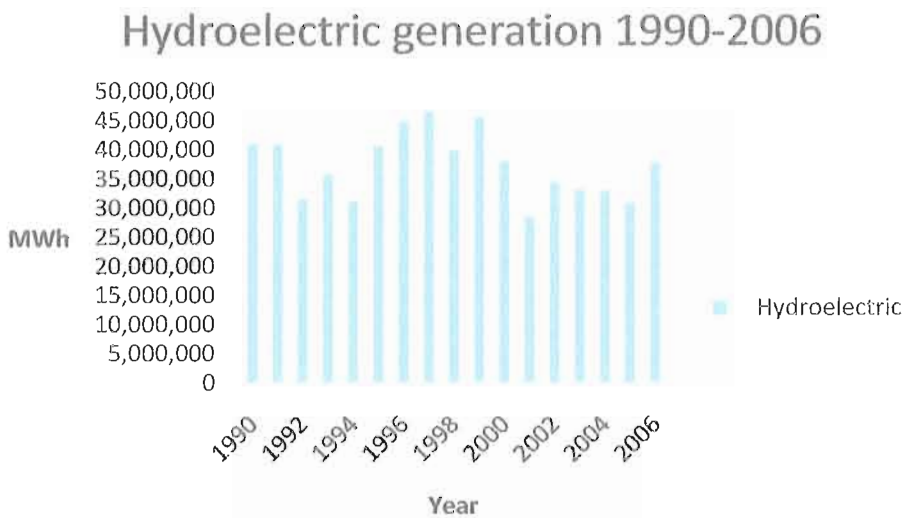


Figure 3-15. Sixteen-Year Oregon Trend in Coal, Natural Gas, and Non-Hydroelectric Renewable Energy Generation

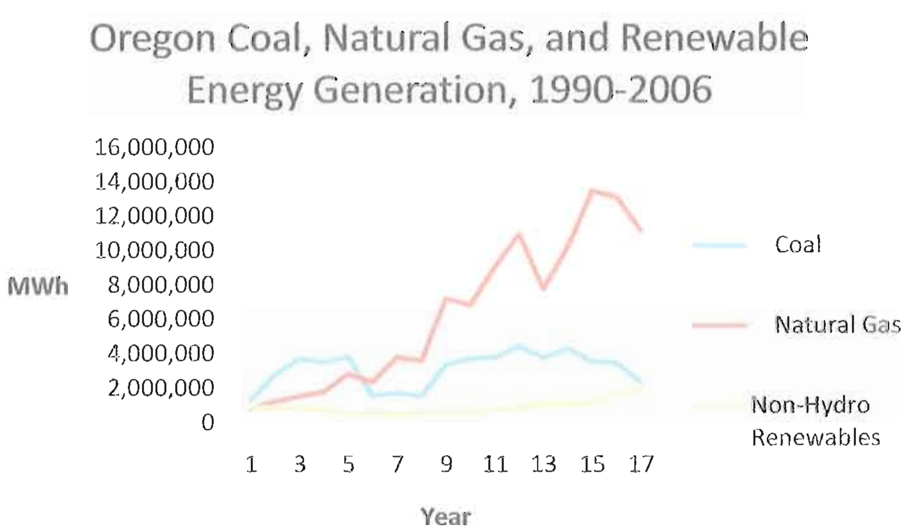


Figure 3-16. Sixteen-Year Oregon Trend in Natural Gas and Hydroelectric Energy Generation

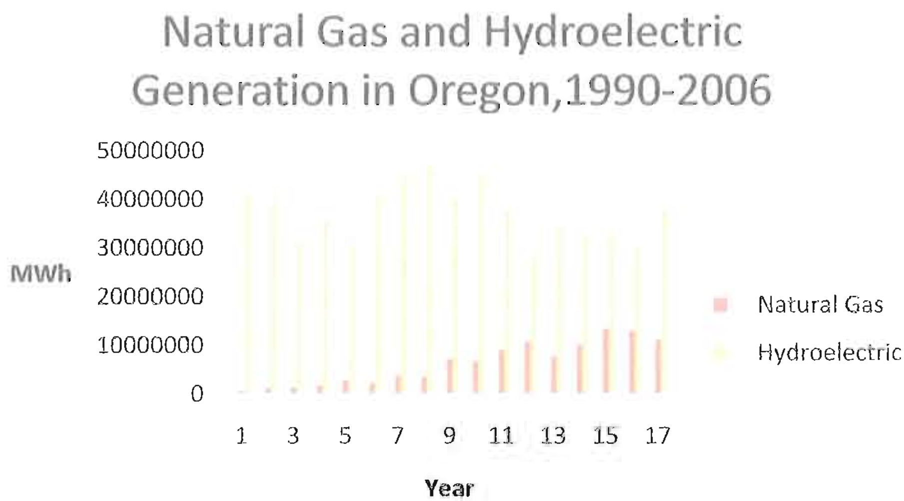


Figure 3-17. 2008 Active Oregon Geothermal Projects

Phase I: Identifying site, secured rights to resource, initial exploration drilling
• City of Klamath Falls - 1 MW (Distributed Generation Project) - City of Klamath Falls • Geoheat Center at the Oregon Institute of Technology (OIT) - 1.2 MW – OIT • Liskey Greenhouse - 10 MW - Raser Technologies • Hood River County - 20 MW (Pending Action of Volume II of the PEIS) – PGE • Willamette - 20 MW (Pending Action of Volume II of the PEIS) - Estate of Max Millis • Hood River County - 30 MW (Pending Action of Volume II of the PEIS) – PGE • Willamette - 30 MW (Pending Action of Volume II of the PEIS) - Estate of Max Millis
Phase II: Exploratory drilling and confirmation underway; PPA not secured
• Neal Hot Springs – 25-30 MW - U.S. Geothermal
Phase III: Securing PPA and final permits
• Geoheat Center at the Oregon Institute of Technology (OIT) - 0.2 MW (Distributed Generation Project) – OIT • Crump Geyser - 40-60 MW - Nevada Geothermal Power • Newberry Geothermal - 120 MW - Davenport Power, U.S. Renewables Group, Riverstone
Phase IV: Production drilling underway; facility under construction
• None as of August 2008

Source: Geothermal Energy Association (Geothermal Energy Association, 2008).

Summary

Oregon's population, population growth rate, and net migration rate are substantially higher than Iceland's. Both Oregon and Iceland generate the majority of their electricity using hydropower. Oregon's hydroelectric system is essentially developed, while Iceland's hydroelectric system has ample room to grow. Oregon's geothermal potential could feasibly grow to 2,200 MW which is less than Iceland had in 2006, and Iceland's geothermal generation has the potential to grow by another 80 %. Oregon is able to export hydroelectricity to neighboring states. Iceland, as an island nation, is unable to export its excess generated electricity. Because of this, Iceland uses its abundance of electricity as a natural resource to lure industries that require large amounts of energy, like aluminum smelters. Historically, Oregon used its abundance of affordable hydroelectric power as a natural resource to lure industries that required large amounts of energy, like aluminum smelters. Recently, Oregon has increasingly used conservation and imported natural gas to meet its generation needs. Iceland imports all of its fossil fuels and has placed an emphasis on using renewable energy to meet its energy needs instead of importing fossil fuels to meet its energy needs.

CHAPTER IV

METHODOLOGY

Given the significance of the zero-emissions renewable energy generation necessary for ZEVs in both Iceland and Oregon, information from the Grjótháls fueling station provides an opportunity to examine the effects on Oregon's renewable energy installation needs. The main purpose of this study is to evaluate the supply of renewable energy necessary for zero-emissions fuel cell vehicles in Oregon. Specifically, Oregon, in contrast to Iceland, has a developed hydroelectric system and increasingly has been using imported natural gas to meet its energy requirements. This situation, along with a desire for lower emissions, encourages the development of renewable energy in Oregon.

The following questions guided this research: (1) What are the energy requirements for Iceland's zero-emissions hydrogen fueling station; (2) How many vehicles can such a station serve; and (3) How much installed solar and wind capacities will Oregon need to follow Iceland's Grjótháls example? In order to answer these questions, energy data was used to systematically evaluate the research questions. The following key steps represent the basic methodological approach:

1. Convert the Grjótháls data into kWh[7] required.
2. Size the appropriate photovoltaic array based on the Grjótháls data.
3. Size the appropriate amount of wind turbines based on the Grjótháls data.
4. Analyze Oregon's energy generation, energy use, and renewable energy portfolio.
5. Scale the Grjótháls data from Iceland to Oregon.
6. Scale the Grjótháls data to Oregon's electricity providers.

Conversion of Grjóthåls Data

The initial step in this study was to define a unit of measurement that would be consistent throughout the study and all of its necessary conversions. Kilowatt hours (kWh) are the standard unit of energy for both gas and electricity consumption and generation. Since this study needed to convert the Grjóthåls data and make it applicable to Oregon's renewable energy needs, it was imperative to choose the proper unit of measurement so the data could easily be tied to vehicle and energy needs.

Of the available Grjóthåls data given by Jon Björn Skulason of Icelandic New Energy, this study focuses on the amount of hydrogen the station could produce each day. According to Jon Björn, "We spend 5.2 kWh to produce 1 Nm3[8] and we need roughly 11 Nm3 for 1 kg[9] hydrogen." This amount of electricity used includes compression of the hydrogen. Jon Björn also stated the Grjóthåls hydrogen fueling station uses an electrolyzer with an efficiency of 75 % (Electrolyzers make hydrogen by passing an

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[7] A standard unit of electricity or consumption equal to 1000 watts over one hour.

