

Geothermal Power Production for Emmonak, Alaska

Anthony Bryant

Senior Project

Alaska Pacific University

May 5, 2010

Abstract

The village of Emmonak, Alaska ran out of diesel fuel for their power plant during January 2009. This paper researches the possibility of using geothermal energy as an alternative energy source for rural Alaska by analyzing articles from the State of Alaska, the U. S. Government, and the Internet. The quantitative research method is used to gather pertinent data. Areas in Alaska with the greatest geothermal potential are identified. The applications of geothermal technology are explained together with obstacles to producing electric power by a geothermic process. Emmonak is not located in or near an active geological region. Given Emmonak's population size and its ability to generate significant revenue, power production from geothermal resources is not viable for Emmonak.

Table of Contents

	Page
List of Tables.....	5
List of Figures	6
Chapter One	8
Introduction	8
Overview of Topic	8
Statement of the Problem	10
Significance of Research	12
Purpose and Research Question	18
List of Abbreviations	19
Review of Related Literature.....	21
Geothermal Geography	22
Geothermal Technology	26
Geothermal Applications	37
Geothermal Energy Investment cost	40
Geothermal use in Alaska	43
Emmonak, Alaska	46
Electricity Production in Emmonak, Alaska	47
Chapter Two	49
Methodology	49
Project Design	51
Chapter Three	58

Table of Contents

	Page
Findings	58
Geothermal Technology	58
Geothermal fields in Alaska	60
Geothermal Application in Alaska	63
Emmonak, Alaska	65
Electricity costs across Alaska	66
Regulations	68
Chapter Four	69
Discussion	69
Limitations of Study.....	70
Recommendations	71
Conclusions	72
References	75

List of Tables

	Page
Table 1. Denizli-Kizidere geothermal field and power plant	21
Table 2. Dichotomy between qualitative and quantitative social science	31
Table 3. Cost of Emmonak power projects	56
Table 4. Alaska Regulations	68

List of Figures

	Page
Figure 1. Total U.S. Energy Consumption 1900–2000	11
Figure 2. Carbon capture and storage	16
Figure 3. Coal Preparation	17
Figure 4. Gasification.....	17
Figure 5. Removing Pollutants.....	18
Figure 6. Electrostatic precipitation	19
Figure 7. Geothermal principle	22
Figure 8. U.S. Direct-Use Capacity (MWt) 2000	31
Figure 9. U.S. Direct-Use (TJ/yr) in 2000	31
Figure 10. Dry steam power plant	33
Figure 11. Flash steam power plant	33
Figure 12. Binary cycle power plant	34
Figure 13. Rankine Cycle	35
Figure 14. Alaska Geothermal Resources	44
Figure 15. Emmonak Village location	46
Figure 16. AVEC RFP fuel proposal assignments for 2010	48
Figure 17. Calista’s villages map	55
Figure 18. Dry steam power plant.....	58
Figure 19. Flash steam power plant	59
Figure 20. Binary cycle power plant	59
Figure 21. Earth’s Underground Temperatures	60

List of Figures (continued)

	Page
Figure 22. Pacific Ring of Fire	61
Figure 23. Geothermal Temperatures and Volcanoes for Alaska	62
Figure 24. Chena Hot Springs Underground Isothermals	64
Figure 25. Energy Cost of Alaska	65
Figure 26. Regional Gasoline Prices	66
Figure 27. Regional Heating Fuel Prices	66

Chapter One

Introduction

Overview of the Topic

Energy consumption in the United States is vastly different now, at the beginning of the 21st century, than it was at the beginning of the 20th century (Smil, 2009, p.1). In the early 20th century total consumption was approximately 15% of what it was by the end of the century (Wagner, n.d.). Per Figure 1, coal and petroleum were nearly equal in 1900 but by the beginning of the 21st century, petroleum was significantly more than that of coal.

Coal and petroleum consumption at the start of the 20th century were equal at ten quadrillion BTUs whereas at the turn of the 21st century, petroleum consumption greatly surpassed that of coal. In the year 2000, petroleum consumption was nearly 100 quadrillion BTUs compared to 60 quadrillion of coal and 35 quadrillion of natural gas, see Figure 1.

There are several reasons for the increase in the volume of consumption and the increased use of petroleum over other sources of energy. One reason is the increase of the population of the United States from 76,094,000 in 1900 to 288,369,000 in 2000, an increase of 212,275,000 or 279% (U.S. Census Bureau, 2003, pp. 1, 2).

A second reason for this change can be attributed to the shift in the methods in how people earned a living. At the beginning of the 20th century, 60 % of the population in the United States lived an agrarian life style (University of Houston, 2009, p. 1).

Today, in the first decade of the Twenty First century, only .7 % earned their living by farming, fishing, or forestry (United States Census Bureau, 2000, table DP-1).

The significance of this demographic change is that in an agrarian life style, the population density is less than that of urban life. The resources required to sustain a ten acre farm owned by one family of six will be less than if that ten acre farm is divided into 20 half acre lots with a family of four on each lot. Petroleum yields more BTUs than coal. One tonne of oil equivalent (toe) equals 39.68 million BTUs (MBTU) versus coal's one tonne of coal (equiv) equals 27.8 MBTUs (Energy Units, 2010)

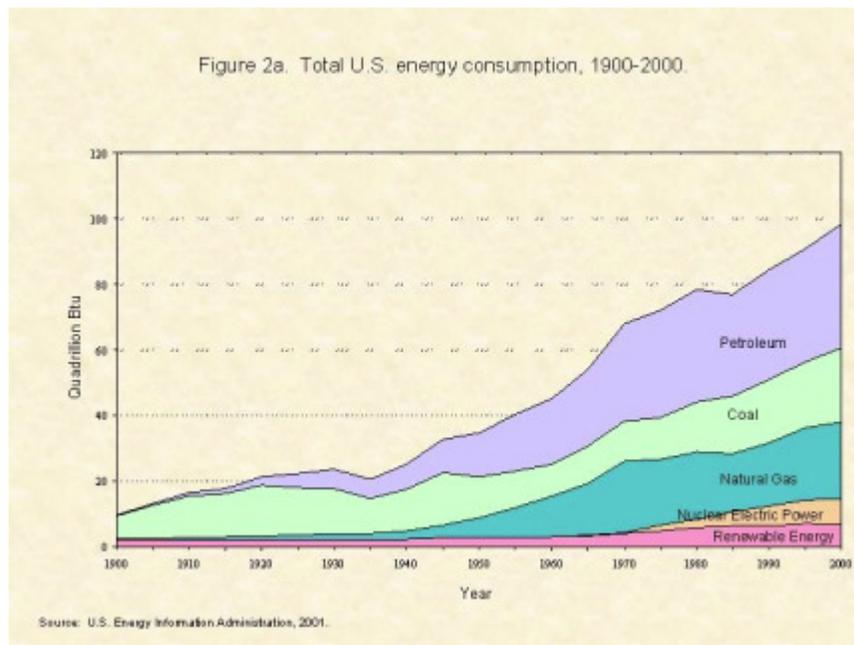


Figure 1. Total U.S. energy consumption, 1900-2000. Adapted from “Productive capacity indicator 5-1: Consumption of materials and energy over time,” by Lorie A. Wagner, n.d., *U.S. Geological Survey*, p. 3. Wagner’s reference is data from the U.S. Energy Information Administration, 2000. This chart was apparently compiled from the raw data in the article.

Energy is a topic of great interest by the population of the United States. Today's high cost of fossil fuels with respect to historical cost in the decades prior to 2000, have caused more of the population to ponder the whole energy cycle from the raw source to production to consumption and finally waste by-products.

Industrial processes and residential home heating as well as cooking can result in incomplete combustion. Incomplete combustion of petroleum and coal yields numerous toxins, such as arsenic, dioxins, carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and chlorofluorocarbons (CFC) just to name a few (Avakian, et al., 2002, p. 1155). The burning of these fuels also contributes to the problem of greenhouse gas accumulation and human health issues (Avakian et al., p. 1156).

Integrating alternative energy sources, such as wind, solar, geothermal, and hydro, may be challenging and appear expensive now but it might be more challenging and expensive in the future to mitigate the harm of continuing to use fossil fuels.

Statement of the Problem

The recent demand for fossil fuels has increased world wide due to the economic growth of countries like China and India (Cox & Alm, 2008, Charts 1-5). The result of this increase in demand has driven the price of oil up to where it is extremely expensive for some small communities to purchase sufficient fuel to sustain their community power plants through the extreme cold and harsh Alaska winter months. China's energy demand is second to that of the United States, even without India, its hunger alone will tax world resources (A hungry dragon, 2004). Rural communities were paying nearly \$6 per gallon for heating fuel in September 2005 compared to \$2.97 in Valdez during the same period (Journal of Commerce, 2006, p. 1). Although the differences between Alaska's rural and

urban regions narrowed in 2009, they have since widened (Divisional of Community and Regional Affairs, 2009, p. 7).

The old saying “necessity is the mother of invention” has proven correct with the apparent national interest in the creative pursuit of alternative sources of energy such as clean coal, wind, solar, tidal, ethanol, and geothermal, to mention some of the major contenders. Given that some of the Alaskan coastal regions are very active geologically, it would seem that geothermal energy may be an alternative energy source to pursue.

One of the factors contributing to public awareness is the decline in household discretionary income due to raising energy cost (Divisional of Community and Regional Affairs, 2009, p. 7). This awareness appears to be new because of the daily attention given to energy in the various media outlets be it print, radio, television or the internet. The rural communities have long been aware of the cost of energy, particularly in rural Alaska.

I personally had resigned to accept the cost of fuel whatever it was, there was a certain parity in that everyone else was experiencing the same cost. Then in January of 2009, I heard a story on the public radio station, KSKA, of the Alaskan village of Emmonak, population 800, running out of fuel in the dead of winter. Reporter, Lori Townsend, stated that the normal fuel prices for Emmonak was, gas \$7.25 per gallon, heating fuel \$7.83 per gallon, and the estimated cost of fuel to be airlifted in was \$11.00 plus per gallon (Alaska Public Radio Network [APRN], 2009).

The report by Lori Townsend contained comments by Emmonak resident Nicholas Tucker Sr. Mr. Tucker gave an account of his expenses on fuel over the previous two months, \$1,500. With the remaining money, \$400, he had to support nine

members in his family. Tucker gathered accounts of other Emmonak residents and wrote a letter to the *Bristol Bay Times* giving an account of Emmonak's plight (Tucker, 2009). The letter generated responses from all over Alaska and the "Lower-48" contiguous states. Many concurred that they were living a similar situation in rural Alaska. Some people were opting to only pay for essentials, which for some were food and fuel. Others quit paying for village water and sewer and reverting to honey buckets and hauling water.

The focus on Emmonak also brought residents of other villages, such as Alakanuk and Nunam Iqua to make their circumstances, which were similar, known.

Significance of the Research

The Prudhoe Bay oil field, on Alaska's North Slope, produces the most oil of any field in the United States (Energy Information Administration, 2009, p. 1). With a state population estimate of a mere 686,293 as of July 1, 2008, energy concerns would appear to be of little concern to Alaskans. However, this is not the case.

A significant portion of the urban population relies on natural gas, not oil or gas, for their fundamental source of heat for homes and businesses. Natural gas is also the main energy resource in the production of electricity. The largest population area in the state is the Anchorage Borough with a population of 279,243 (United States Census Bureau, 2008). The borough is located in south central Alaska with a large portion bordering the Cook Inlet.

The Cook Inlet is a significant supplier of natural gas for south central Alaska and the Kenai Peninsula. However, according to the Energy Information Administration, the supply of natural gas from the Cook Inlet is in decline (Energy Information Administration, n.d., p. 2). On November 5, 2009, the Alaska Journal of Commerce and

the Alaska State Chamber of Commerce, held a luncheon forum at the Denaina Civic and Convention Center in Anchorage to discuss the future energy demands of the Cook Inlet region (Alaska State Chamber of Commerce, n.d., p. 1).

According to the online literature, the supply of natural gas from current wells has passed its production peak and may fall below regional requirements by 2013 to 2018 (Alaska State Chamber of Commerce, n.d., p. 3). This is a potential major concern for a number of stakeholders such as the gas producers, the electric utility providers, businesses and homeowners. The availability of natural gas cascades through each of these stakeholders from one to another with direct affects.

The interconnections between these various stakeholders have advantages in that a multitude of jobs are needed and created to support this energy enterprise. But, as has been stated, Cook Inlet's natural gas supply is declining, it is a finite resource. Even if exploration leads to an increase in production, eventually this resource will be depleted. There are alternatives, such as solar, wind, coal, nuclear, and hydro to name a few. The first two, solar and wind are renewable energy sources, but their energy yields are tied closely to weather conditions. Coal is currently plentiful but it is also a finite resource and the affects of its use on the environment is the subject of much debate. Nuclear is very high tech and its use as a fuel source is beyond the scope of this paper. Hydro energy production is currently being used and an increase in its use is currently being considered in many discussions on energy.

Coal is a bountiful energy resource, however, it currently is a major pollution contributor. The American coal industry releases 2 billion tons of carbon dioxide (CO₂) into the atmosphere a year and accounts for over one-third of the U.S.'s greenhouse gas

emissions (Berman, 2009, p. 17). Clean coal is a term that covers several technologies. These technologies, otherwise known as clean coal technologies (CCT) are; carbon sequestration, often referred to as carbon capture and storage (CCS), coal preparation, gasification, and removing pollutants.

The process for CCS involves capturing the CO₂, Figures 2-6, produced from burning coal and injecting it into an underground aquifer, the deep ocean or into a raw underground oil reserve to increase the pressure on the oil and thereby helping in the extraction.