[8] A normal cubic meter is a unit of mass for gases equal to the mass of 1 cubic meter at a pressure of 1 atmosphere and at a standard temperature.

[9] A kilogram is the base unit of mass in the International System, equal to 1,000 grams (2.2046 pounds).

electric current through water containing an electrolyte.), and this is included in the amount of electricity used. With this data, this study was able to ascertain the electricity requirements necessary to make 125 kg of hydrogen at the Grjótháls station.

Figure 4-1. Energy Conversion for Zero-Emissions Fueling Station

- 5.2 kWh to produce 1 Nm3 of hydrogen
- 57.2 kWh to produce 1 kg of hydrogen
- 57.2 kWh multiplied by 125 kg = 7150 kWh to make 125 kg hydrogen

For the next step of the conversion process this study needed to convert the needs of three fuel cell buses at the Grjótháls hydrogen fueling station into the number of fuel cell ZEVs in Oregon. By taking the ODOT year 2000 total vehicle miles travelled (VMT) and dividing them by Oregon's 2000 census population, this study defined the average VMT each year by an Oregonian. This number was divided by 365 to get the average VMT a day. This number was verified through research, and found to be consistent with multiple sources that listed Oregon's daily average VMT as being 16 miles.

Figure 4-2. Oregon's daily VMT assumptions

- Vehicle Miles Traveled year 2000 (ODOT, 2007) = 20,450,700,000
- Oregon's 2000 census population = 3,421,399
- 20,450,700,000 / 3,421,399 =5,977
- 5,977/ 365 =16 average Oregon VMT per day

To merge the VMT data into the number of cars the model Grjóthāls hydrogen fueling station could meet the daily needs of, this study based its assumption of the average mileage per gallon on an evaluation done by Popular Mechanics. Popular Mechanics evaluated the Chevy fuel cell vehicle over 3 months and 35 fill-ups and determined that the Equinox averaged more than 41 miles per gallon.[10]

Figure 4-3. Number of Vehicles Served Based on Oregon Average VMT

- 125 kg a day = approximate energy equivalent of 100 gallons of gasoline
- Average VMT/day in Oregon = 16 miles
- Average mpg for fuel cell = 41
- 100 Gals of gas/day times 41 mpg/day = 4100 miles/day
- 4100 miles/day / 16 miles/day = 256 average vehicles

In conclusion, to drive 4100 miles a day (256 vehicles) requires 7150 kWh/day of electric generation.

Solar Assumptions

Research data from Florida Solar Energy Center (FSEC), a research institute of the University of Central Florida (FSEC, 2007), allows for 1 kg of hydrogen to require 51 kWh of photovoltaic (PV) electricity, assuming 10 % PV efficiency, 5 hours of PV generation a day, and electrolyzer efficiency (Ee) of 65 %.

[10] Chevy Equinox evaluation done by *Popular Mechanics*: over 41 average mpg over 3 months and 35 fill-ups. Retrieved on March 16,2009, from http://www.popularmechanics.com/automotive/new_cars/4276771.html

Figure 4-4. Energy Conversion to PV Requirement

- 1 kg of hydrogen = 51 kWh using an Ee of 65 %
- 51 kWh * 125/day = 6375 kWh/day
- 6375 kWh/day / 5 hours/day = 1275 kWp

Assuming 1 kWp[11] requires approximately 10 square meters in area for PV at 10 % efficiency, the resulting PV array would need to cover an area an area roughly 375 feet by 370 feet (an American football field, including end zones, is a 160 feet wide by 360 feet long).

Table 4-5. Sizing of Required PV Array

- 1 kWp requires approximately 10 square meters in area for PV at 10 % efficiency.
- 12750 square meters necessary for installation
- 12750 m^2 = 137,241 square feet, or an area roughly 375 feet by 370 feet.

In conclusion, to drive 4100 miles a day (256 vehicles) requires 1275 kWp or 1.275 MW of PV generation and 137,241 square feet of space.

[11] A kilowatt peak is the PV generator's peak power at maximum solar radiation under Standard Test Conditions.

Wind Assumptions

Assuming 1 kg of hydrogen equals 60 kWh of wind generation,[12] including electrolysis and compression efficiency (Bartholomy' 2004),[13] the needs for 125 kg of hydrogen a day would be 7500 kWh/day or 7.5 MW.

According to the Oregon Department of Energy, the average output from a 1.5 MW wind farm turbine in Oregon is 4 million kWh/year, and a 1.5 MW wind turbine in a wind farm requires half of an acre (ODOE, 2007).

Figure 4-6. Sizing of Required 1.5 MW Wind Turbines

- 1 kg of hydrogen = 60 kWh (includes electrolysis and compression efficiency)
- 60 kWh * 125/day = 7500 kWh/day or 7.5 MW
- Average output from a 1.5 MW wind farm turbine in Oregon = 4 million kWh/year or 10,959 kWh/day
- 11 MW/day = 7 (1.5 MW) turbines
- A 1.5 MW wind turbine in a wind farm takes .5 acres.
- 7 wind turbines require 3.5 acres

In conclusion, to drive 4100 miles a day (256 vehicles) requires seven 1.5 MW wind turbines and 3.5 acres in one of Oregon's existing wind farms.

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[12] Assumption based on information from the Basin Electric Power Cooperative as provided to the Legislative Committee of North Dakota, the American Hydrogen Association, and the Electric Power Research Institute. Retrieved March 18, 2009, from
http://www.legis.nd.gov/assembly/60-2007/docs/pdf/edt030508appendixf.pdf
http://www.hydrogenassociation.org/general/epriHug/16_Rebenitsch.pdf

[13] Assumption based on hydrogen potential in kg/day assuming electrolysis and compression efficiency 60 kWh/kgH2 by wind generation in California, and in consideration of the above assumption.

Oregon Renewable Energy Analysis

Analysis of The U.S. Department of Energy's Energy Information Administration (EIA) and The Northwest Power and Conservation Council (NPCC) data on Oregon's energy portfolio, its energy generation, and its energy use does allow for the separation of Oregon's renewable energy from hydropower, and its energy use from its energy generation. The EIA data for renewable energy (excluding hydropower) is not broken down by type. Therefore, this data is inclusive of all types of renewable energy generation in Oregon, which the NPCC lists as being biomass, solar, and wind. Use of the NPCC allowed for the filtering of biomass from solar and wind data. Biomass has the potential to reduce air pollution by being a part of the carbon cycle, potentially reducing carbon dioxide emissions by 90 % compared with fossil fuels. However, it still produces emissions, including sulfur dioxide (Union of Concerned Scientists, 2009). Because of this fact, this study has not used biomass energy generation in its ZEV methodology. NPCC data shows Oregon's installed MW capacity of biomass energy generation as being 225 MW (Northwest Power and Conservation Council [NPCC], 2009). Oregon's installed MW capacity of solar and wind energy generation is 1211.2 MW (NPCC, 2009).Table 4-7 lists Oregon's solar and wind generation.

Table 4-1. Solar and Wind Generation in Oregon

Oregon Solar and Wind Generation, 500 kW capacity or greater (Megawatts)				
	Installed Capacity MW	Average Energy MWa[14]	Status (Oct. 2008)	Resource Type
Kettle Foods	0.1	0.0	Operating	Solar
Pepsi Solar	0.2		Operating	Solar
Portland Habilitation Center	0.9		Construction	Solar
Biglow Canyon Ph I	125.4		Operating	Wind
Combine Hills I	41.0	14.0	Operating	Wind
Condon	49.8	12.0	Operating	Wind
Elkhorn	100.0		Operating	Wind
Klondike I	24.0	7.4	Operating	Wind
Klondike II	75.0	23.1	Operating	Wind
Klondike III	221.0	74.0	Operating	Wind
Klondike IIIA	76.5	25.0	Operating	Wind
Leaning Juniper	100.5	34.0	Operating	Wind
Pebble Springs	99.0	31.5	Construction	Wind
Rattlesnake Road	102.9		Construction	Wind
Vansycle Wind Energy Project	25.0	8.5	Operating	Wind
Wheat Field	96.6	28.0	Construction	Wind
Whiskey Run	1.3	0	Retired	Wind
Willow Creek	72.0	22.8	Construction	Wind

Source: Northwest Power and Conservation Council

Oregon's renewable energy generation, transmission, and distribution extends beyond our state lines, and thus is difficult to isolate. This applies to hydroelectric as well as other renewable energy sources. For instance, a company like PacificCorp, the parent company of Pacific Power, moves electricity into, and out of, the state to meet its

[14] An average megawatt is the average number of megawatt-hours, not megawatts, over a specified time period. In this example, it is the average number of megawatt-hours the PV arrays and wind turbines produced over the course of one year. The extreme difference between the installed capacity and the MWa is reflective of the intermittent nature of wind, and to a lesser degree, solar.

customers' needs, which span many states. The low-cost hydropower they generate or purchase from an Oregon hydroelectric source is used to serve retail loads first. To divert this low-cost hydropower to another area would result in raising the rates charged to Oregon's retail customers, and this is not allowed by the Oregon Public Utility Commission.[15]

The Bonneville Power Administration does sell surplus electricity, when available, to other areas (frequently California), which it lists as secondary revenues. It uses assumptions based on these revenues, which are sold on the spot-market[16] for a higher rate, when planning to keep its customers rates low. In essence, using occasionally available surplus electricity to generate hydrogen would result in an increase in rates, and would not be allowed by the Federal Energy Regulatory Commission.[17]

Oregon's hydroelectric loads[18] are greater than their generation capability. Figure 4-1 uses 2005 data from the EIA to illustrate an example of a yearly hydroelectric load exceeding its generation capability.