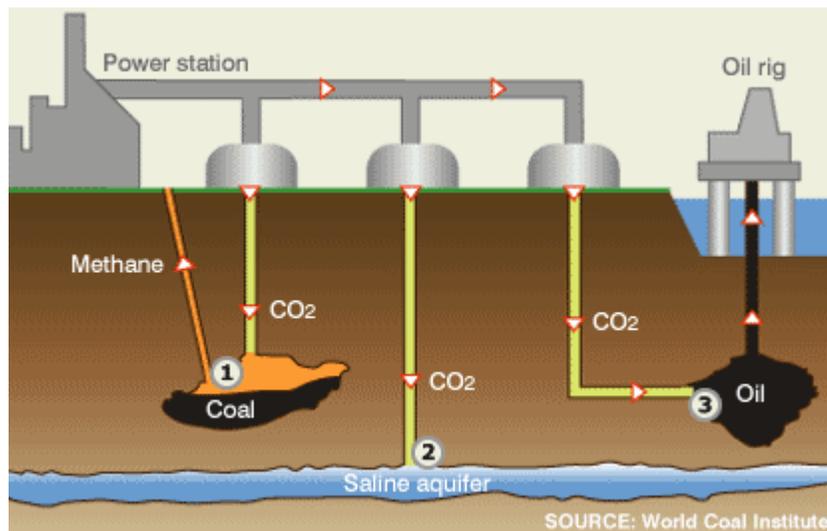


Figure 2. Carbon capture and storage. Adapted from “Clean Coal Technology: How it Works,” by British Broadcasting Corporation, *BBC News*, 2005, p. 1. Copyright 2005 by BBC MMX.

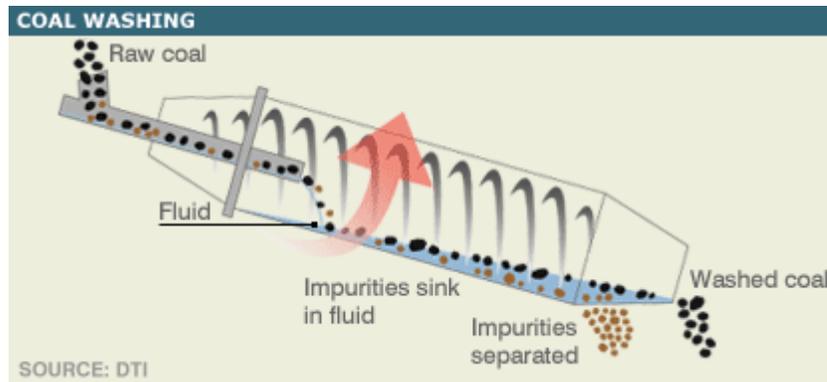


Figure 3. Coal Preparation. The coal preparation process mixes the coal with a liquid solvent that has a density greater than that of coal which causes the coal to float. Adapted from “Clean Coal Technology: How it Works,” by British Broadcasting Corporation, *BBC News*, 2005, p. 1. Copyright 2005 by BBC MMX.

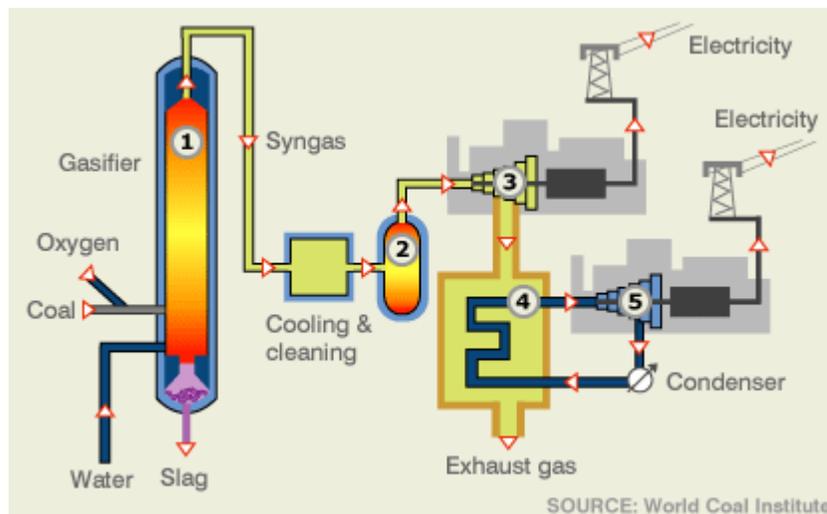


Figure 4. Gasification or Integrated Gasification Combined Cycle (IGCC) systems, combine steam and oxygen to form a “syngas” that is then burned to power a steam turbine which in turn produces electricity. Adapted from “Clean Coal Technology: How it Works,” by British Broadcasting Corporation, *BBC News*, 2005, p. 1. Copyright 2005 by BBC MMX.

The process of removing pollutants has several methods, two of which are removing sulfur dioxide (SO_2), the agent in acid rain, or nitrogen dioxides (NO_x), ground-level ozone agent that can cause respiratory problems, and electrostatic precipitation, Figure 5 and 6, (British Broadcasting Corporation, 2005, p. 1). The SO_2 and NO_x removed by a washing technique that produces a flue gas leaving “cleaned coal”.

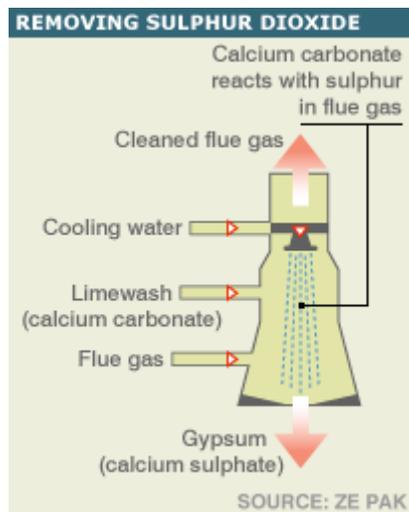


Figure 5. Removing Pollutants. Adapted from “Clean Coal Technology: How it Works,” by British Broadcasting Corporation, *BBC News*, 2005, p. 1. Copyright 2005 by BBC MMX.

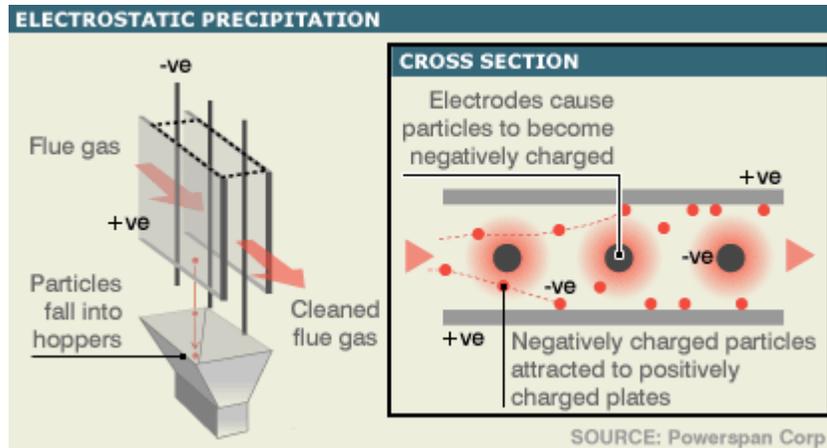


Figure 6. Electrostatic Scrubbing. The flue gas is then scrubbed by a electrostatic process that removes 99% of the SO₂ and NO_x. Adapted from “Clean Coal Technology: How it Works,” by British Broadcasting Corporation, *BBC News*, 2005, p. 1. Copyright 2005 by BBC MMX.

Although CCT is included as a viable clean fuel alternative, not all specialists in the field agree that this is the case. Ari Berman’s 2009 article “The Dirt on Clean Coal”, outlines the pros and cons of clean coal and the principles supporting each position. Berman also points out in his article that the coal industry has spent millions on ad campaigns to block legislation that would move the country towards clean coal.

The majority of rural Alaskan communities have a population of less than 1,000 and participate in the State’s Power Cost Equalization program (Alaska Energy Authority, 2009, pp. 5-13). This program helps lower the energy cost to rural residents. The utility companies’ main technology to produce electricity is by diesel generators.

Another possible energy source not mentioned earlier that is clean and abundant is geothermal. In addition to Cook Inlet being a significant resource for natural gas, it is also the location of several active volcanoes, Augustine, Redoubt, and Spur to list a few

(Alaska Volcano Observatory, 2010). The use of this geothermal resource as a possible solution to south central Alaska's energy concerns is worth exploring. While this paper will not focus on geothermal energy production for south central Alaska, some of the findings such as the yields one could expect from various sizes of geothermal fields may be helpful to determine whether or not geothermal energy production is worth considering. Also, is the cost of a geothermal energy plant worth the benefits and energy yields over the life of the facility? According to the Sierra Geothermal Power Corp (2009), the life span of the geothermal reservoir can be indefinite, however, the life span of the equipment to extract the geothermal energy is 30-50 years.

Purpose and Research Question

Geologic activity in Alaska is very high with earthquakes, volcanic eruptions, and natural hot springs. This paper will explore the possibility of reducing the energy cost in rural Alaska. More specifically, can geothermal energy production be produced on a small enough scale with energy yields that are cost effective for application in the rural Alaskan community of Emmonak?

List of Abbreviations and Definitions

- Ampere..... the practical meter-kilogram-second unit of electric current that is equivalent to a flow of one coulomb per second or to the steady current produced by one volt applied across a resistance of one ohm
- BTU British Thermal Unit (BTU) is the amount of heat required to raise the temperature of one pound of water (at or near 39.2 degrees Fahrenheit) by one degree Fahrenheit
- Gigaequals 1 billion (1,000,000,000)
- Gpm.....gallons per minute
- GWhr/yrGiga Watt hour per year
- Joule.....unit of measure for energy. 1 joule equals:
- The International System (SI) unit of electrical, mechanical, and thermal energy.
 - A unit of electrical energy equal to the work done when a current of one ampere is passed through a resistance of one ohm for one second.
- kWeKilo Watt of electrical energy
- kWhrKilo Watt hour
- Megaequals 1 million (1,000,000)
- MWtMega Watt thermal
- ppmparts per million
- Quadrillion BTU.....1 quadrillion BTU is equal to approximately the energy of 171.5 million barrels of oil (Tenenbaum, 1995, p. 2).

List of Abbreviations and Definitions (continued)

Tetra.....equals 1 trillion (1,000,000,000,000)

TJ/yrTetra joules per year

W.....Watt is a unit of measure for electric power or
work equal to: 1 watt of power is dissipated when a current of 1 ampere (A) flows
across a difference in potential of 1 volt (V)

Review of Related Literature

Geothermal energy seems self explanatory. Rarely is the actual process explained with any detail in general public forums. Geothermal energy is accepted as clean and in general an earth friendly process. Is it or is it not earth friendly? If it is, why is it that the construction of geothermal plants not given as much importance as that given to drilling new oil wells? Could it be geothermal energy production is more of an academic exercise than a viable real world possibility?

As this paper progresses, geothermal energy and the applications of its use will be referred to often. A definition of what is meant by geothermal energy is in order. Bruce Buzby from the State of Alaska Department of Natural Resources Division of Oil and Gas, gave the following definition of geothermal resources during the Alaska Geothermal Conference on April 28, 2009.

It is the natural heat of the earth at temperatures greater than 120 degrees Celsius, measured at the point where the highest-temperature resources encountered enter or contact a well or other resource extraction device, and includes

- the energy, including pressure, that may be extracted from that natural heat;
- the material medium, including the geothermal fluid, and substances artificially introduced to serve as a heat transfer medium; and
- all dissolved or entrained minerals and gases in material medium, excluding hydrocarbon substances and helium. (Buzby, 2009, p. 5)

Literature has been gathered from the internet in the form of discourse journals, websites from the various U.S. governmental agencies, university papers and audio reports from the Public Broadcast Station, KSKA to research this paper. The University of Alaska Anchorage/Alaska Pacific University Consortium Library is the source of books and journals not available on-line. The Alaska Village Electric Cooperative

(AVEC) is the intended source for current power production plant data for the village of Emmonak along with the City of Emmonak. The U.S. Geographical Survey office, Anchorage is the source of some of the topographical maps.

Geothermal Geography

Along with the current interest in alternative energy sources and in this case geothermal energy production, the question; “What type of geography is most suitable for geothermal energy production?” is relevant. Figure 7 depicts a cross sectional overview of a geothermal source and how it supports energy production.

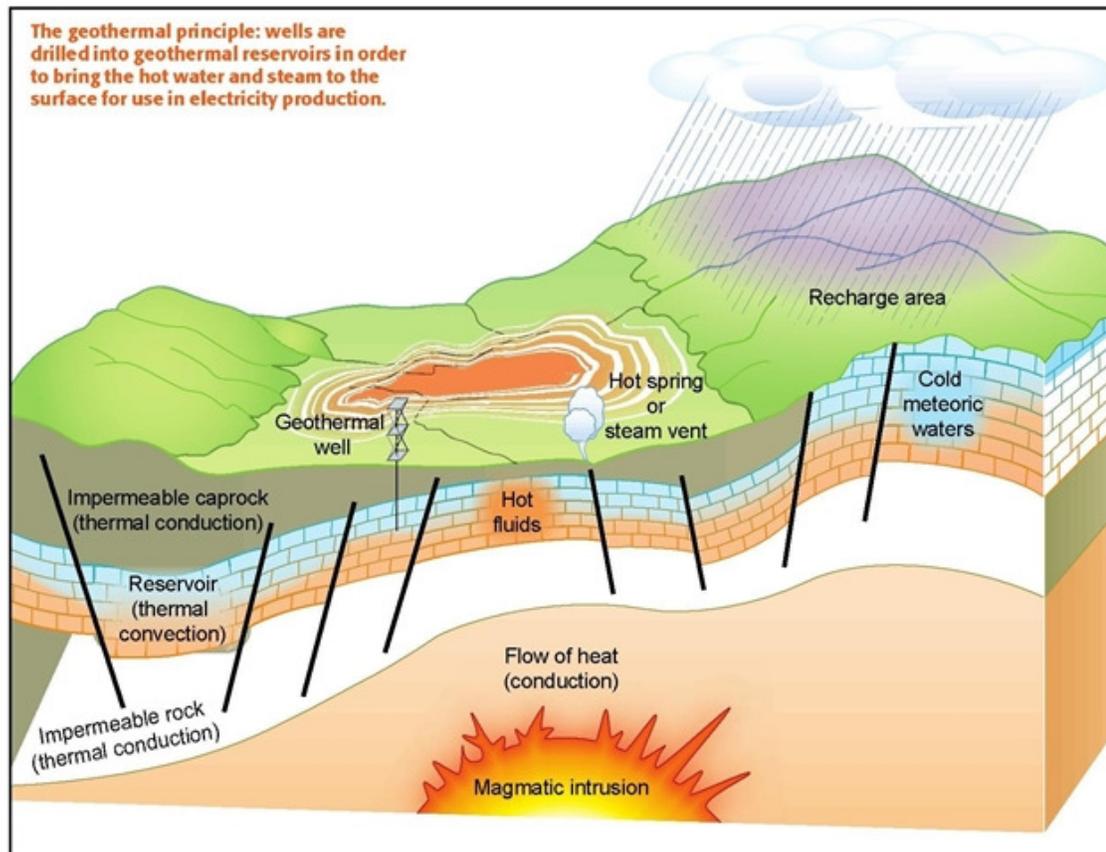


Figure 7. Geothermal principle (Davies, 2009, p. 4).