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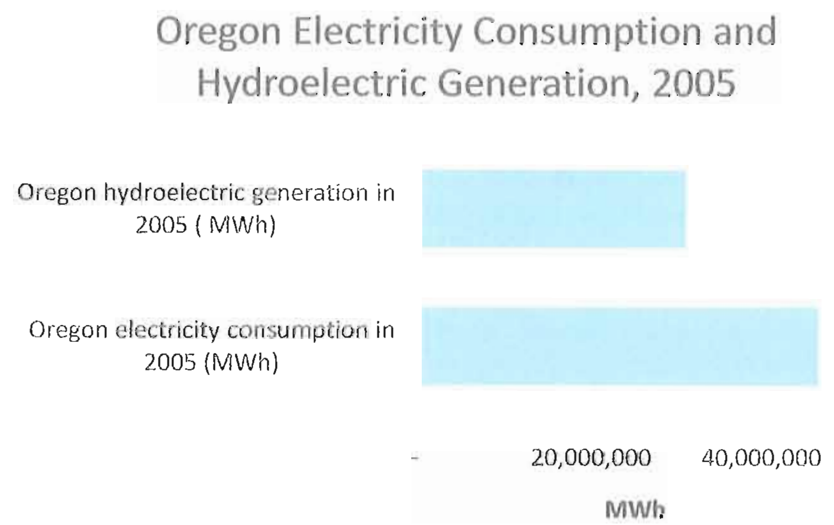
[15] The Public Utility Commission of Oregon (PUC) regulates customer rates and services of the state's investor-owned electric, natural gas and telephone utilities; and certain water companies. The PUC is tasked with ensuring consumers receive utility service at fair and reasonable rates.

[16] There is a North American market for buying and selling electricity and natural gas. It's essentially a commodity market that trades electricity and natural gas like other commodities. The price is set based on supply and demand for immediate requirements. The spot price is the price of electricity at one point in time on that market. The price varies extensively in times of extreme heat or cold. In effect, when there is a strong demand for electricity and/or gas, they are worth more and can be sold on the spot market for a higher spot price.

[17] The Federal Power Act of 1935created the Federal Power Commission, now the Federal Energy Regulatory Commission (FERC). FERC carries out the principal functions for the interstate economic regulation of investor-owned electric utilities under a mandate to ensure that wholesale rates are just and reasonable.

[18] In this case, the electric load (or demand) is the power requirement of Oregon's electricity consumers. In electricity generation terminology, a Base load is the minimum amount of electric power delivered or

Figure 4-7. Comparison of 2005 Oregon Electricity Consumption and Hydroelectric Generation



In conclusion, analysis of Oregon's hydroelectric, solar, and wind data demonstrates insufficient generation to meet demand. Oregon does not have any hydroelectric power available to allocate to hydrogen generation, and its installed wind and solar projects are just a small portion of what is needed to meet the base load demand above what Oregon's hydroelectric generation is able to provide. Oregon's geothermal energy has no generation facilities being built, and its planned generation of 297.4-322.4 MW (see Table 3-1.) will be needed for base load demand (Geothermal Energy Association, 2008). Any renewable energy devoted specifically to hydrogen production in Oregon for ZEVs will need to be installed.

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required over a given period of time. A Peak load is the maximum load delivered or required during a specified period of time. Oregon's electric load fluctuates between base loads and peak loads.

Scaling Grjóthåls Data to Oregon

According to the 2008 *World Factbook* (CIA, 2008), Iceland has an estimated population of 304,367. Oregon's estimated population for 2008 is 3,791,060 (PSU, 2008). This means that Oregon has about 12 citizens for every 1 Icelander. Another way of looking at population is in a geographical context. Iceland has an area 39,756 square miles and an estimated 2008 population of 304,367. This gives Iceland an average of approximately 7 people per square mile. Oregon has an area of 97,074 square miles and a 2008 estimated population of 3,791,060 giving it an average of approximately 39 people per square mile. The concentration of urban population constitutes the majority of both Iceland and Oregon populations. The Grjóthåls Hydrogen fueling station "could produce enough H_2 to satisfy up to 600 personal cars in general operation" (INE, 2008). Whereas this study has assigned a similar station in Oregon as being able to meet the needs of 256 fuel cell vehicles each day.

In consideration of this varied information, this study has decided on an assumption that is a factor of 10 difference between Iceland and Oregon. This was done to reflect the overall population difference, the larger urban population of Oregon versus Iceland, and the difference in Iceland's daily personal vehicle hydrogen requirements versus Oregon's daily VMT.

In conclusion, Oregon's needs to have ZEVs based on the Icelandic example of the Grjóthåls Hydrogen fueling station, with the differences in Oregon's population, population concentration, and daily mileage are scaled to meet the needs of 2,560 fuel cell vehicles each day.

Scaling Grjóthâls Data to Oregon's Electricity Distributers

The three main providers of electricity in Oregon are the investor-owned utilities Portland General Electric (PGE) and Pacific Power (a PacifiCorp company), and the Bonneville Power Administration (BPA). Pacific Power serves 31 % of Oregon's electric utility load, providing power to more than 486,000 customers. PGE serves 40 % of Oregon's electric utility load, providing power to about 733,000 customers. The BPA provides power to Oregon's 36 consumer-owned utilities which include people's utility districts (PUDs), municipally owned utilities and electric cooperatives (ODOE, 2009). A majority of these PUDs, municipally owned utilities and electric cooperatives are BPA full requirements customers, meaning they purchase all their power from BPA. Some PUDs and electric cooperatives have small generation capabilities. Eugene's utility provider, Eugene Water and Electric Board (EWEB), is an exception to the full requirements customers because it has substantial generation assets (Public Power Council, 2002). Idaho Power, another investor-owned utility, serves about 1 % of Oregon's electric load (ODOE, 2007). With this in mind, this study is operating under the assumption that the BPA serves 25 % full requirement load. Thus, Oregon's 2,560 fuel cell vehicles are broken down as Pacific Power (2560 x .31) 794 ZEVs, PGE (2560 x .4) 1024 ZEVs, and BPA (2560 x .25) 640 ZEVs. The remaining 154 ZEVs are assigned to EWEB and not Idaho Power based solely on the urban status of Eugene as Oregon's third largest city. Table 4-2 lists Oregon's electricity providers.

Table 4-2. Oregon's Electric Utilities

Oregon Electricity Providers			
Investor-Owned Electric Utilities	Cooperative Electric Utilities	Peoples Utility Districts (PUDs)	Municipal Electric Utilities
Idaho Power Company	Blachly-Lane Electric Co-op.	Central Lincoln PUD	Canby Utility Board
Pacific Power (PacifiCorp)	Central Electric Co-op.	Clatskanie PUD	City of Ashland Electric Dept.
Portland General Electric (PGE)	Consumers Power	Columbia River PUD	City of Bandon
	Coos-Curry Electric Co-op.	Emerald PUD	City of Cascade Locks
	Douglas Electric Co-op.	Northern Wasco PUD	City of Forest Grove
	Lane Electric Co-op.	Tillamook PUD	City of Drain
	Midstate Electric Co-op. Inc.		City of Monmouth
	Salem Electric		Eugene Water & Electric Board
	Umatilla Electric Co-op.		Forest Grove Light & Power
	Columbia Basin Co-op.		Hermiston Energy Services
	Columbia Power Co-op.		McMinnville Water & Light
	Columbia Rural Electric		Milton-Freewater Light & Power
	Harney Electric Co-op.		Springfield Utility Board
	Hood River Electric Co-op.		
	Oregon Trail Electric Co-op.		
	Surprise Valley Electric Corp.		
	Umpqua Indian Utility Co-op		
	Wasco Electric Co-op.		
	West Oregon Electric Co-op.		

Source: Oregon Department of Energy

CHAPTER V

FINDINGS

This study evaluated the renewable energy needs of the Grjótháls Hydrogen fueling station to determine the renewable energy installation requirements necessary within Oregon for fuel cell ZEVs at the electric utility provider level. Using the methodology outlined in the previous chapter, the information presented in this chapter reveals the number of model hydrogen fueling stations required, the renewable energy necessary for the model hydrogen fueling stations, as well as the location and integration of these model hydrogen fueling stations throughout Oregon's electricity distribution regions.

Hydrogen Fueling Station Needs

The model Grjótháls Hydrogen fueling station has the ability to produce and distribute 125 kg of zero emissions hydrogen a day. This amount will provide the hydrogen necessary for Oregonians to drive 4100 miles a day, which can be further defined as meeting the needs of 256 vehicles, based on Oregon's daily average VMT.

Oregon's 2,560 fuel cell vehicles, which are broken down in the previous chapter as Pacific Power 794 ZEVs, PGE 1,024 ZEVs, BPA 640 ZEVs and EWEB 154 ZEVs, will thus require 10 model hydrogen fueling stations to follow the Icelandic example. Since the model Grjótháls Hydrogen fueling station was the designed to produce and distribute 125 kg of zero emissions hydrogen a day, this study has assigned a value of 1 model hydrogen fueling station per 256 cars. This study chose to round the number of required model fueling stations up rather than not run a model station at its designed capacity. Table 5-1 lists the scaled number of model hydrogen fueling stations required to emulate the Icelandic example in Oregon.

Table 5-1. Number of Model Hydrogen Fueling Stations Required Following the Icelandic Example in Oregon by Electricity Provider

	Number of ZEVs	Number of model hydrogen fueling stations	Number of model hydrogen fueling stations (rounded)
Pacific Power	794	3.1	4
PGE	1024	4	4
BPA	640	2.5	3
EWEB	154	.6	1
Total	2560	10.2	12

Iceland located its model zero emissions hydrogen fueling station (the Grjótháls station) in its most populated city. With this in mind, this study has placed its zero emissions hydrogen fueling stations accordingly.

EWEB's hydrogen fueling station was rather straightforward since EWEB is a municipal consumer-owned utility and serves only Eugene. This study proposes a model hydrogen fueling station be placed in Eugene to reflect the Icelandic example of a zero emissions hydrogen fueling station in Oregon. Eugene, with a 2008 US Census Bureau estimated population of 149,004, is Oregon's third-largest city.

Pacific Power requires four model hydrogen fueling stations. Pacific Power's service territory in Oregon spans portions of the entire state with the exception of Oregon's southeast corner, which also happens to be the state's least populated region. Pacific Power's Portland service territory includes portions of downtown Portland between I-405 and I-5, as well as the entire northeast area that lies within the area bordered by I-5 on the south, I-205 on the east, and I-84 on the south. This study proposes a model hydrogen fueling station in each of these highly populated areas. Portland, with a 2007 US Census Bureau estimated population of 550,396, is Oregon's largest city. Pacific Power's service territory covers most of southwestern Oregon, including Medford. Medford, with a 2007 US Census Bureau estimated population of 72,186, is Oregon's eighth-largest city. This study has suggested this area for a model hydrogen fueling station. Pacific Power's service territory covers part of central Oregon, including Bend. Bend, with a 2007 US Census Bureau estimated population of 74,563, is Oregon's seventh-largest city and this study suggests this area for a model hydrogen fueling station. This study views the placement of model hydrogen fueling stations in these areas as meeting the requirements necessary to follow the Icelandic example as scaled to Oregon and its needs.

PGE also requires four model hydrogen fueling stations. PGE's service territory in Oregon covers more than 4,000 square miles including practically all of southeast Portland, all of southwest Portland with the exception of a few downtown areas, the majority of the Salem area, and Gresham. Salem, with a 2007 US Census Bureau estimated population of 151,913, is Oregon's second-largest city. Gresham with a 2007 US Census Bureau estimated population of 99,721, is Oregon's fourth-largest city. This study proposes these areas for the necessary model hydrogen fueling stations to follow the Icelandic example as scaled to Oregon and its needs.

The BPA 25 % full requirement load for the PUDs, municipally owned utilities and electric cooperatives is three model hydrogen fueling stations. The City of Forest Grove has a municipal electric utility. Forest Grove's 2007 US Census Bureau estimated population was 20,402. Forest Grove is adjacent to The City of Hillsboro, which is Oregon's fifth-largest city. The City of La Grande, in the northeastern corner of the state, is served by the Oregon Trail Electric Cooperative. La Grande's 2000 US Census Bureau estimated population was 12,327. This does not rank it among Oregon's more populated cities, but its location along I-84 in northeastern Oregon approximately 60 miles from Pendleton (US Census Bureau 2007 estimated population 16,477) is an area of Oregon that would serve a fueling need for ZEVs travelling to and from Oregon. Newport, (US Census Bureau 2007 estimated population 9,852) is served by Central Lincoln PUD. Similar to La Grande, its strategic location at the junction of US-101 and US-20 would serve a fueling need for ZEVs travelling to and from the Oregon coast. This study proposes these areas for the necessary model hydrogen fueling stations to follow the

Icelandic example as scaled to Oregon and its needs. Table 5-2 lists the recommended locations of this study.

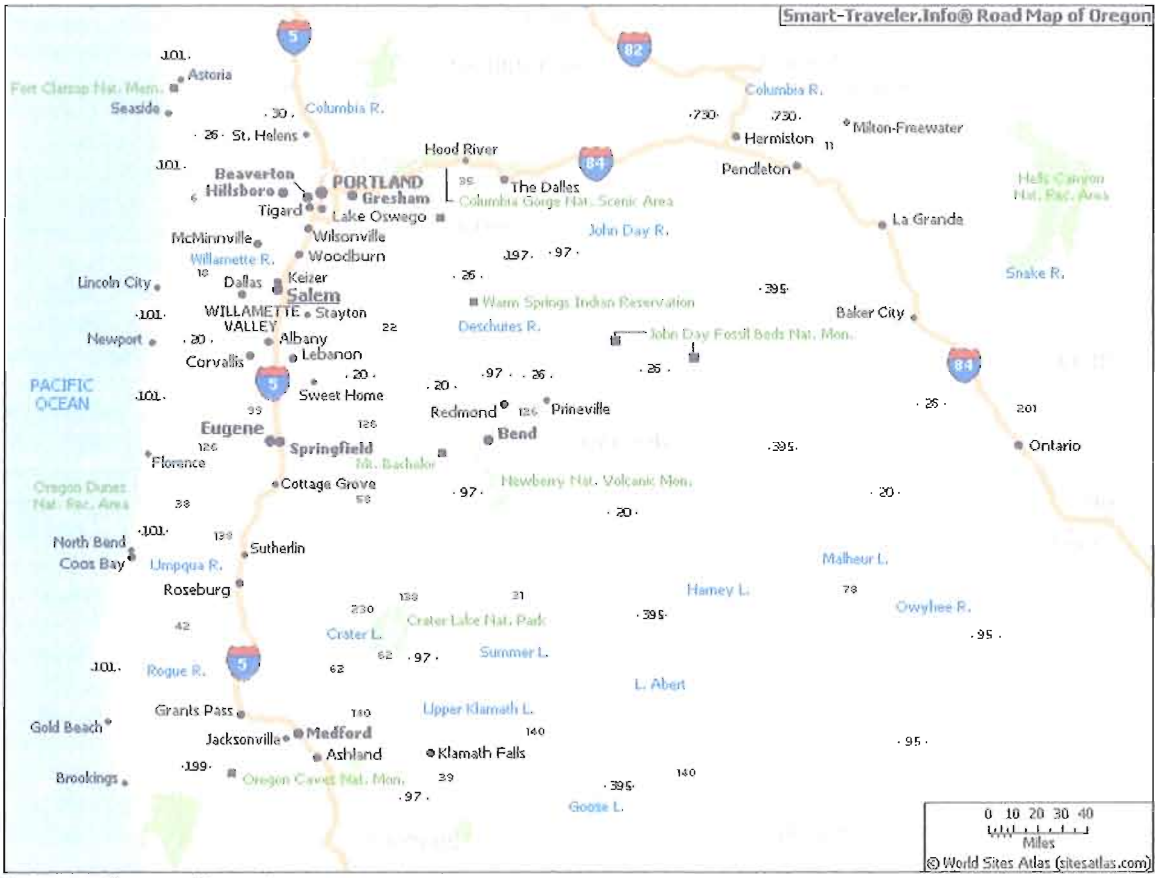
Table 5-2. Locations of Hydrogen Fueling Stations

	Number of ZEVs	Number of hydrogen fueling stations (rounded)	Location of hydrogen fueling stations
Pacific Power	794	4	Downtown Portland N.E. Portland Medford Bend
PGE	1024	4	S.E. Portland S.W. Portland Salem Gresham
BPA	640	3	Forest Grove La Grande Newport
EWEB	154	1	Eugene

In conclusion, this section of the study has located the model hydrogen fueling stations necessary to follow Iceland example throughout Oregon in a way that reflects population density, as well as geographic convenience for the population centers. The Willamette Valley, where 70 % of Oregon's population lives has almost 70 % (≈.67 %) of the model hydrogen fueling stations. The other four locations (Ashland, Bend, La Grande, and Newport) are popular destinations for Oregon's Willamette Valley denizens.

This was a major factor in their choice as hydrogen fueling station locations for this study. Map 5-1 shows Oregon and the location of the towns mentioned in this study.