There is evidence of geothermal activity around the world everyday from geysers and natural hot springs to active volcanoes but is this type of visible activity necessary for a viable geothermal energy project? The article, “An Overview of the Awibengkok Geothermal System, Indonesia”, addresses this question with respect to Indonesia (Stimac, Nordquist, Suminar & Sirad-Azwar, 2008, p. 300). The article focuses on the Awibengkok geothermal field otherwise known as Salak and is located on the island of Java, Indonesia (Stimac et al., p. 302).

Exploration of this field began in 1982 as a joint venture between Unocal Geothermal Indonesia (UGI), the Indonesian National Oil Company (Pertamina) and the Indonesian National Power Company (PLN) (Stimac et al., 2008, p. 301). The geography of the area is discussed in detail to highlight the major faults and tectonic plates in the region as well as the layers of the earth’s crust (Stimac et al., pp. 305, 306, 310, 311). The article uses high technical language that is directed towards those individuals who are members of this discourse community. That, said, there is sufficient information applicable to use on a comparison basis such as the depth of wells, cross-sectional diagrams of the earth’s crust, and geothermal temperatures for specific well regions. Isotherms were shown in very crude conceptual drawings of the earth’s crust but there was no measured data given for specific well depths.

Turkey has been a point of interest for geothermal energy production since 1962 as outlined in the article, “Geothermal Fields Suitable for Power Generation” (Gokcen, Ozturk & Hepbasli, 2004, p. 441). This article discusses the geographic features of Turkey in relation to geothermal energy. It also delves into the types of technologies and applications in use. Specifically, it identifies the two categories of electric energy

production and direct use (Gokcen et al., p. 442). The technology referred to as binary cycle or the Rankine cycle is discussed along with its suitability to use low temperatures. It compares Turkey's potential energy production to its current use as well as the amount of energy production of other countries such as the United States, Italy and the Philippines (Gokcen et al., p. 442).

The comparison of Turkey's geothermal fields is in Table 1 of the article includes the topics of temperature, current utilization and possible utilization opportunities (Gokcen et al., 2004, table 1). The development of Turkey's geothermal fields is explained in a text timeline, which chronologically outlines the geothermal progress and helps to validate Turkey's commitment to geothermal energy production (Gokcen et al., 2004, p. 445). Unlike the article on Indonesia, this article studies the active production of the Denizli-Kizildere geothermal field (DKGF) and the Denizli-Kizildere geothermal power plant (DKGPP) (Gokcen et al., p. 446) The main characteristics are displayed in Table 1 (Gokcen et al., table 2).

Table 1

Some characteristics of the Kizildere geothermal field and plant

Description	Unit	Value
Reservoir temperature	°C	200–242
Wellhead steam fraction	%	10–12
Total dissolved solid (TDS)	parts per million (ppm)	2500–3200
CO ₂ partial pressure	MPa	3.0–5.0
NCG content in steam (by wt)	%	10–21
CO ₂ content	%	96–99
H ₂ S content	ppm	100–200
Number of production wells		9
Optimum wellhead pressure	MPa	1.6 (because of scaling)
Wellhead operation pressure	MPa	1.28–1.58
Wellhead temperature	°C	180–190
Total flow rate	kg/s	320.83

NCG flow rate	kg/s	6.1345
Installed capacity	MWe	20.4
Gross capacity	MWe	14.0
Net capacity	MWe	11.2

(Gokcen, Ozturk, & Hepbasli, 2004, table 2)

Problems such as dealing with wastewater, scaling, pressure drop and environmental challenges are identified and prove helpful to understanding what is necessary to sustain a geothermal operation (Gokcen et al., 2004, pp. 448,449).

Mexico has an extensive history of geothermal production. It drilled its first geothermal well in January of 1956 (Serrano, 1998, p. 743). After a brief history, the three geothermal fields of Cerro Prieto, Los Azufres, and Los Humeros are covered. Unlike the article by Gokcen et al, (2004) the characteristics of each field are not compared in one table. Instead, the particulars of each field are in their own stand along tables

(Serrano, pp. 745-747). Very little technology is discussed for any of the fields. The article may have been produced as an informational guide about Mexican geothermal energy production for possibly some type of investment group or government agency.

Iceland's latitudes fall within those of Alaska. The 65° latitude runs through approximately the middle of Iceland as well as Alaska (Bartholomew, J. & Bartholomew, 1982, pp. 32, 86). Geothermal surface activity in Iceland is very high. In fact, the word "geysir" is Icelandic (Motavalli, 2008, p. 14). Iceland is 200 miles south of the Arctic Circle and straddles the North American and Eurasian tectonic plates (Motavalli, p. 14). Iceland has been using geothermal energy sources since 1928; currently, over 85% of its homes are heated by them (Motavalli, p. 14). In addition to geothermal resources, Iceland

also has an abundance of surface water. The consumption of geothermal energy by Iceland is only 1% of its projected capacity. And since 60% of Iceland's domestic income is from the fishing industry, there is an abundance of energy remaining. This hydro resource is used to fuel one of the Alcoa's aluminum plants. Alcoa finds that it is cheaper and cleaner to transport bauxite, a raw material used for making aluminum, from distant Australia to Iceland to use in its smelters (Motavalli, p. 15).

Daniel Gross, in his article on Iceland titled, "Iceland Has Power to Burn", gives a slightly different account of the Icelandic economy than given by Motavalli (Gross, 2008, p. 1). Gross states that Iceland's economy has diversified in recent years from that of fishing with the addition of tourism, manufacturing, and financial services (Gross, p. 1). He does concur with Motavalli that geothermal energy is the source that heats most homes and goes on to say that fossil fuels are only used in cars and fishing boats (Gross, p. 2). Another factor not mentioned by Motavalli, is the role of the Icelandic government in the development of energy sources. Even though Iceland has an abundance of geothermal potential, the country is moving towards easier and more futuristic energy sources, hydro systems and hydrogen, respectively (Gross, p. 4). The Icelandic government is strongly pushing the use of hydro electricity production in order to make itself attractive to world markets and a place for clean manufacturing, free of fossil fuel pollutants (Gross, p. 4).

Geothermal Technology

The United States Department of Energy has a web site dedicated to geothermal issues titled Geothermal Technologies Program within the Energy Efficiency and

Renewable Energy section (U.S. Department of Energy, 2006). It covers several of the major topics on the subject and contains a wealth of information on each specific topic.

First, the Geothermal Technologies Program (GTP) is introduced. This program is designed to find, access, and apply the use of geothermal resources in the United States.

It also focuses on programs that will support the research and development of geothermal resources via the assistance of industry, academia, and Department of Energy (DOE) laboratories. The main emphasis is on: 1, Enhanced Geothermal Systems (EGS); 2, Hydrothermal Power Generation; and 3, Technology Validation.

Additional information on resources is within the categories: publications, maps, software and data, laws and standards, and related links. Each category has hyper-links to related topics.

The Congressional Digest's article *Alternative Energy Sources* lists nine energy sources other than fossil fuels, bio-diesel, biomass, electricity, ethanol, geothermal, hydrogen and fuel cells, natural gas, solar, and wind (Alternative energy sources, 2008, pp. 196-224). There is a paragraph or two on each source. The DOE's website and links together with the Alternative Energy Sources article, give a good overview of alternative energy sources and energy production.

Biodiesel is as its name suggests organically based. The byproducts of plant matter and animal fats make up its composition. It burns cleaner than pure petroleum diesel and sometimes the two are mixed. Biodiesel is environmentally friendly in that it is nontoxic and biodegradable (Alternative energy sources, 2008, para. 2).

Biomass, sometimes referred to as biomass energy or bioenergy, is plant based with no animal products. The main source of biomass energy is wood, followed by an

array of other plant material from the agriculture and forestry industries. Bioenergy produces approximately the same amount of carbon dioxide as fossil fuels however, the difference between them is that fossil fuels were created from photosynthesis eons ago and when they are burned now, they are considered *new* (emphasis added) greenhouse gases. Whereas current bioenergy fuels consumed the same amount of carbon dioxide to grow as they release when burned. In essence the gas exchange is neutral (Alternative energy sources, 2008, para. 4).

Electricity has the advantage of producing no tail pipe emissions from automobiles. Atmospheric emissions are only produced by the power plants creating electricity for the electric power grids. Another advantage of electricity is the availability of electrical outlets to recharge car batteries. In addition, there is the real possibility that fuel cells will some day be a viable option. Fuel cells create electricity by the conversion of hydrogen or chemical energy to electricity (Alternative energy sources, 2008, p. 196).

Ethanol is explained as far as what it is, liquid biomass, its sources, use, and distribution network. It is primarily used as an additive to gasoline for automobile fuel (Alternative energy sources, 2008, p. 197).

The article also covers hydrogen and fuel cells, natural gas, solar and wind (Alternative energy sources, 2008, pp. 197, 198, 224).

Hydrogen and fuel cells are explained as clean and futuristic. Hydrogen only emits heat and water vapor when used. The positive for hydrogen is that it produces a great amount of heat for its weight. The negative is that the amount of heat per volume is low and that it does not occur naturally, it has to be manufactured (Alternative energy sources, 2008, p. 197, 198).

Fuel cells are a promising source of energy. Like hydrogen, they have no toxic or greenhouse emissions. They are, however, a new technology in the early stages of development (Alternative energy sources, 2008, p. 198).

Natural gas is an excellent clean source of energy. It is non-toxic non-corrosive and non-carcinogenic. It is produced from many sources, landfills, synthetic gas, biogas resources and coal-derived gas. It accounts for approximately one quarter of the energy used in the United States (Alternative energy sources, 2008, p. 198).

Solar and wind are also alternative energy sources. There is an abundance of solar while wind, although abundant, is dependant on upon the uneven heating of the earth's atmosphere (Alternative energy sources, 2008, p. 198).

The geothermal section mentions the two basic types of geothermal power plants in use: steam and binary.

In a steam system, the temperatures of steam and hot resources typically are more than 300 °F (148.9 °C). Some plants use a method that “flashes” the hot resource to produce steam to turn turbines. Turbines are devices that drive generators that in turn produce electricity (Alternative energy sources, 2008, p. 197). The cost per kilowatt hour (kWhr) is approximately four to six cents.

A binary system operates at lower temperatures in the 100 °F (37.8 °C) – 300 °F (148.9 °C) range. This process combines the hot water with another secondary liquid such as isobutane or isopentane (Alternative energy sources, 2008, p. 197). The secondary liquid has a lower boiling point than water and thereby evaporates to steam and activates the turbines to spin. The secondary fluid is then captured and reused while the hot water is returned to the geothermal reservoir. The whole process operated within a

closed system and therefore there are no emissions (Alternative energy sources, p. 197). The cost per kWhr is five to eight cents.

The U.S. Department of Energy's website contains topics with great detail. The main topics are: Geothermal Basics, Enhanced Geothermal Systems, Hydrothermal Systems, Direct Use of Geothermal Resources and Heat Pump Technology (U.S. Department of Energy, 2006, p. 1). The Congressional article, on the other hand, as described in the paragraphs above, is more general and meant to familiarize a person with the various types of alternative energy sources (Alternative energy sources, 2008).

The article, "Direct-Use of Geothermal Energy in the USA" by John W. Lund (2003), is a good source on geothermal technology put out by the United States government (p. 33). This article adds a bit of confusion to the understanding of the application of the different types of geothermal energy production. Direct use is in the title of the article but the author refers to direct use and ground source heat pumps interchangeably. He does not make the case that these are similar applications, as does the Geo-Heat Center at their web site (Geo-Heat Center, 2008). Upon closer examination of this web site, all the articles listed are products of the Geo-Heat Center in Klamath Falls, OR. They may very well be excellent articles on their subject matter, but readers need to be aware of this single source of information and lack of inclusion of information from other publications.

There are also symbols of measurement throughout Lund's paper that are not clearly defined, TJ/yr, GWhr/yr and MWt (Lund, p. 33). This adds a layer of separatism between the layman reading the article and this discourse community. TJ/yr indicates

tetra joules per year, GWhr/yr is Giga Watt hour per year and MWt is Mega Watt thermal (Farlex, 2010; Rowlett, 2005).

U.S. Direct-Use Capacity (MWt) in 2000 without heat pumps

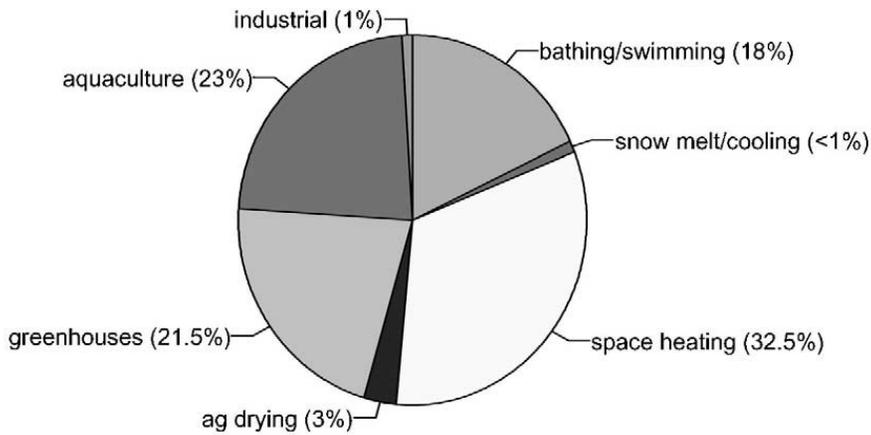


Figure 8. U.S. Direct-use capacity (MWt). Adapted from “Direct-use of geothermal energy in the USA,” by John W. Lund, 2003, *Applied Energy*, 74, p. 35.