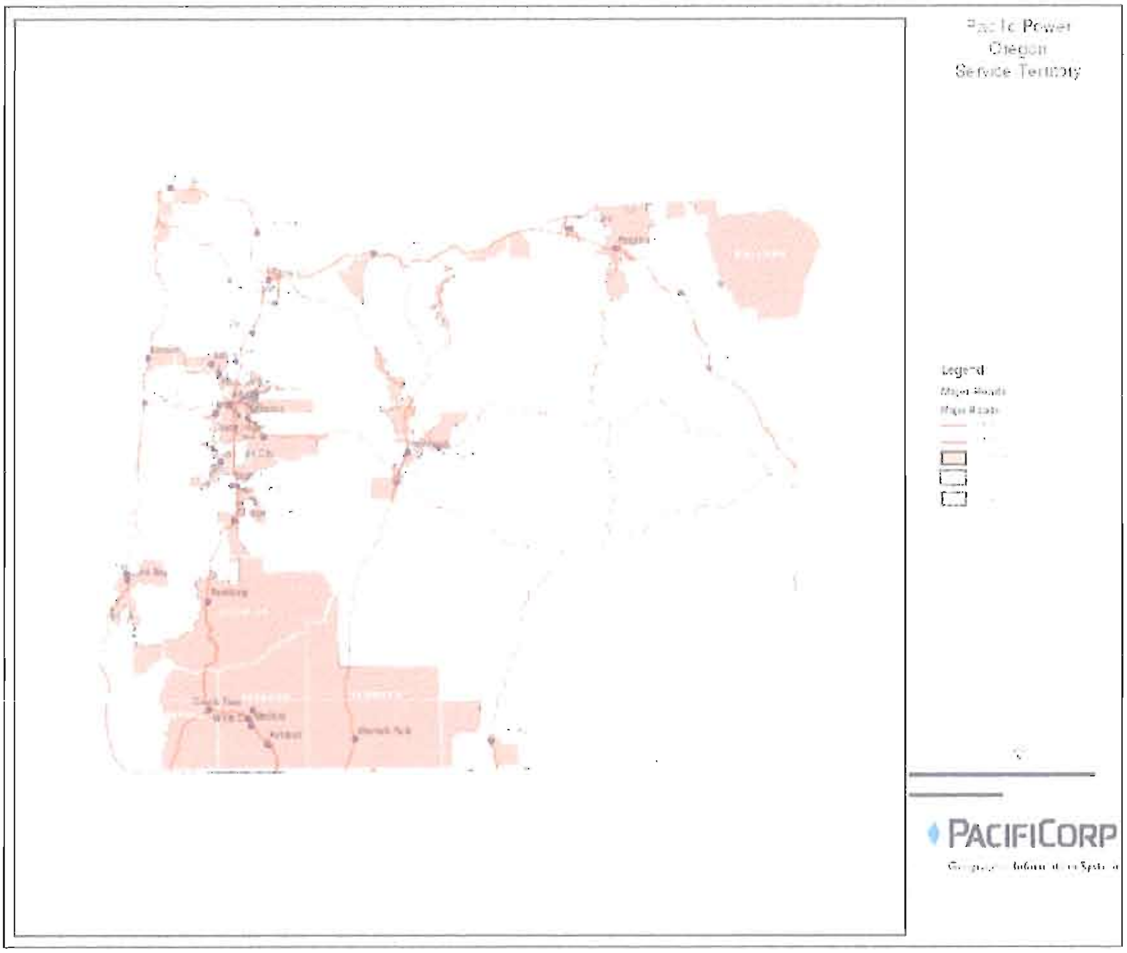
Map 5-1. Locations of Hydrogen Fueling Station Cities



Source: Smart-Traveler

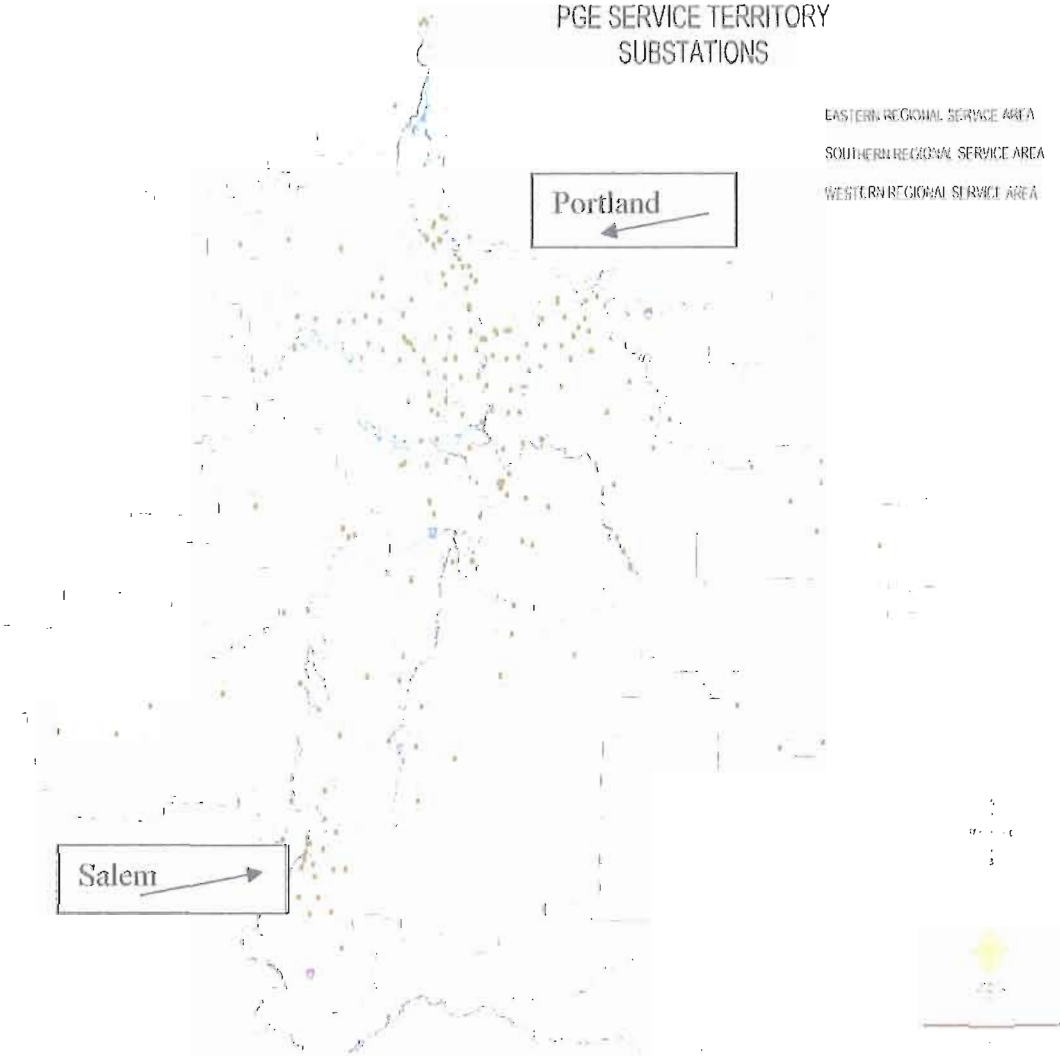
Oregon's electricity utilities are scattered throughout the state in an almost patchwork quilt sort of pattern. Map 5-2 shows Pacific Power's service territory in Oregon, Map 5-3 shows PGEs service territory, Map 5-4 shows Oregon's PUDs, municipally owned utilities and electric cooperatives.

Map 5-2. Pacific Power's Oregon Service Territory



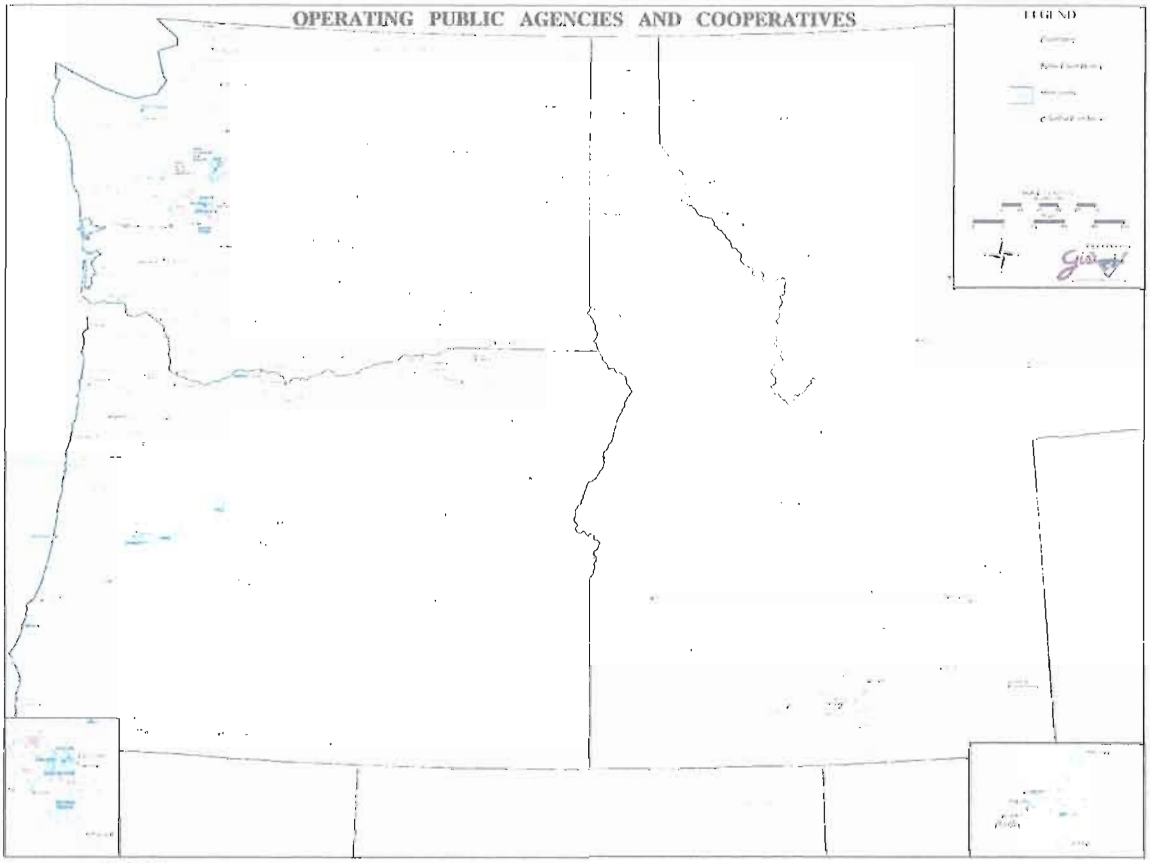
Source: PacficCorp

Map 5-3. PGE Service Territory



Source: PGE

Map 5-4. Pacific Northwest PUDs, Municipally Owned Utilities and Electric Cooperatives



Source: PGE

Evaluation of Renewable Energy Needs

The previous chapter posited any renewable energy devoted specifically to hydrogen production in Oregon for ZEVs will need to be installed. This is because of two factors: 1) demand exceeds generation; and 2) policy prohibits decisions that would increase Oregon electricity customer's rates.