U.S. Direct-Use (TJ/yr) in 2000 without heat pumps

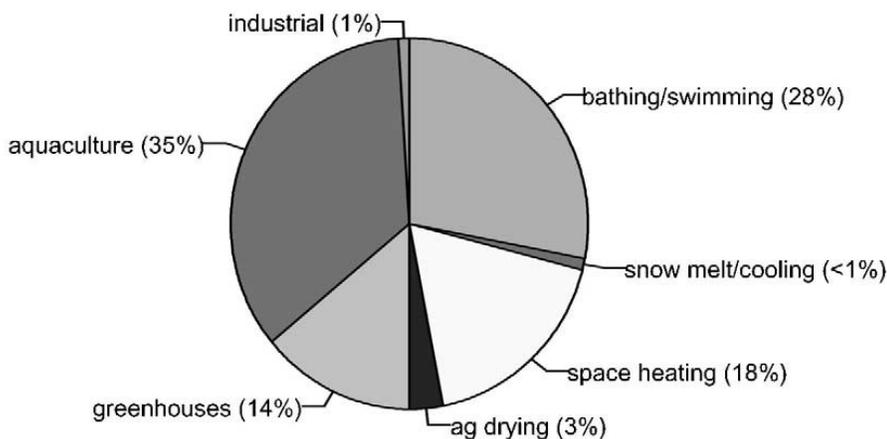


Figure 9. Direct-use energy (TJ/year) in the US. Adapted from “Direct-use of geothermal energy in the USA,” by John W. Lund, 2003, *Applied Energy*, 74, p. 35.

The relationships between joules and watt-hours are defined in the List of Abbreviations and Definitions on page 8 of this paper.

The current applications of direct use technology are outlined and the regions in the United States that are using it the most are defined (Lund, 2003, p. 33). Several pie charts are illustrated with respect to direct use capacity and direct use energy (Lund, p. 35). These charts allow the reader to quickly grasp the percentages of use by various commercial businesses. None of the previous articles use pie charts.

In addition to identifying the industries that consume direct use geothermal energy, each are discussed individually in their own section. Some of these businesses are: fish farming, resorts/spas, space heating, greenhouses, and industrial processes. Following these sections, there is a discussion of the energy savings realized per year through geothermal use verses that of fuel oil, (2.46 million tonnes), reduced air pollution 0.51 million tonnes (natural gas), 2.16 million tonnes, (oil) and 2.51 million tonnes carbon (coal) (Lund, p. 40).

The Congressional Digest 2008 article, “Alternative Energy Sources,” mentions that there are two main geothermal energy types steam or direct and binary.

Geothermal energy is utilized by two main categories, power production and direct use of energy (DiPippo. 2004). These categories are further compartmentalized into several applications.

Under power production there are three applications:

- Dry steam
- Flash steam (Vapor-dominated) hydrothermal
- Moderate-temperature (binary) hydrothermal

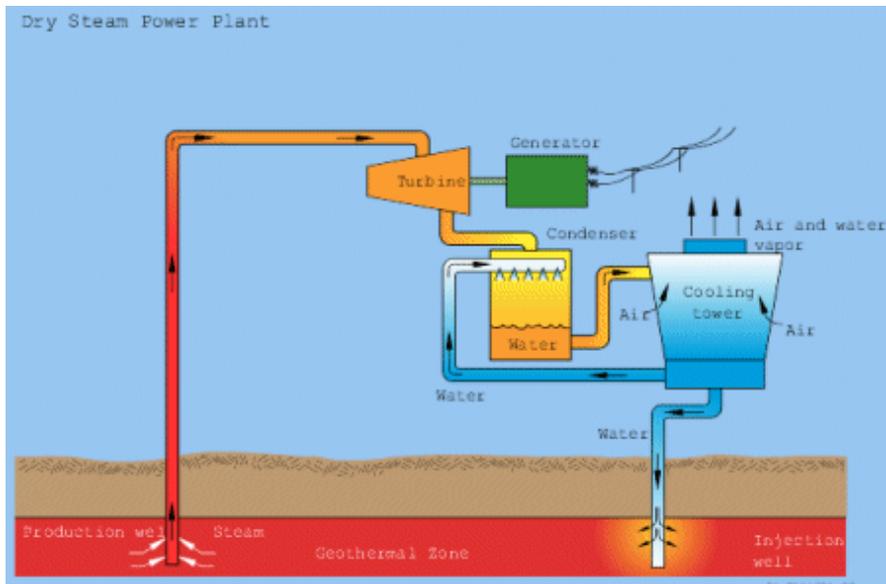


Figure 10. Schematic of the dry steam power plant (Idaho National Laboratory, 2010, p. 1).

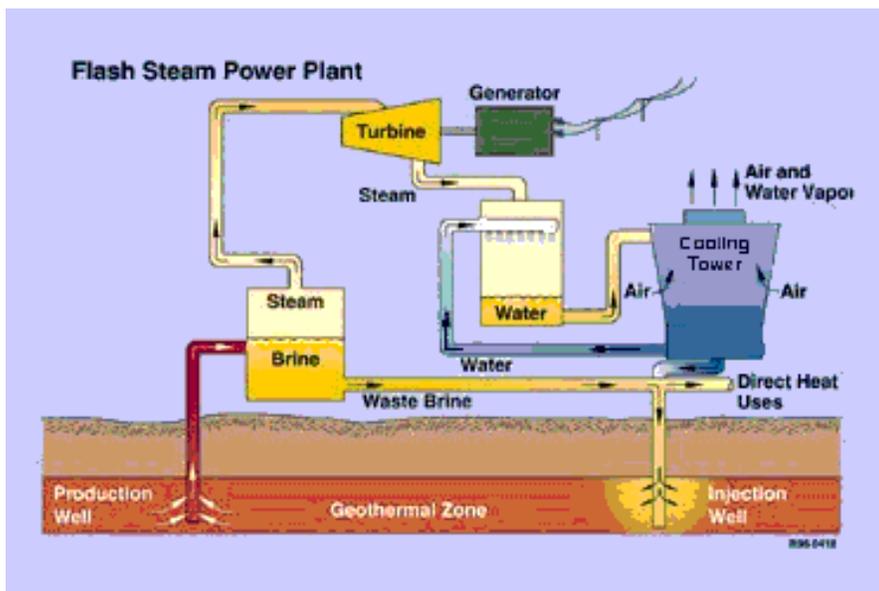


Figure 11. Schematic of the flash steam power plant (Idaho National Laboratory, 2010, p. 1).

Figures 10, 11, and 12 are simplified diagrams of these applications (Idaho National Laboratory, 2010, p. 1).

Again, the primary difference between these three applications is that steam is a high temperature application, 300 °F (148.9 °C) +, whereas a binary application operates at lower temperatures (Alternative energy sources, 2008, p. 197). The article by Ronald DiPippo examines the binary technology in depth (DiPippo, 2004, p. 565). This article begins with an abstract and introduction that clearly state the purpose and focus of the paper, which are to assess and compare the two binary-type energy conversion systems know as the Organic Rankine Cycles (ORC) and a proprietary system known as Kalina cycles (DiPippo, p. 565).

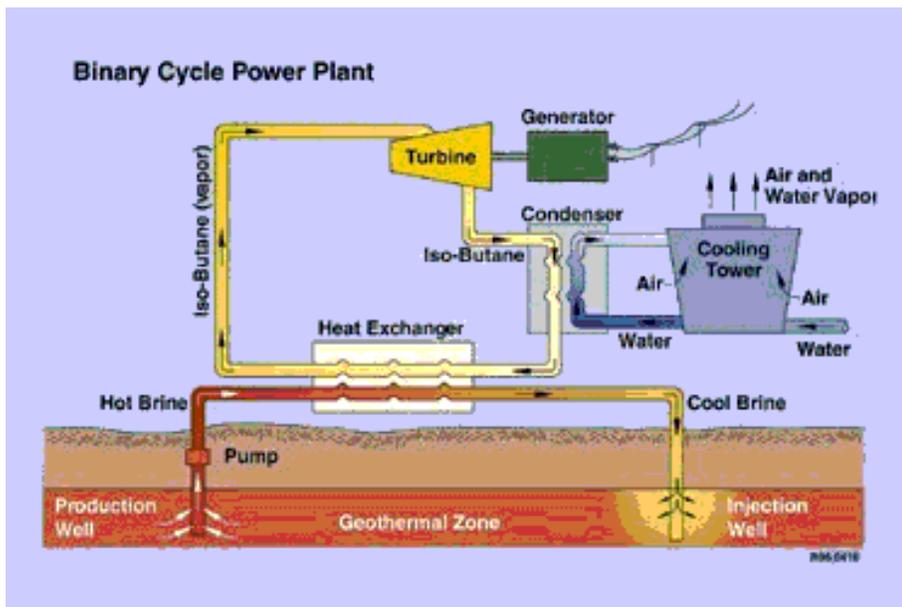


Figure 12. Schematic of the binary cycle power plant (Idaho National Laboratory, 2010, p. 1).

The Rankine Cycle (RC) converts energy to work in a closed loop system. It is named after the Scottish engineer and inventor William John Macquorn Rankine, (1820 – 1872). Rankine developed several theories on steam and heat engines (Turboden, 2010, p. 1) The simplified overview of the Rankine Cycle is water is compressed by a pump into a chamber that is heated to produce steam that drives a electricity producing turbine engine. As the steam passes over the turbine blades, it is collected and cooled back to a water state where it is cycled again to the pump and thereby repeating the cycle.

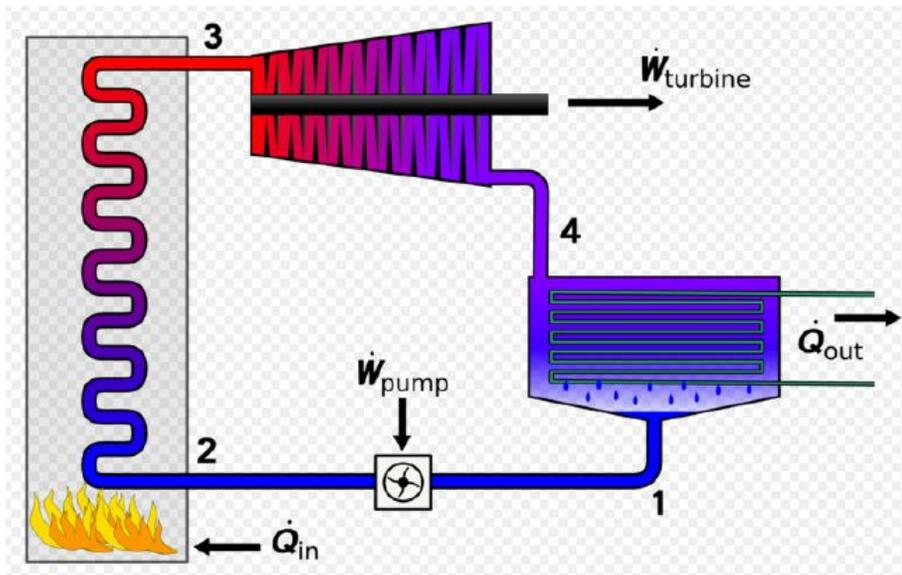


Figure 13. Rankine Cycle (Montara Energy Ventures, 2008, p. 1).

An Organic Rankine Cycle (ORC) uses a liquid that has a lower boiling point than water's 100 °C. This liquid is usually isobutane or isopentane. ORCs are less efficient than RCs but they operate in the temperature range of 75 – 150 °C whereas RCs need to operate at 250 °C or higher (Montara Energy Ventures, p. 1).

The Kalina Cycle is a variation of an ORC. Whereas the ORC uses isobutane or isopentane as the working fluid, a Kalina Cycle uses a two part fluid of ammonia and

water that operates at the same lower temperatures as an ORC however, it is more efficient (Montara Energy Ventures, 2008, para. 4).

There is a general overview of both systems followed by a brief explanation of the fundamentals of the second law of thermodynamics (DiPippo, 2004, p. 567). The article is very technical and compares a number of power plants using the two types of technologies that is applicable to understanding their suitability of these technologies for rural Alaska.

To better understand the second law of thermodynamics, it helps to state the first.

The First Law of Thermodynamics, commonly known as the Law of Conservation of Matter, states that matter/energy cannot be created nor can it be destroyed. The quantity of matter/energy remains the same. It can change from solid to liquid to gas to plasma and back again, but the total amount of matter/energy in the universe remains constant. (All about Science, 2010, para. 2)

The second law of thermodynamics is also the Law of Increased Entropy. Entropy is “a thermodynamic measure of the amount of energy unavailable for useful work in a system undergoing change...entropy always increases and available energy diminishes in a closed system” (Neufeldt & Guralnik, 1996, p. 454). In a closed system, all energy is accounted for even though the energy may change states.

In the application of the second law of thermodynamics in one of the above types of Rankine cycles, as the gas, whether from water or another fluid, releases energy by moving turbine blades and thereby creating electricity, it returns to a liquid state. It is then pressurized again, heated, and the cycle repeats.

Traditionally, geothermal energy production centered around heated regions of the earth's crust close to the surface. However, there are future technologies poised to allow for drilling to greater depths in the neighborhood of 15,000 ft. (Wicker, 2005, p. 2).

These newer depths have the potential to turn most of the world into a geothermal resource (Wicker, p. 2).

The article discusses dry plants (i.e., flash steam) and binary-cycle plants. The range of operation temperatures are given, above 300 °F (148.9 °C) for dry plants and 100 °F (37.8 °C) – 300 °F (148.9 °C) for binary-cycle plants as described in *Alternative Energy Sources* (Alternative energy sources, 2008, p. 197) The output power capacity difference between these two types of plants can range from 5 MW to over 100 MW (Wicker, 2005, p. 3). A brief history of geothermal energy use in the United States from the early 1920s to present day is mixed in with an accounting of types and capacity of power plants around western United States.

Geothermal Applications

To better understand the practical side of geothermal energy production, a perusal of the technology as it is used around the world becomes relevant. First, geothermal energy production is divided into two main categories, electricity production and direct use (Ozgener & Ozgener, 2008, p. 167). Electricity production is self explanatory, direct use refers to geothermal heat used for balneology, space heating, greenhouse and open-ground heating, industrial processes, aquaculture pond and raceway heating, and snow melting (Ozgener & Ozgener, p. 167). This paper will focus mainly on the electricity production.

Nicaragua is using geothermal resources to meet its growing demand for electricity (Olijnyk, 2005, p. 1). Olijnyk establishes Nicaragua's electricity demand as of 2004 and projects a 6% increase in annual use for the next 15 years (2005, p. 2). The number of turbines that are in use, along with the type of steam, dry, that drives them is

explained. Also mentioned is Nicaragua's connection to the geothermal energy program that is being promoted by the World Bank. Nicaragua has over 69 volcanoes with at least 10 currently active. The temperatures of the underground water sources can reach as high as 350 °C. This gives the country a potential of producing 2,000 MW of geothermal power (Olijnyk, p. 2). Olijnyk goes on to mention that the geothermal production of the world is 9,000 MW and that of the United States is 2,800 MW (p. 3). The life of a geothermal plant is noted using statistics of plants in Larderello, Italy and Wairakei, New Zealand (Olijnyk, p. 3). This article also delves into the potential cost advantages for foreign investment along with carbon credits (Olijnyk, p. 4).

The plant in Wairakei, New Zealand is one of the oldest producing geothermal power plants in the world. Construction started over 50 years ago during 1953-1963 (Thain & Carey, 2008, p. 48). The article, "Fifty Years of Geothermal Power Generation at Wairakei," is segmented into three main sections, the introduction, the power plant as designed and commissioned, and station and steam field issues. Given the fact that this facility has been in use for such a long time, relatively speaking with respect to geothermal power production, it has a well documented history from its conception to its growth and setbacks therein to its current status. Unlike the article featuring Nicaragua's geothermal production, which did not use illustrations, this article uses a multitude of visual aids from maps, pictures, and application diagrams to graphs, tables, and charts. Even though it is technical and aimed at the geothermal community, these strategically placed illustrations make the article accessible to the layman.

The conception and technical objectives are covered in the section on design and commissioning. The topics of location, system steam pressures, and material and

metallurgical consideration are discussed (Thain & Carey, 2008, pp. 49, 50). Next the issues of steam production, transmission and the inner operations of power production are covered with the assistance of detailed illustrations and water temperature charts.

There are two main plants at Wairakei, Plant A and Plant B. Plant A uses multi-pressures: high pressure (HP), intermediate pressure (IP), and low pressure (LP) with the tips of its turbine blade reaching high speeds of 3,000 rpm. Plant B, on the other hand, uses medium pressure (MP) with the tips of its turbine blades reaching lower speeds of 1,500 rpm (Thain & Carey, 2008, p. 54). The auxiliary functions of non-condensable gas removal and its cooling water plant finish off this section.

In addition, it addresses steam field issues, is in the format of a timeline that highlights the various stages of technical problems and solutions encountered from commissioning in 1958 until 2008 (Thain & Carey, 2008, p. 56). Production drilling, maintenance requirements, and technical challenges along with applications are covered. The binary and direct use applications are discussed in detail whereas they were not in the Nicaraguan article.

Geothermal energy production, generally, is the result of a large scale and expensive project. This fact leads to one of the underlying factors: cost. As such, applications are geared toward commercial markets. Germany moved into the construction of large geothermal plants in the mid 1980s (Sanner, Mands & Sauer, 2003, p. 590). Heat pumps are a central element to the application of geothermal technology where the production of electricity is not the main focus (Sanner et al., p. 591). Sanner, Mands, and Sauer studied of how Germany used Ground Source Heat Pumps (GSHP) to cool as well as heat the German Air Traffic Control Headquarters in the center of

Frankfurt. There is some mention of the geography in Germany but the illustrations are not in color and the sharpness of the image is poor (Sanner et al., pp. 590, 599, 600).

The industry journal, *Power*, investigates the current upswing interest in geothermal energy production in a 2005 article titled, “Geothermal: Hotter Than Ever” (Wicker, 2005, p. 2). Two primary factors in the renewed interest in geothermal energy resulted from the United States Production Tax Credit incentive and the improvements in drilling and electricity production methods (Wicker, p. 2). The author discusses the results of the Energy Production Tax Credit (PTC), newer drilling techniques and the world’s capacity potential. None of the other articles addressed the tax incentive as a stimulus, however, Alaska’s Senator Lisa Murkowski mentioned the steps that the Federal Government was taking to promote energy production from renewable sources in an address to the Alaska Forum on the Environment (Alaska Forum Inc., 2008, para. 14, 15).

Geothermal Energy Investment Cost

The geothermal energy potential of the world is substantial. One percent of the geothermal energy in the uppermost 10 kilometers of the world’s crust is more than 500 times that of the known oil and gas reserves of the world (U.S. Department of the Interior, U.S. Geological Survey [USGS], 2003, p. 1). The technology is proven and the production of power plants is reliable with longevity. However, the calculated current use is well below that potential. There may be a number of valid reasons for the low usage. It may be the difficulty of accessing the viable geographical regions, the cumbersomeness of application and interfacing with the current infrastructures of

societies or it could be that the cost of applying geothermal energy systems are not price competitive. In other words there are alternative energy sources that are cheaper.

Researcher Valgardur Stefansson investigated the cost of investing in geothermal power plants in his article, "Investment cost for geothermal power plants" (Stefansson, 2002, p. 263). Stefansson's paper described two methods of building a geothermal power plant. One was to build to the maximum capacity of the geothermal reservoir from the beginning. The second method was to build up to the capacity of the reservoir in steps (Stefansson, pp. 264,265). Iceland is a model of successful use of geothermal energy as outlined in the above article and others by Gross (2008) and still again by Motavalli (2008).

As with most revenue generating endeavors, investors want to know the risk of the involved, the cost and the time lag between investment and seeing a return on their investment. The authors Eugene Brigham and Joel Houston discussed the previous statement with their analysis of the cost of money in their academic text, *Fundamentals of Financial Management* (Brigham & Houston, 2007, p. 175). Stefansson also identified the above investment concerns. One of which is, "It is of economic importance to reduce the time lapse between the investment in drilling and the moment when the investment can begin generating income" (Stefansson, 2002, pp. 264, 265). The downside of the first method, building to the capacity of the reservoir from the beginning can take a long time, mainly because of the time it take to drill a number of wells to determine the size of the geothermal reservoir. Drilling a large number of wells is referred to as reconnaissance and can add several years to a project, during which time the economic dynamics can substantially change (Stefansson, p. 265).

The second method is considered a better approach because it uses the smallest power plant platform and brings it on line then adds to it if the field proves large enough to handle more capacity. This is a six-year process consisting of:

- 1. Reconnaissance 1 year
- 2. Surface exploration 1 year
- 3. Exploration drilling 1 year
- 4. Production drilling and power plant 3 year
- Total time 6 years

(Stefansson, 2002, p. 266)

By using the second method, several power plants can be built simultaneously, thus rendering a shorter time to realize an investment return.

Cost is not mentioned often in discussions because it can be difficult to project (Stefansson, 2002, p. 263). Stefansson addresses the issue by separating a power plant project into two major sections, above ground and below ground. The above ground cost are consistent with established and common construction cost, there are few unknowns (e.g., building materials, architectural design, land acquisition, etc). The subsurface cost on the other hand can present a huge unknown cost factor, mainly, how deep the well will need to be to reach a viable geographic area? These subsurface cost can take from 20-50% of the overall construction expense (Stefansson, pp. 264, 265).

The cost of drilling a well for geothermal use is difficult to predict as stated above. There are several reasons why this is so, namely two, propriety information and the history of the number of wells drilled specifically for geothermal use are limited (U.S. Department of Energy, 2006, chap. 6). There is an excellent section on the U.S.

Department of Energy's web site under the Information Resources titled The Future of Geothermal Energy lead by the Massachusetts Institute of Technology (MIT), of a comprehensive study on geothermal energy. The link to chapter 6 on this page is on drilling technology and cost (U.S. Department of Energy, 2006, p. 1).

Geothermal use in Alaska

The main purpose of this paper as previously stated, "...can geothermal energy production be produced on a small enough scale with energy yields that are cost affective for application in a rural Alaskan community?" The following questions are relevant to answering the above question.

1. Where are the locations of current operational geothermal systems in Alaska?
2. What is the population size being supported?
3. What are some of the applications using geothermal energy?
4. Where are the areas in Alaska that are potential geothermal sources?

The map below is very exciting in that it shows geothermal areas for Alaska. This map indicates the depth of heat sources by color. The United States Department of Energy is an excellent reference to understanding the basic technology and its derivatives.

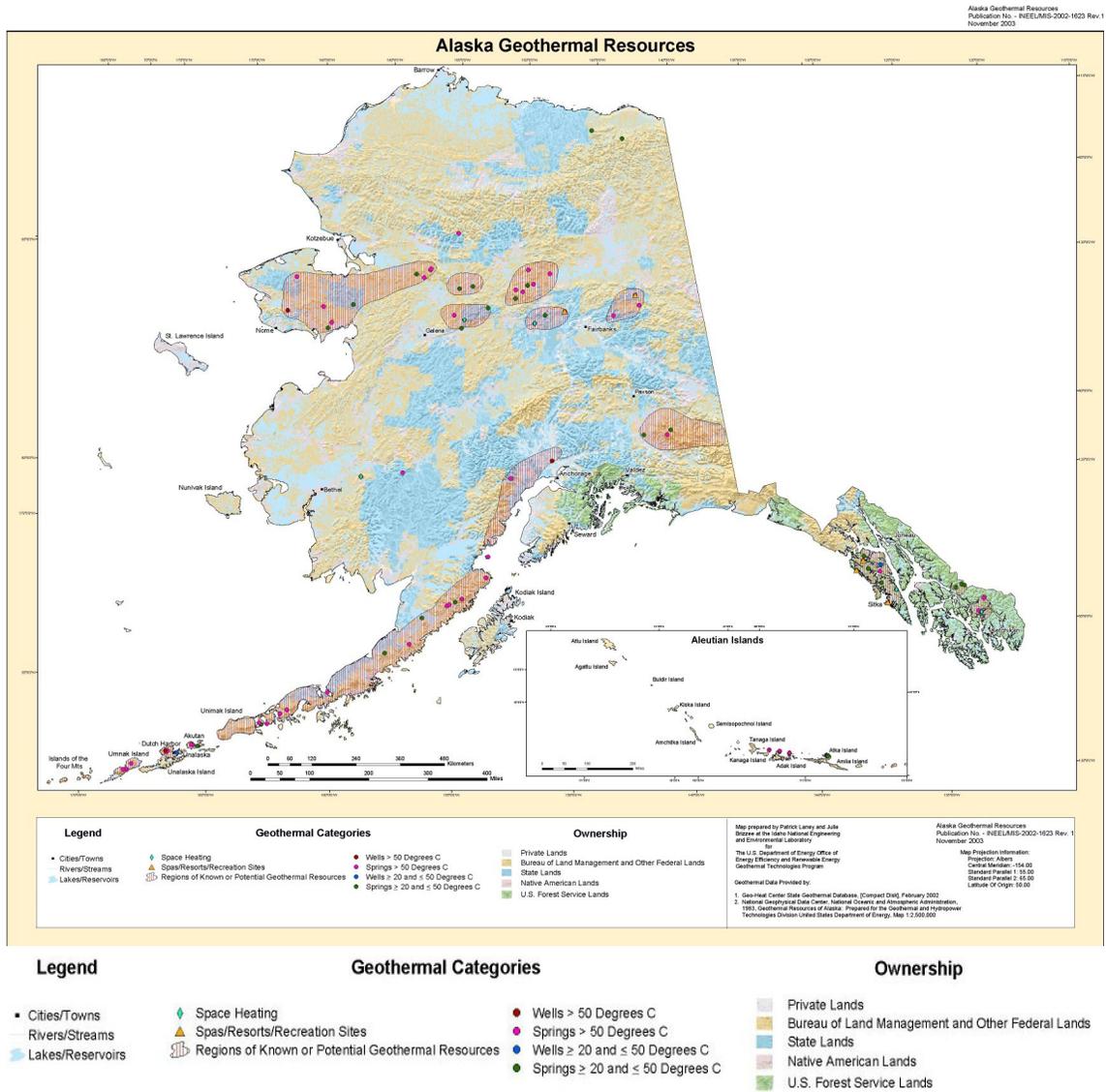


Figure 14. Alaska Geothermal Resources (Idaho National Laboratory, 2010, jpg version 1). Obtained via web link from United States Department of Energy (U.S. Department of Energy, 2008, p. 1).

Popular Mechanics ran an article titled, “Alaska’s Energy Surprise” (Bogo, 2008). This article is an excellent write up on the first geothermal energy production venture in Alaska. The history of the origin of the project as conceived by the owner of Chena Hot Springs, Bernie Karl (Bogo). The original engineer, Gwen Holdmann, had insights into using the extreme cold temperatures of this unique northern environment for geothermal energy production which would not have worked in warmer climates. The article compares the competitive price of low temperature geothermal energy production against that the cost of conventional commercial electricity production. It also delves into alternative uses such as refrigeration of a local tourist attraction, the Aurora Ice Museum. Innovative concepts that were developed for the Chena Hot Springs venture are explained along with identifying academic and government support (Bogo).