There are two separate governing authorities that help set the rates Oregon's electricity providers are able to charge, FERC and Oregon's PUC. The policies that give these regulators their authority have roots derived from the time the hydroelectric dams of the region were first constructed.

Section 4 of the 1937 Bonneville Project Act says:

> In order to insure that the facilities for the generation of electric energy at the Bonneville project shall be operated for the benefit of the general public, and particularly of domestic and rural consumers, the [BPA] administrator shall at all times, in disposing of electric energy generated at said project, give preference and priority to public bodies and cooperatives... (Public Power Council, 2002).

Section 2 of the 1964 Pacific Northwest Preference Act says:

> ...the sale, delivery, and exchange of electric energy generated at, and peaking capacity of, Federal hydroelectric plants in the Pacific Northwest for use outside the Pacific Northwest shall be limited to surplus energy and surplus peaking capacity (Public Power Council, 2002).

This principle is known as public preference. "Congress granted preference for several reasons. One was to ensure that the benefits of federal power were passed through to the public at the lowest possible cost" (Public Power Council, 2002). BPA is committed to cost-based rates and public and regional preference in its marketing of power because the Federal Power Act of 1935 created the Federal Power Commission, now the FERC. FERC "carries out the principal functions for the interstate economic regulation of investor-owned electric utilities, including financial transactions, wholesale rate regulation, interconnection, transmission of wholesale electricity, and ensuring adequate and reliable service. It also gives FERC a mandate to ensure that wholesale rates are just and reasonable" (Public Power Council, 2002). Because BPA markets energy and transmission at cost, rather than at market prices, it has traditionally provided some of the lowest cost electricity in the nation. Oregon customers have a preference to purchase this low-cost electricity. Sales of surplus energy and surplus peaking capacity on the spot market help to ensure BPA customer's rates are just, reasonable, and among the lowest cost electricity in the nation. Redirection of this surplus energy and surplus peaking capacity to generate hydrogen would result in a rate increase that would most probably be considered by FERC to not be just and reasonable.

The Public Utilities Holding Company Act (PUHCA) of 1935 is aimed at controlling the corporate abuses and misconduct of private power's public utility holding companies. Under PUHCA, "state operated public utility commissions (PUCs) have jurisdiction over the interstate operations of investor-owned utilities (IOUs), retail ratemaking and retail bundled electricity service. Retail prices are set through an adversarial hearing process where the issues are the revenue requirement (total amount of money that the utility will be permitted to collect) and how the burden will be recovered from customers in the customer classes (residential, commercial, and industrial)" (Public Power Council, 2002). Oregon's PUC ensures consumers receive utility service at fair and reasonable rates, while allowing regulated companies the opportunity to earn an adequate return on their investment. The Utility Program of Oregon's PUC uses research, analysis and technical support to make sure regulated companies provide safe, reliable and high-quality service at reasonable rates. Their efforts also promote effective competition in those industries. Oregon's IOUs are required to compete with each other and with the BPA. This helps to ensure the low-cost hydropower that is generated in Oregon stays in Oregon. It also helps to ensure any redirection of hydroelectric energy and surplus to generate hydrogen would result in a rate increase that would most probably be considered by Oregon's PUC to not be fair and reasonable.

Thus, policy prohibits the use of Oregon's hydroelectric electricity to generate hydrogen. Even if this were not the case, Oregon's electricity consumption is greater than its hydroelectric and other renewable energy generation abilities. Any renewable energy devoted specifically to hydrogen production in Oregon for ZEVs will need to be installed.

Renewable Energy Requirements

With the need for necessary renewable energy to be installed to make the hydrogen for Oregon's ZEVs clearly defined, an overall assessment of required installations was able to be accomplished.

The previous chapter's methodology showed the model Grjóthâls Hydrogen fueling station as requiring7150 kWh/day of electric generation. Thus, 12 stations would require 85,800 kWh/day of electric generation.

This equates to a PV Requirement of 15,300 kWp, or an array that is 1,646,892 square feet. Such an array would require the equivalent of almost 38 acres (≈37.8).

The wind turbine requirement would be 84 1.5MW wind turbines. Such a wind farm would require the equivalent of 42 acres of land.

Electricity Distribution Requirements

The renewable energy installation requirements for Oregon's electricity providers have been allocated according to the number of model hydrogen fueling stations proposed to each electric utility in this study.

EWEB with one model hydrogen fueling station would require a PV array capable of 1275 kWp or 1.275 MW of PV generation and 137,241 square feet of space. Such an array would require the equivalent of roughly 3 acres (≈3.15). The model station would require seven 1.5MW wind turbines. A wind farm of this size would require 3.5 acres.

BPA with three model hydrogen fueling stations would require a PV array capable of 3825 kWp or 3.825 MW of PV generation and 411,723 square feet of space. Such an array would require the equivalent of roughly 9.5 acres (≈9.45). The model stations would require a total of 21 1.5MW wind turbines. A wind farm of this size would require 10.5 acres.

Pacific Power and PGE with four model hydrogen fueling stations each would require PV arrays capable of 5100 kWp or 5.1 MW of PV generation and 548,964 square feet of space. Such arrays would require the equivalent of roughly 12.6 acres (≈12.6025). The model stations would require a total of 28 1.5MW wind turbines for each utility. Wind farms of this size would each require 14 acres. Table 5-3 lists the required MW of the PV arrays, the required acres for the PV arrays, the required number of 1.5MW wind turbines, and the acreage required for the wind farms for each electric utility provider.

Table 5-3. PV and Wind Requirements by Electric Utility

	Required PV generation (in MW)	Acres required for PV array	Required number of 1.5 MW wind turbines	Acres required for wind farm
Pacific Power	5.1	12.6	28	14
PGE	5.1	12.6	28	14
BPA	3.825	9.5	21	10.5
EWEB	1.275	3.15	7	3.5

Individual Requirements

Breaking down the energy requirements from the electric utility providers to the individual customers allows for personal involvement. Furthermore, this may provide to be useful for future policy.

Individual PV requirements per vehicle and based on 16 daily VMT, results in an array that is approximately 644 square feet (≈643.32). Such an array would require an area of space with full access to the sun that roughly measures 25 feet by 26 feet. Two hundred fifty six such arrays would equal the electricity needs of one model hydrogen fueling station.

1.5MW wind turbines are problematic to scale individually because very few individuals would be able to erect these turbines. Assuming some form of program allowed an individual to purchase a portion of a wind turbine, the individual requirements would be roughly 31 individuals per wind turbine (≈30.47 people per wind turbine).

Scaling to One Million Vehicles

Breaking down the energy requirements necessary for one million ZEVs allows for a way to envision the renewable energy implications on a larger scale and in a future context.

Assuming that it takes 50 kWh on average to make 1 kg of hydrogen gas, and that it takes 70 kWh to make 1 kg of liquid hydrogen, 8750 kWh will make 125 kg of liquid hydrogen to meet the equivalent of 100 gallons of gas. This is an approximate scale of 90 kWh to make 1 gallon of gas, which can then be simplified to a round number scale of 100 kWh per gallon.

To meet the needs of one million vehicles driving an average of 10,000 miles a year each, and assuming an average of 25 miles per gallon for these vehicles, a total of 250 million needed gallons a day are required.

Since the scenario of one million vehicles is a futuristic scenario, the scaling assumptions for both wind and solar can be based on futuristic assumptions that reflect optimal locations.

Wind turbines located off of Oregon's coast offer the ability for a better capacity factor[19] because off-shore wind is more reliable than on-shore wind. Thus, a large 7.5 MW wind turbine with a 40 % capacity factor could feasibly have a net power capacity of 3 MW. This would mean an annual total output of approximately 25,000 MWh (3 MW x

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[19] A capacity factor is the ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period. In this context, it is the amount of energy produced when the wind blows versus the amount of energy produced if the wind blew continuously.

8760 hours in a year = 26,280 MWh or rounded down to 25,000 MWh). Under such a scenario, 1000 7.5MW turbines could meet the needs of one million vehicles.