Gwen Holdmann also coauthored an article with Kamil Erkan, Walter Benoit, and David Blackwell, titled Understanding the Chena Hot Springs, Alaska, geothermal system using temperature and pressure data from exploration boreholes in *Geothermics* (Benoit, Blackwell, Erkan & Holdmann, 2008).

Emmonak, Alaska



Figure 15. Emmonak, Alaska. Adapted from Andrew Halcro's blog, however, the map is no longer on this website. Retrieved from <http://www.andrewhalcro.com/blog/admin?from=28>

The State of Alaska gives a historical overview of Emmonak (ee-MAHN-nuck) on its Alaska Community Database Community Information summaries (CIS) website Emmonak (2009) (State of Alaska, n.d., pp. 1-3). The website covers the village's location, climate, history, culture and demographics as well as facilities, utilities, local and regional organizations.

Another source of demographics on Emmonak is the City-Data.com website (Advameg, Inc, 2003-2008). Although this website is loaded with ads by Google, it has many graphs, maps and charts that give more detail than similar categories listed on the State's website. City-Data.com states on their home page that their data is gathered from

numerous sources, however, those sources are not listed. The website also boasts of having 12.1 million site hits in October, 2009 alone and is featured in 121 books, used by CNN, WABC in New York and by Bay 9 News in Tampa, FL (Advameg, Inc, 2009-2009). The stats used in City-Data.com's website track closely with that of the State of Alaska's CIS website. Both appear to be good sources to use.

Electricity production in Emmonak, Alaska

The Alaska Village Electric Cooperative (AVEC), a private non-profit organization, provides electricity for Emmonak (Alaska Village Electric Cooperative, 2009). This website gives a general overview of the structure of AVEC. It outlines who is on its Board of Directors and how they are selected as well as various links to other items of interest such as job opportunities, request for proposals (RFP), scholarship programs and other frequently asked questions (FAQ).

This website is of particular importance and relevant to this research paper because it gives an accounting of the source of electricity production for several rural communities and organizations throughout Alaska see figure 5. The website has been updated since the map depicted in Figure 5 was retrieved November 30, 2009. The current map, on the website, redirects the reader from the map to a detailed section on a selected village.

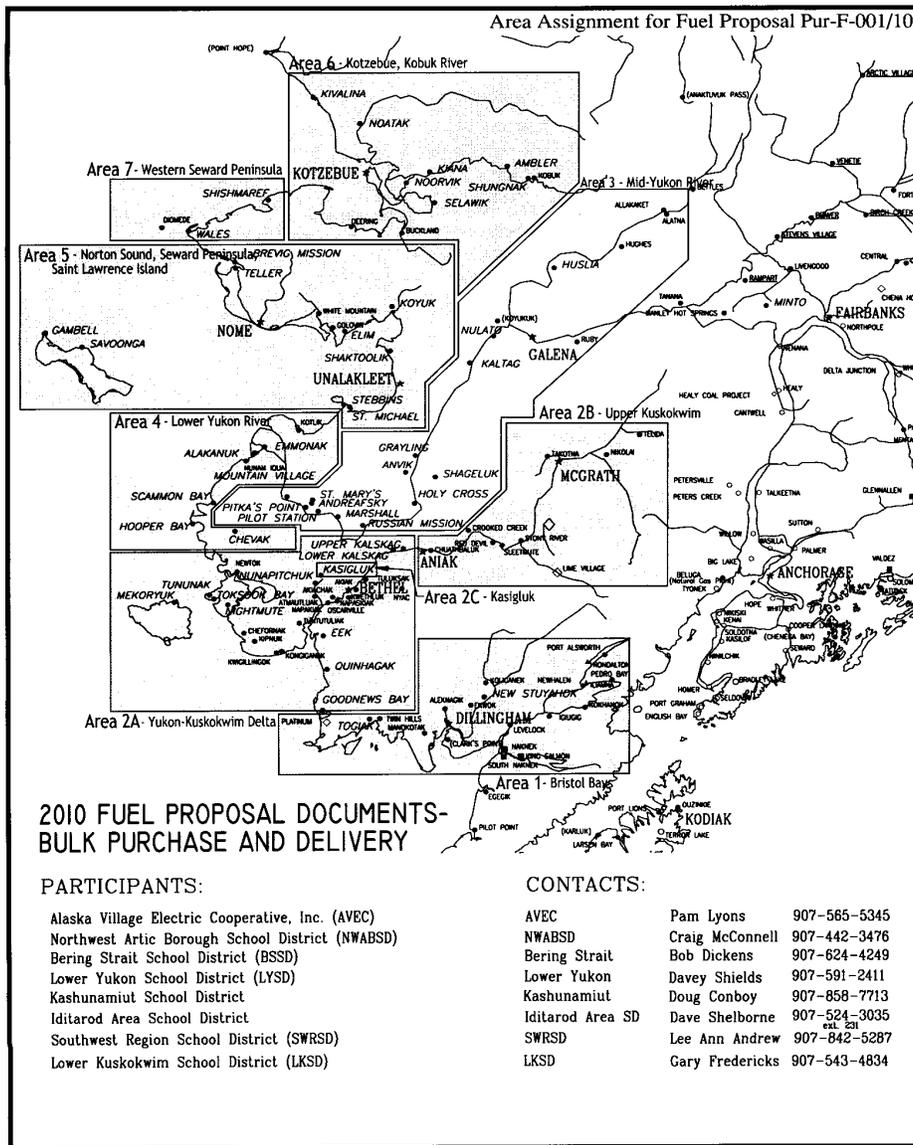


Figure 16. 2010 Request For Proposals (RFP) fuel proposal assignments. Emmonak is located in the upper right corner of Area 4. (Alaska Village Electricity Cooperative, 2009)

These sections, geology, technology, application, costs, and Emmonak data provides a foundation to build a methodology for researching the purpose of this paper.

Chapter Two

Methodology

Introduction

The science and social science disciplines recognize two main methods of research. They are the qualitative method and the quantitative method. The quantitative method is the august of the two and up until recent times was considered the gold standard method of research. In the period of 1983-1988, the quantitative method dominated at 40-50% compared to the qualitative method's 15-18%. However, their positions shifted in the 1996-1999 timeframe where quantitative usage dropped to 10% while qualitative increased to 30-40% (Clearinghouse on Adult, Career, and Vocational Education, 2002).

This shift may be the result of the flexibility of the qualitative method over the quantitative method. The quantitative method is one that uses deductive reasoning for interpretation of its data. The initial proposal for the research is that there is an intrinsic truth the researcher is attempting to prove. The collected data is based on natural phenomena. That is to say, that the data can be reduced, manipulated and displayed in quantitative formats. These formats are many such as facts with relationships to mathematics, statistical analysis, charts graphs and trends.

Quantitative research strives to establish conclusions from empirical data collected that can be replicated by other researchers if the same parameters of the study are used in a similar research project (Mays, Pope, 1995, p. 43). Qualitative data tends to be related to the questions of how or what verses the why that would apply to quantitative research. How and what type questions lend themselves to data that is collected from

interviews with individuals, descriptions of interactions between members of a closed system such as a family, a groups, a company or segment of society. The conclusions drawn from the researcher are influenced by his or her own biases. This is expected and the researcher tries to identify their potential bias up front when stating the objective of the proposal (Marshall, Rossman, 2006, pp. 25, 30, 59).

The significance of the qualitative study is that it is a snapshot in time and probably cannot be reproduced by another researcher for a similar but different study. However, if the principles are sound, a different researcher should come close to approximating the same conclusions of the initial researcher by analyzing the same group with the same data.

As stated previously, qualitative research is flexible. It is flexible in the sense that the researcher is allowed to go back and adjust his initial proposal as often as he wants in order to make the proposal fit the collected data and the conclusion to which it is leading. This acceptable practice may explain why the recent trend in the social sciences has been a shift from quantitative to qualitative research. If the researcher is skillful in stating his proposal and using the data, then disproving the proposal becomes very difficult if not impossible.

Table 2 gives a side-by-side comparison of the differences between qualitative and quantitative research methods with respect to the social sciences.

Table 2

Comparison between Qualitative and Quantitative Research Methods

	Qualitative	Quantitative
Social theory:	Action	Structure
Methods:	Observation, interview	Experiment, survey
Question:	What is X? (classification)	How many Xs? (enumeration)
Reasoning:	Inductive	Deductive
Sampling method:	Theoretical	Statistical
Strength:	Validity	Reliability

(Mays & Pope, 1995, p. 44)

The intent of this paper is to use primarily the quantitative method, which is the experimental and deductive rather than observational and inductive data. However, there may be elements of the qualitative method that need addressing. Therefore, both may apply resulting in using a mixed method approach.

Project Design

The topic of geothermal energy production covers a broad range of applications and technologies. Before a specific area is examined, a general overview of geothermal technologies, applications, and costs are discussed to form a foundational starting point.

There are geothermal production plants sponsored by several governments through out the world as well as private endeavors in the United States. The application type, physical size, production capacity and cost will be compared before a narrower analysis is done on smaller applications that may be suitable for rural Alaska.

Document Collection.

To answer the research question, this paper used the following topics and subtopics. All material was drawn from hard data and proven technologies.

Foundation.

1. Identify the major different types of geothermal energy production

The following resources explain the various types of applications and methods used for geothermal energy production.

- a) “Direct-use of geothermal energy in the USA” (Lund, 2003)
- b) “Geothermal fields suitable for power production” (Gokcen et al., 2004)
- c) “Assessment of operation of an underground closed-loop geothermal heat exchanger” (Nowak & Stachel, in press)
- d) “Hybrid geothermal for hotel” (Barfield, 2008)

2. Outline the size capacity of each system

There are systems that are electricity producers and systems that are what is referred to as direct use. It is not the object of this paper to explain in depth the make up of each. However, a general overview of a sample of a few established systems will help lend to the understanding of the nature of the requirements for a particular size plant. The resources listed below are used for this purpose.

- a) “Direct-use of geothermal energy in the USA” (Lund, 2003)
- b) “Geothermal fields suitable for power production” (Gokcen et al., 2004)

3. What is the production cost?

There are various costs in the production of geothermal energy. For the purpose of this paper, the production cost analysis was limited to bringing a geothermal power plant into production and the maintaining that production. To assist in understanding these costs the following resources are used.

- a) “Investment cost for geothermal power plants” (Stefansson, 2002)

- b) “Iceland has power to burn” (Gross, 2008)
- c) “Thermomechanical exergy and thermoeconomic analysis of geothermal district heating systems” (Ozgener & Ozgener, 2008)
- d) “U.S. Department of Energy—energy efficiency and renewable energy” (U.S. Department of Energy, 2006)
- e) “Tapping the fire down below” (Tenenbaum, 1995)
- f) Alaska Village Electric Cooperative (Alaska Village Electricity Cooperative, 2009)
- g) Calista Corporation (Calista Corporation, 2009)

Electricity for Emmonak is provided by AVEC. In that it is a private corporation, the operating cost of the power plant in Emmonak may not be available to the public. A request was sent to AVEC for information, however, there has been no response. AVEC provides power to Emmonak as a contractor for the Calista Corporation. Calista may have data they are willing to share. This data serves as a baseline for cost comparisons.

4. Where are similar systems being used around the world?

To help identify the type of system, systems or applications most suitable for rural Alaska, a sampling of power plants currently in production around the world are examined.

- a) “Larger geothermal heat pump plants in the central region of Germany” (Sanner, Mands, & Sauer, 2003)
- b) “Mexican geothermal development and the future” (Serrano, 1998)

- c) “Full steam ahead” (Olijnyk, 2005)
 - d) “Fifty years of geothermal power generation at Wairakei” (Thain & Carey, 2008)
 - e) “World geothermal power generation in the period 2001-2005” (Bertani, 2005)
4. Disadvantages of geothermal energy systems (Stefansson, 2002).

Cost Analysis.

Three books are the initial sources for how to perform a benefit-cost analysis, *Management of Energy/Environment Systems*, *Environmental Economics – a critique of benefit-cost analysis*, and *How to Prepare a Feasibility Study* (Foell, 1979; Graves, 2007; Stevens & Sherwood, 1982).

Emmonak Data.

Emmonak is a member of the Calista Corporation, the second largest of the 13 corporations created in 1971 under the Alaska Native Claims Settlement Act (ANCSA) (Calista Corporation, 2009). This website has good historical and current data on its member villages.

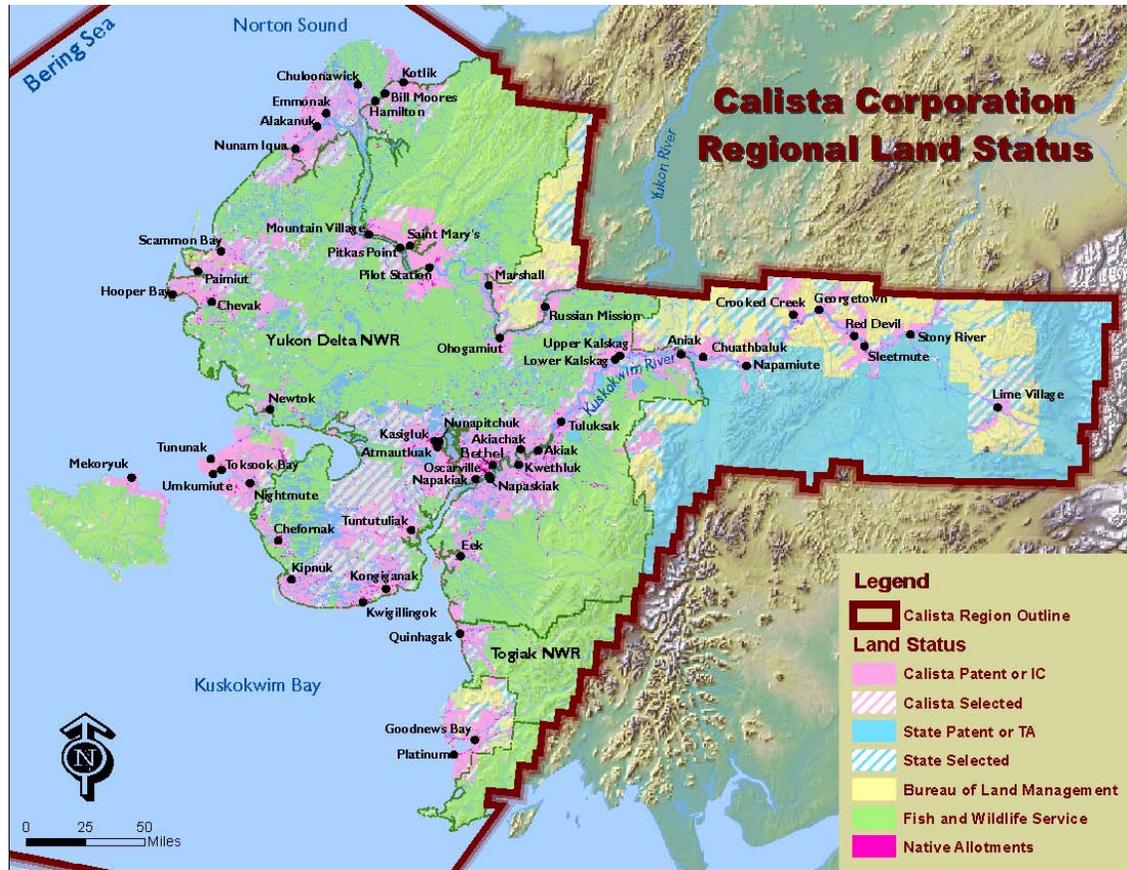


Figure 17. Calista Corporation geographical boundaries and Calista villages (Calista Corporation, 2009) “Founded in 1972, Calista Corporation is the second largest of the 13 regional corporations established under the Alaska Native Claims Settlement Act (ANCSA) of 1971” (Calista Corporation, 2009).

Table 3

Cost of Emmonak power projects

Calista Region Community Economic Development Capital Projects Database							
Emmonak							
Agency	Fiscal Year	Project Status	Project Description	Project Stage	Agency Cost	Total Cost	Contractor
Denali	2003	Funded	Power Plant	Contract	\$65,000	\$65,000	AVEC
Denali	2003	Funded	Wind Generation	Contract	\$35,000	\$35,000	AVEC
Denali	2003	Funded	Design	Contract	\$15,000	\$15,000	AVEC
Denali	2001	Funded	Heat Recovery Bulk Fuel Storage Project	Contract	\$185,000	\$185,000	AVEC

Note. Adapted from Calista region community economic development capital projects Database, Emmonak link.

1. What energy consumption data is available?
2. What is the current method of energy production?

Document Analysis.

What is the projected need of Emmonak in five years, ten years? This is a crucial question that needs an answer to really make a determination as to whether or not the pursuit of geothermal power production on a small scale is worth the effort and cost. All of the above documents have relevance in making this determination.

One of the first items that will be researched is whether or not the geography of the major rural villages, specifically Emmonak, is viable to support geothermal energy production. Under this topic several questions are asked:

- a) What depth would wells need to be drilled?

- b) How large geographic area is required for the size of a plant needed?
- c) Who owns the land and what would be the cost to acquire it?

Another topic that would need examining is that of building the physical structure. The village of Emmonak is approximately 800, which would indicate that funding would have to come from other sources. Of these other sources, do they currently have a stake in the power production of Emmonak as it currently is? If they do, would the possibility of a geothermal power plant be welcomed or would it be considered a threat. The classic strength, weaknesses, opportunity and threats (SWOT) analysis would certainly lend to the understanding of the projects viability.

After construction, the operating cost would be a major factor in making the decision to build or not to build. For example, if outside sponsors built the facility, would the revenues that are currently realized from today's power plant sufficient to maintain operations. If it is, then when is the break even point realized, that is, at what point in the future would the plant begin to be profitable?

Chapter Three

Findings

Introduction

Geothermal resources are used in two primary applications, Direct-Use and electricity production. Heating sidewalks, heating ventilation and air conditioning (HVAC), and heating agriculture systems are examples of Direct Use (Barfield, 2008; Bogo, 2008). In a Direct-Use application, hot water from a geothermal source is pumped from the well through various networks of plumbing systems to extract the heat. The applications of Direct-Use are not the focus of this paper.

Geothermal Technology

Electricity production uses geothermal heat to create steam to power steam operated turbines that in turn operate electricity-producing generators. There are three main methods of producing electricity for geothermal heat;

- Dry steam
- Flash steam (Vapor-dominated) hydrothermal
- Moderate-temperature (binary) hydrothermal

See Figures 10, 11, and 12 (Idaho National Laboratory, 2010, p. 1).

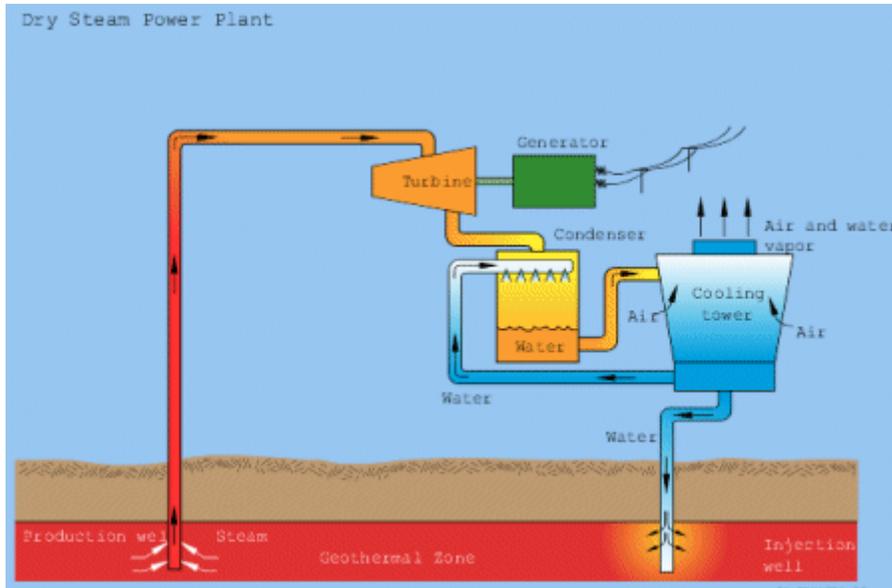


Figure 10. Schematic of the dry steam power plant (Idaho National Laboratory, 2010, p. 1).

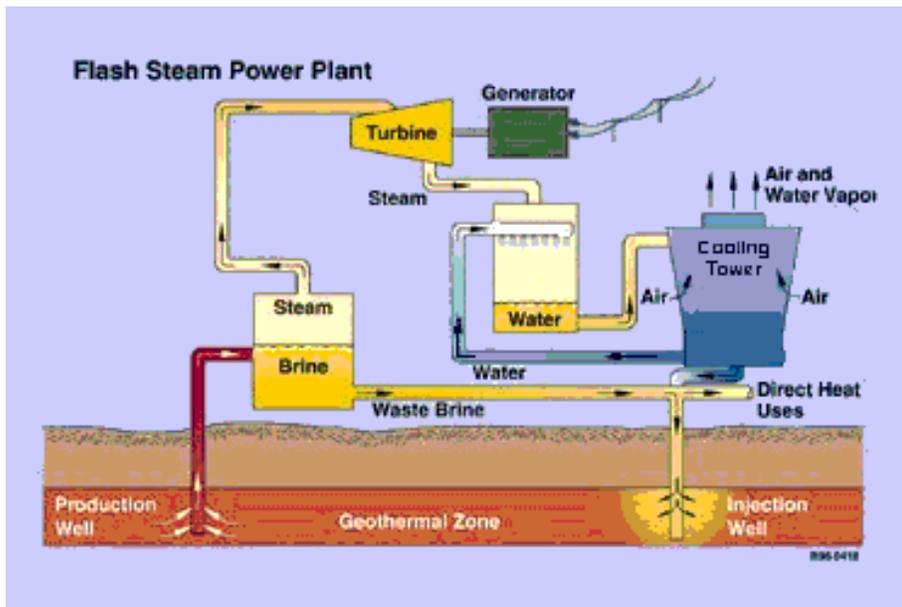


Figure 11. Schematic of the flash steam power plant (Idaho National Laboratory, 2010, p. 1).

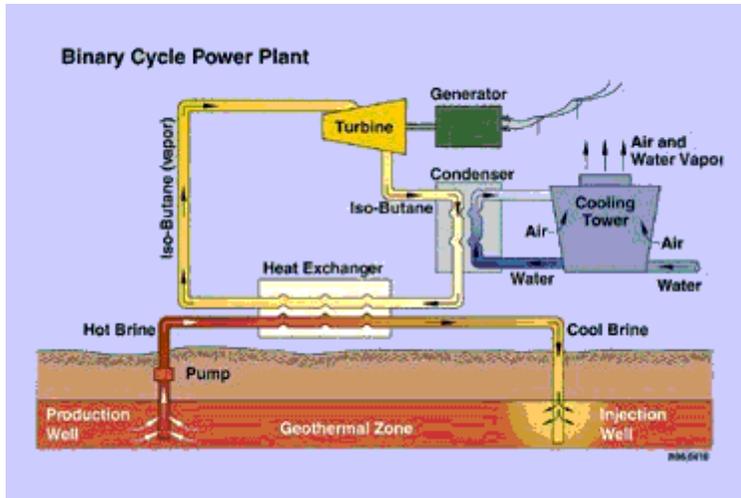


Figure 12. Schematic of the binary cycle power plant (Idaho National Laboratory, 2010, p. 1).

To assess the viability of whether or not a region is suitable for geothermal applications, an understanding of underground temperatures is needed. Two questions that must be answered first are, what are the temperatures with reference to depth and what locations are suitable from a surface map perspective?

Geothermal fields in Alaska

The earth's temperature increases with depth. According to Our-Earth, a website with many references to energy sources and topics, "For every 100 meters you go below ground, the temperature of the rock increases about 3 degrees Celsius. Or for every 328 feet below ground, the temperature increases 5.4 degrees Fahrenheit" (Our-Energy, 2008).

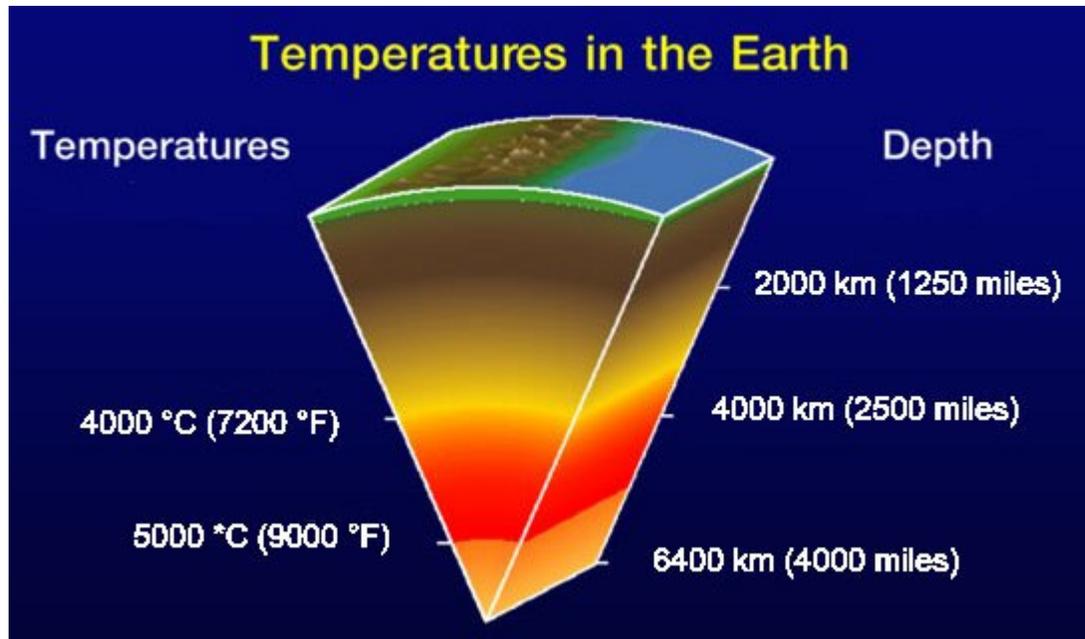


Figure 18. Earth's underground temperatures. Temperatures of the Earth increase with depth (Our-Energy, 2007).

There are many regions in the world that are suitable for geothermal energy applications, however, this paper is only concerned with Alaska. Alaska is located in a very active geological region known as the Ring of Fire, see Figure 19. This region is populated with numerous volcanoes due to the different interaction of Pacific tectonic plates (U.S. Department of the Interior, U.S. Geological Survey, 2003).

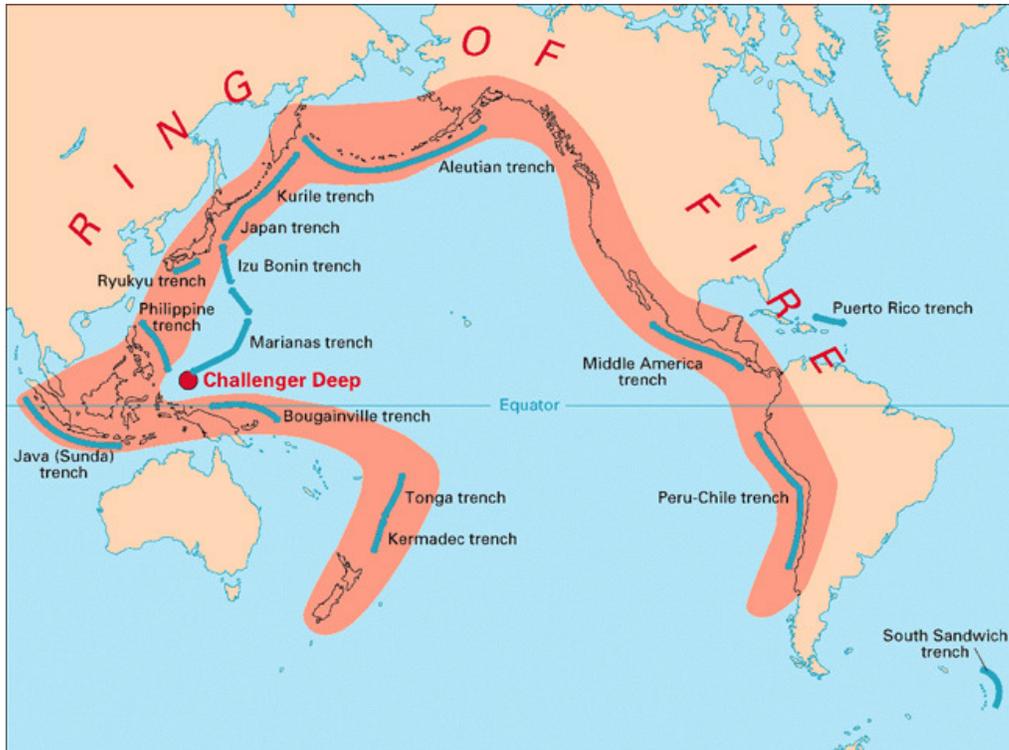


Figure 19. Pacific Ring of Fire (Duffield & Sass, 2003, p. 8).