Similarly, solar sites in Central and Eastern Oregon offer better solar potential. Assuming a site in Eastern Oregon averages 1000 watts per square meter over 6 hours a day, and a PV efficiency of 10 %, the resulting energy per day per square meter is 600 Watt hours (1000 * 6 * 0.1 = 600 Watt hours). Thus, with an annual energy per square meter of 0.2 MWh, a one square kilometer array would produce 200,000 MWh. Accordingly; an array sized to meet the needs of 25 million MWh would require a 125 square km PV array, or one that is 11 x 11 km (≈6.84 x 6.84 miles).

CHAPTER VI

SUMMARY AND IMPLICATIONS

Introduction

Emissions reductions for air quality improvement have been desired in Oregon for at least the last quarter century. Lately, emissions reductions in the context of addressing climate change have gained an equal importance that is being reflected in Oregon's current planning and policy decisions. Studies have shown a need to reduce emissions to improve air quality and to mitigate their effects on climate change. Population growth and its effect on Oregon's energy needs have created a situation where more vehicles are being driven and more emissions-producing electricity generating sources are being used to meet demands. To reduce the vehicle and electricity generation emissions, fuel cell ZEVs offer the potential to meet Oregon' vehicle needs in a way that produces only water as a byproduct if renewable energy is exclusively used at the hydrogen fueling stations.

Vehicles that require electricity as part of their operations are currently being marketed. Since Oregon's renewable energy demand is greater than its generating capability, electricity-dependent vehicles will result in an increase in power plant emissions. Furthermore, these non-renewable power plant emissions are externalized to areas far removed from Oregon's cities, and these power plants require natural gas and coal fossil fuels to generate electricity. Under such conditions, electricity-dependent vehicles will not be sustainable.

Thus, Oregon's ability to address the supply of renewable energy necessary for ZEVs has a direct effect on the quality of life for its residents. The Pacific Northwest in general and Oregon specifically, already have a high percentage of their electricity generation needs met by hydroelectricity. Because of this fact, and their relatively low populations in comparison to other states in the U.S., the renewable energy infrastructure investment necessary for ZEVs is much lower than it is for the majority of the states in the U.S. The expansion of renewable energy in Oregon may translate into job opportunities, competitive advantage, and other ancillary economic effects. A shift to ZEVs and an energy portfolio that does not produce emissions will result better health for both people and the environment. It is in a region's best interest to coordinate efforts that promote a healthy economy and environment while advancing greater social and regional equity. One method for achieving this goal is for a region to be self sufficient for its own energy needs through the implementation of ZEVs into the region. Iceland recognized these very same issues more than a decade ago and acted upon them. Today, their Grjóthāls hydrogen fueling station produces zero emissions hydrogen.

This context formed the basis for the primary thesis question: Can Oregon generate the hydrogen necessary to follow the Icelandic example of using renewable energy to generate sufficient hydrogen for zero-emissions vehicles using solar and wind energies? This study used Iceland's Grjótháls hydrogen fueling station as a model for the beginnings of hydrogen-powered transportation in Oregon. Through the evaluation of the Grjótháls hydrogen renewable energy requirements, a baseline can be set for Oregon's renewable energy needs.

Iceland has ample renewable energy to electrolyze hydrogen from water and Oregon does not. Iceland has developed a considerable amount of geothermal energy as a part of its energy portfolio. Oregon does not have any geothermal energy in its energy portfolio, but it does have emissions free wind and solar in its energy portfolio.

To help answer the primary question, the following secondary questions also informed the analysis: (1) How much installed capacities will Oregon need to follow the Icelandic example?; (2) How can Iceland's information on the renewable energy requirements necessary for hydrogen ZEVs be scaled to Oregon?; (3) What are the suitable energy requirements of hydrogen ZEVs for solar and wind energies?; and (4) How many units would need to be installed, and what is the area required for the installation of wind and solar energies?

The remainder of this chapter will present the specific findings of the primary and secondary research questions, the implications of these findings, and ideas for further research.

Summary of Findings

Case Study Findings

Iceland continues to decrease its percentage of fossil fuel electricity generation. It has installed 833MW of geothermal and hydroelectric energy sources since 2006. Since "only 20 to 25 % of the technically and environmentally feasible hydropower, and only 20 % of the conventional geothermal potential available for electricity production in Iceland, have been harnessed" (NEAI, 2007), Iceland has considerable room to develop renewable energy sources for end use. The continued development of renewable energy and its effect on decreasing fossil fuel electricity generation is evident in Iceland's total installed capacities. In 2005 Iceland's total installed capacity of fossil fuel generated electricity was 115MW; by 2006 it had decreased to 113MW. During this same time Iceland's population grew by almost 0.8 %.

The allure of such abundant and affordable hydroelectricity has attracted aluminum smelters to Iceland. There are currently three aluminum smelters in Iceland, with a fourth under construction and others planned. Aluminum smelters require vast amounts of electricity. Because of this, electricity consumption has more than doubled in recent years creating the situation where Iceland now uses more power per person than any other country in the world (Economist, 2008). Iceland's aluminum industry uses more Gigawatt Hours each year then all of its other electricity consumers combined (NEAI, 2007).

Iceland is an island nation with no fossil fuel reserves. As an island nation, it is unable to export surplus electricity through conventional means such as high-voltage transmission lines and pipelines. It uses its inexpensive renewable energy to attract energy intensive industries, like the aluminum industry. The abundance of affordable renewable energy and lack of fossil fuels has influenced Iceland to be the first country in the world to commit to replacing fossil fuels with hydrogen.

Based on the data from INE, the model Grjótháls hydrogen fueling station which produced Iceland's ZEVs has the ability to produce and distribute 125 kg of zero emissions hydrogen a day, which meets the need of 600 personal cars in Reykjavik. The electricity requirements for this station are 5.2 kWh to produce 1 Nm3. This study is assuming that such a station being able to meet the needs of so many personal cars means a low (2-4) daily average vehicle miles travelled.

Oregon has no commercial hydrogen fuelling stations. Oregon's technically and environmentally feasible hydropower has all been developed and it continues to increase the amount of fossil fuel (natural gas) electricity generation to meet its growing energy needs. Steam reformation of natural gas is the principal form of making hydrogen in U.S. Oregon currently imports all of its natural gas and its hydrogen. The continued development of renewable energy (wind, solar, and biomass) has not had the effect of decreasing fossil fuel generated electricity. This is evident in Oregon's increase in natural gas for electric power generation from 1,636,828 MWh in 1996 to 2,988,707 MWh in 2006.

During the last 25 years, Oregon's population growth rate has averaged better than 1 % while its average annual increase in electricity consumption was only 0.8 %. This is reflective of Oregon's energy conservation efforts and the electricity made available due to plant closures or reduced output from mills and aluminum smelters. The United States has the ninth highest electricity consumption, per capita, of any country in the world and Oregon's 2005 per capita consumption of electricity in Oregon homes ranked it 25 out of the 50 U.S. states. Oregon's energy needs and generation extend beyond its state lines, and it is able to import and export electricity to and from neighboring states. However, Oregon's demand for affordable hydroelectric generation exceeds its generating capacity. Because of this fact, Oregon needs to install emissions free electricity generation to have true ZEVs in the state. Of the current emissions free electricity generation options in Oregon being planned and built, geothermal and wave energy are not producing commercially available electricity, which leaves wind and solar as the only present alternatives.

Methodological Findings

The answer to the primary question of this thesis is; yes, Oregon can generate the hydrogen necessary to follow the Icelandic example of using renewable energy to generate sufficient hydrogen for zero-emission vehicles using solar and wind energies. The methodological findings of the secondary questions of this study solidify the primary questions answer.

The answers to the secondary questions are as follows: (1) How much installed capacities will Oregon need to follow the Icelandic example? Each model Grjótháls hydrogen fueling station in Oregon will require 7150 kWh/day of electric generation to meet the driving needs of 256 vehicles based on Oregon's 16 miles per day average VMT. This equates to 4100 miles a day. This study assigned a value of 12 stations as being necessary to follow the Icelandic example in Oregon. Twelve stations modeled after the Grjóthâls hydrogen fueling station would require 85,800 kWh/day of electric generation.; (2) How can Iceland's information on the renewable energy requirements necessary for hydrogen ZEVs be scaled to Oregon?; Oregon's population is 12 times Iceland's population, and the distribution of people in urban and rural areas is different. Iceland's Grjóthâls hydrogen fueling station could serve the estimated daily needs of at least 3 buses, or possibly even 600 personal cars in Reykjavik, while a similar station in Oregon would only serve the estimated needs of 256 personal cars. Oregon has roughly two and a half times (≈2.44) the land area of Iceland. In consideration of the population difference, the larger urban population of Oregon, the difference in daily personal vehicle hydrogen requirements, and the larger land area of Oregon, this study chose a scale that differed by a factor of 10. This study took into consideration the need to locate model hydrogen fuelling stations near Oregon's most populated cities based on Iceland's choice of locating the Grjóthâls hydrogen fueling station in Reykjavik, an urban area that accounts for approximately two-thirds of Iceland's total population, when scaling the renewable energy requirements necessary for hydrogen ZEVs. The four main providers of electricity in Oregon are PGE, Pacific Power, the BPA, and EWEB, which serve the majority of Oregon's population. This study allocated the distribution of model hydrogen fueling stations in Oregon based on the percentage of electricity customers served and the populations within the electric utility provider's service area.; (3) What are the suitable energy requirements of hydrogen ZEVs for solar and wind energies?; The energy requirements, as scaled to Oregon, are a PV Requirement of 15,300 kWp, and a wind turbine requirement of 132MW a day.; and (4) How many units would need to be installed, and what is the area required for the installation of wind and solar energies? Solar panels (PV) vary in size and efficiency. This study assumed a PV panel efficiency of 10 %. Assuming a PV panel size of 4 feet by 2 feet (8 ft^2) in an array that is 1,646,892 square feet, it would require more than 200,000 (≈205,862) panels. Such an array would require the equivalent of almost 38 acres (≈37.8). The wind turbine requirement would be 84 1.5MW wind turbines. Such a wind farm would require the equivalent of 42 acres of land.

Implications of This Study

The wind and solar infrastructure investments necessary to follow the Icelandic example are substantial. The accompanying costs of such investments also will prove to be substantial. Recently (April, 2009) both PGE and PacifiCorp filed requests with the Oregon Public Utility Commission to raise rates for their customers starting in early 2010. PGE and PacificCorp are seeking to increase their rates to offset the costs of renewable energy sources which are being installed to meet Oregon's renewable portfolio standard, among other reasons. Pacific Power has requested a 9.1 % increase in rates and PGE has requested a 2.3 % increase in rates (Sabatier, 2009). This study has shown Oregon can follow the Icelandic example of generating zero emissions hydrogen. In the context of a changing climate, future carbon penalties, "green" jobs, and a potential for urban air quality improvement and the accompanying health improvements, traditional cost/benefit analysis is problematic at this point in time.

Oregon is going to need to install electricity generating facilities to meet future needs. Oregon, due to its location, is fortunate to have an energy portfolio that has a high percentage of renewable energy (hydropower). If Oregon decides to install renewable energy to meet future needs, certain ancillary effects will occur. One such effect is the option of having true zero-emissions vehicles. For zero-emissions hydrogen fuel cell vehicles the baseline number for planners to consider is 7150 kWh/day of emissions-free electricity generation to meet the driving needs of 256 vehicles based on Oregon's 16 miles per day average VMT, or 7150 kWh/day of emissions-free electricity to drive 4100 total miles a day.

Future Research

This study represents the very beginning of zero-emissions hydrogen fueled transportation planning, and it does not take into account electricity transmission challenges. Studies that take into account the locations of renewable energy generating plants with electricity transmission taken into account are needed avenues for future research. A similar study that would look at the imminent needs of zero-emissions plug in electric vehicles is an obvious opportunity for research in the very near future. As geothermal and wave energy options come online and their electricity generation outputs become documented and available, a similar study with these technologies also would be helpful to planners. As efficiencies and technologies change, new studies can offer cost/benefit analysis among the renewable options for generating zero emissions hydrogen. As Iceland progresses toward its goal of eliminating fossil fuels in its transportation sector, certain milestones will be passed and certain lessons will be learned that will offer opportunities for future research, one of which will be Iceland's and INE's example of using a fuel cell in a marine application to power a boat.

Fuel cell vehicles themselves offer opportunities to merge into a carbon constrained future of electricity generation. Fuel cells are reversible, they can make electricity efficiently or they can be a source of hydrogen when supplied with electricity. By using the ability of fuel cell vehicles to store energy, the possibility exists of fuel cell vehicle owners filling up with hydrogen during times of low demand on the grid with accompanying lower costs for fuel, and plugging into the grid to generate and sell electricity during times of high demand and higher costs for electricity. This could lower the costs of VMT for the fuel cell vehicle owners. This also could mitigate the problem of what to do with excess wind generation during times it is not needed. Future studies could take into account the opportunities available for using fuel cell vehicles as a part of Oregon's energy planning to meet peak demands in ways that could produce fewer emissions.

Finally, the implementation of ZEVs will offer many opportunities to research their effects on the economy, health, and the environment. Should Oregon install the renewable energy necessary for ZEVs, the opportunities to study the impacts on each of the constituents of the triple bottom line individually, together, or in totality, will allow for studies that take into account costs to the environment and social equity as they relate to traditional economic costs. If fuel cells are introduced without the renewable energy necessary to qualify them as ZEVs, research can be done on the increase in externalized emissions to power plants and the increase in greenhouse gas emissions along with the downwind and downstream costs of such emissions versus the immediate urban air quality gains (if any).

APPENDIX

CORRESPONDENCE WITH JÓN BJÖRN SKÚLASON

Jón Björn Skúlason
to me 11/3/08

Dear Dean,
See my answers below.
Jon Bjorn

-----Original Message-----
From: Dean Fisher [mailto:fisherjdean@gmail.com]
Sent: 2. nóvember 2008 16:21
To: Jón Björn Skúlason
Subject: Data for my Thesis on "The Icelandic Example: Planning for Hydrogen Fueled Transportation in Oregon"

Dear Jón Björn,

I am working on gathering the necessary data to finalize my thesis proposal. I am really excited to apply your model (the Icelandic model) of using renewable energy and electrolysis to generate the hydrogen necessary in Oregon, and perhaps elsewhere in the Pacific Northwest, or even the other regions of the U.S.

My thesis adviser has asked me to come up with the following data before the end of the term:

* the amount of hydrogen produced and distributed;

Im not sure what you mean by this. We can produce 60Nm3 an hour which is 125 kg a day. In total we have dispensed over 30 tons of hydrogen over the last 4 years for vehicles. The hydrogen is all produced on site.

* the energy required producing this amount;

You need 5,2 kWh for the production of 1Nm3 hydrogen - that includes compression.

* the source of the hydrogen;

All the hydrogen is produced from water, i.e. via electrolysers

* the source of the energy;

Hydro and geothermal energy - we still have vast amount of renewable energy available.

* and the types and numbers of transportation that were using hydrogen in Iceland for the last two years (2007-2008), although I could potentially use any combination of recent years data (2006-2007, 2005-2008, or ?).

Currently there are 15 hydrogen vehicles in operation in Iceland. There were 3 fuel cell buses until end of January 2007.

Jon Bjorn Skulason
to me 3/17/09

Dear Dean,
I have no other calculations methods. We spend 5,2 kWh to produce 1 Nm3 and we need roughly 11 Nm3 for 1 kg hydrogen so you can multiply.
Isnt your miscaluculations because there is difference in efficiency?

Jon Bjorn Skulason
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128 Reykjavik
Phone / fax / mobile: (354) 588 0310 / (354) 588 0315 / (354) 863 6510
www.newenergy.is

-----Original Message-----
From: Dean Fisher [mailto:fisherjdean@gmail.com]
Sent: 17. mars 2009 07:44
To: Jón Björn Skúlason
Subject: Re: Data for my Thesis on "The Icelandic Example: Planning for Hydrogen Fueled Transportation in Oregon"

Dear Jón Björn,

I am struggling with something about my data. The physicist I have on my thesis committee has recommended I use the 125 kg a day number because 125 kg a day = approximate energy equivalent of 125 gallons of gas/day and I can easily take this to the necessary kWh a day. e.g.

- . 125 kg a day = approximate energy equivalent of 125 gallons of gas/day
- o 125 gallons of gas/day = 4575 kWh/day or 4.5 MW/day
- o .75 % Ee times 4575 kWh/day = 6100 kWh/day

But something about this troubles me.
When I compare your 5.2 kWh for the production of 1 Nm3 hydrogen with an estimate derived from NREL work that lists for an Avalence: Hydrofiller 175 as the system requiring 5.4 kWh/Nm3 or 60.5 kWh/kg, and I multiply the 125 kg a day Grjótháls total capacity with 60.5 (or even 58) I come up with a much larger number. e.g. 60.5 kWh/kg * 125 kg = 7562 kWh

I would like to have a number I feel comfortable using, and I seem to get different answers when I seek assistance in converting 5.2 kWh for the production of 1 Nm3 hydrogen into kWh a day necessary for 125 kg of hydrogen.

Would you be willing help me come up with the correct kWh a day requirement for 125 kg of hydrogen?

I know you are very busy and (as always) I really appreciate your help,

My Best Regards,
Dean

Jón Björn Skúlason
to me 3/18/09

Of course not. This is the actual figures. If the electrolyser would be woring at 100% efficiency we would only need like ~ 4 kWh per Nm3

-----Original Message-----
From: Dean Fisher [mailto:fisherjdean@gmail.com]

Sent: 17. mars 2009 15:44
To: Jón Björn Skúlason
Subject: Re: Data for my Thesis on "The Icelandic Example: Planning for Hydrogen Fueled Transportation in Oregon"

Thank you Jón Björn,

It has been many years since I took "intro to Physics," so I frequently doubt myself when I am converting data. I believe the issue is that the direct conversion my Physicist committee member recommended (125 kg a day = approximate energy equivalent of 125 gallons) is the chemical energy contained in fuel. I was looking for the electricity required to make the fuel. Thus, I can now multiply 5.2 kWh by 11 to get 1 kg of hydrogen and then multiply this by 125 to get my desired answer (it takes 7150 kWh to make 125 kg hydrogen). Do I still need to factor in the electrolyzer efficiency to the 7150 kWh?

As always, best regards and thank you so much,
Dean

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