The maps showing geothermic temperatures, Figures, 16, 19, and 20, of Alaska appear to indicate that there are several areas prime for geothermal energy productions. However, there is only one active geothermal power plant in production, the plant at Chena Hot Springs resort.

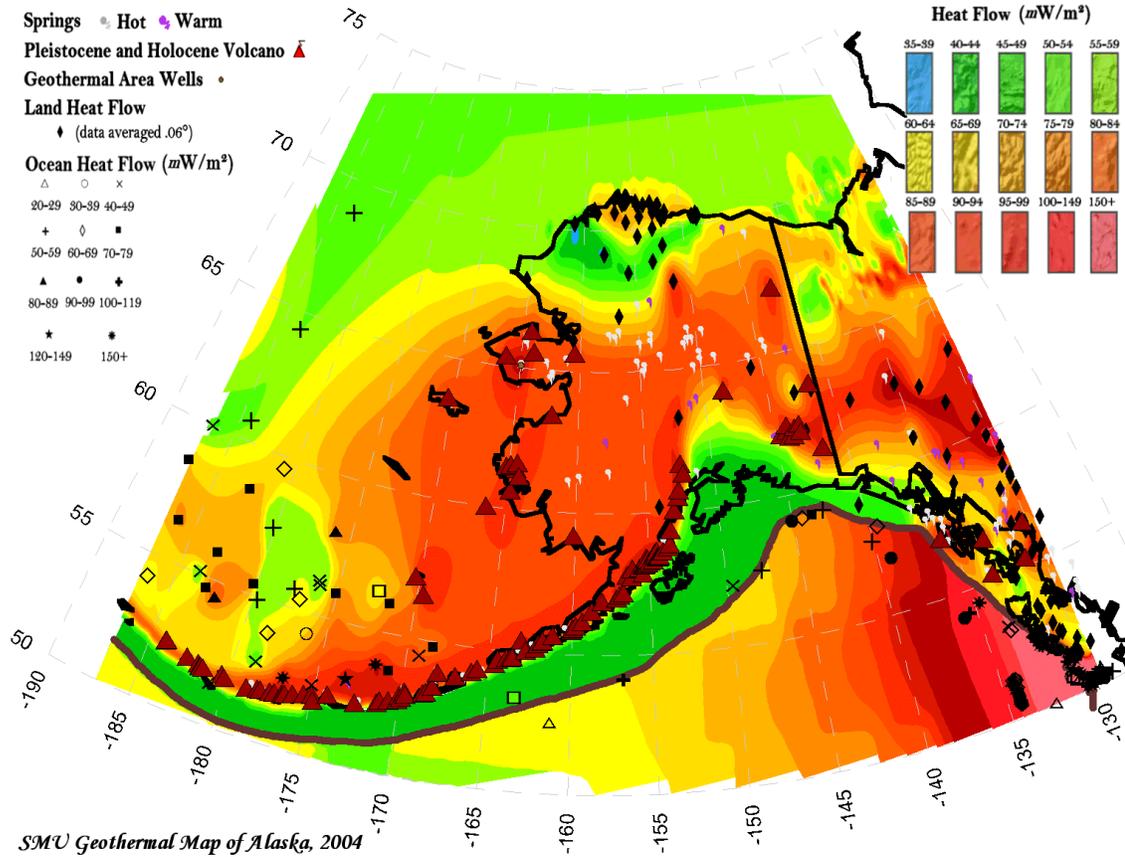


Figure 20. Geothermal Temperatures and Volcanoes for Alaska (Southern Methodist University [SMU], 2004, p. 1).

Geothermal Applications in Alaska

The Chena Hot Springs resort is located approximately 60 miles northeast of Fairbanks, Alaska. The plant came on line in 2006. It is classified as a 400 kWe, low temperature, binary plant, operating at approximately 57 °C, well below the boiling point of water (Benoit et al., 2008). By Chena Hot Springs being the first geothermal power plant in Alaska, many studies and articles have been done and written on the geography and system operation.

Chena Hot Springs is located in the middle of Alaska away from the Ring of Fire, however, it is located near a volcano per Figure 23. Figure 21 shows what the temperatures would be if the Earth's crust and underlying layers were uniform however, this is not the case. Figures 16 and 20 show that geologic temperatures vary around the state. Figure 24 is a cross sectional representation based on the boreholes (i.e. wells), denoted by TG-1 through 11, drilled for the Chena Hot Springs project (Benoit et al., 2008, p. 579).

The borehole data from the Chena Hot Springs project is helpful in that it gives a point of reference of what temperatures to expect at possible depths in a real world hot spring environment. The data on the depth of the boreholes to their temperatures also gives further insight into drilling costs. One estimate is that drilling cost \$100-\$300 per foot (Tenenbaum, 1995). The resort partnered with United Technologies Corporation (UTC) to help bring the cost down. UTC already had a product called PureCycle 200 that is a modular ORC power generation system operated from waste heat. UTC wanted to develop a product that used geothermal resources (Chena Power Company, 2007, p. 6) The final cost of the Chena Hot Springs project was \$2,007,770, 5% over the original estimate of \$1,899,065 (Chena Power, 2007, p. 37). Once operations began, the cost dropped from 30¢ per kWhr to 5¢ per kWhr. Maintenance costs are expected to drop to 1¢ per kWhr once loans are paid off (Chena Power, 2007, p. 3).

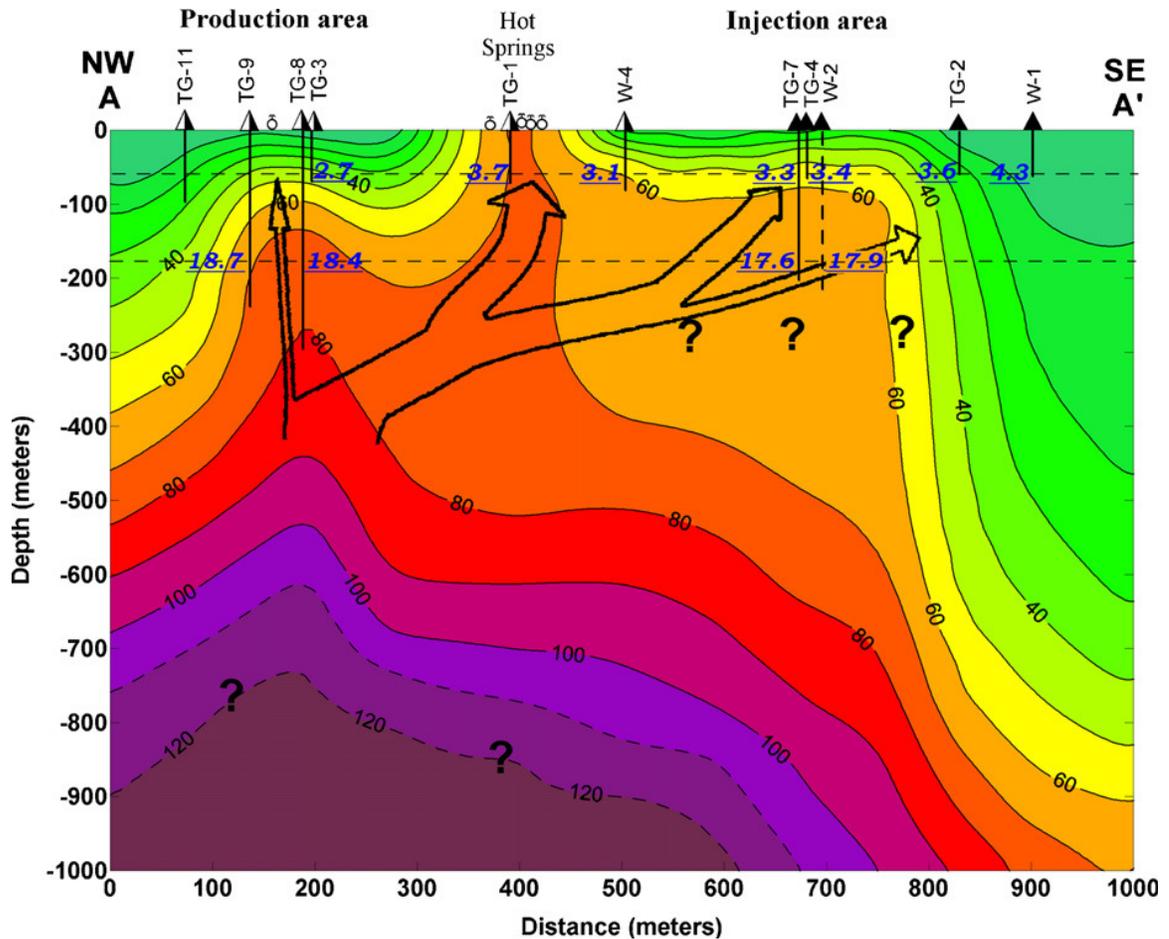


Figure 21. Cross sectional isothermal representation of the Chena Hot Springs area based on borehole data (Benoit et al., 2008, p. 579).

Emmonak Data

Emmonak, Alaska has a population of approximately 800 with 277 customers paying for electricity provided by AVEC (AVEC, 2010). A geothermal power plant of one megawatt is recommended for a community of 1000 (U.S. Department of the Interior, 2003). The current total diesel generating capacity provided by AVEC's is 2,307 kw (AVEC, 2010).

AVEC is pursuing providing power to their customers from renewable energy sources with the application of wind turbines. It currently is using wind turbines to

supplement the power production in 13 rural Alaskan communities with plans to add four more in 2010. Emmonak is currently under study for wind assistance (AVEC, 2010).

AVEC currently pays \$3.00 per gallon for fuel. In 2009 it purchased 5,100,360 gallons of fuel. It plans to replace 25% of this amount by 2018 by using wind turbines (AVEC, 2010)

Energy Costs across Alaska

The cost of energy in Alaska varies greatly between communities accessible by road and those that are not see Figure 22.

Gulf Coast	On Road System	Off Road System	Interior	On Road System	Off Road System
Heating Fuel:			Heating Fuel:		
High	\$3.10	\$6.21	High	\$4.50	\$10.00
Low	\$2.64	\$3.23	Low	\$2.46	\$4.92
Average	\$2.93	\$4.21	Average	\$3.00	\$6.49
Gasoline:			Gasoline:		
High	\$3.44	\$7.34	High	\$4.50	\$10.00
Low	\$3.35	\$3.19	Low	\$2.94	\$4.75
Average	\$3.40	\$4.41	Average	\$3.59	\$6.20

Figure 22. Energy Cost of Alaska (Divisional of Community and Regional Affairs [DCRA], 2009, p. 5).

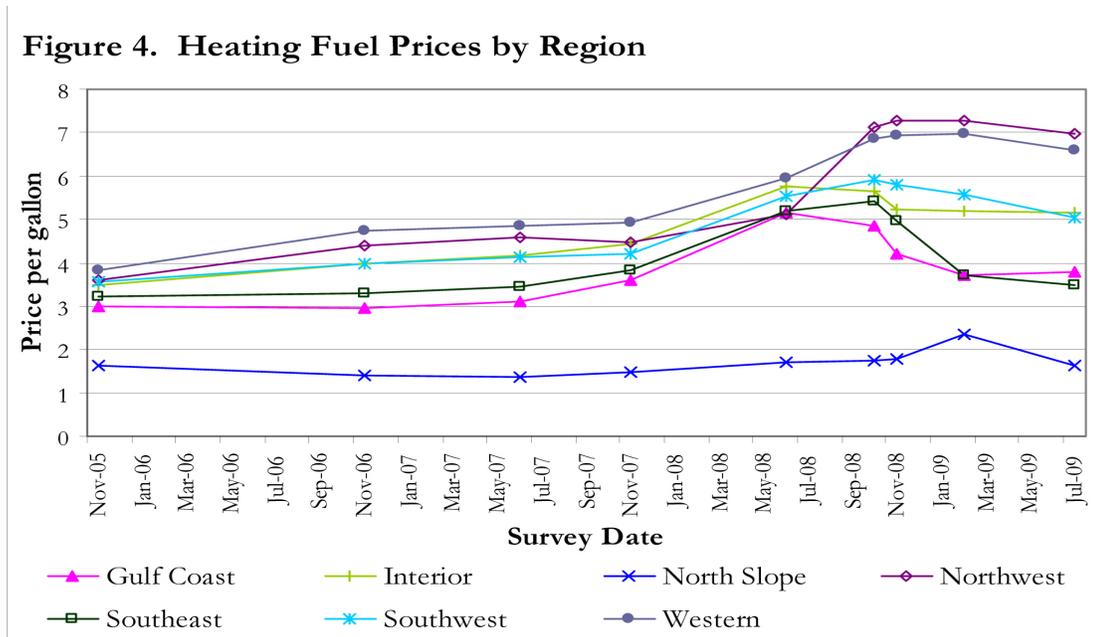


Figure 23. Region Heating Fuel Prices (DCRA, 2009, p. 7).

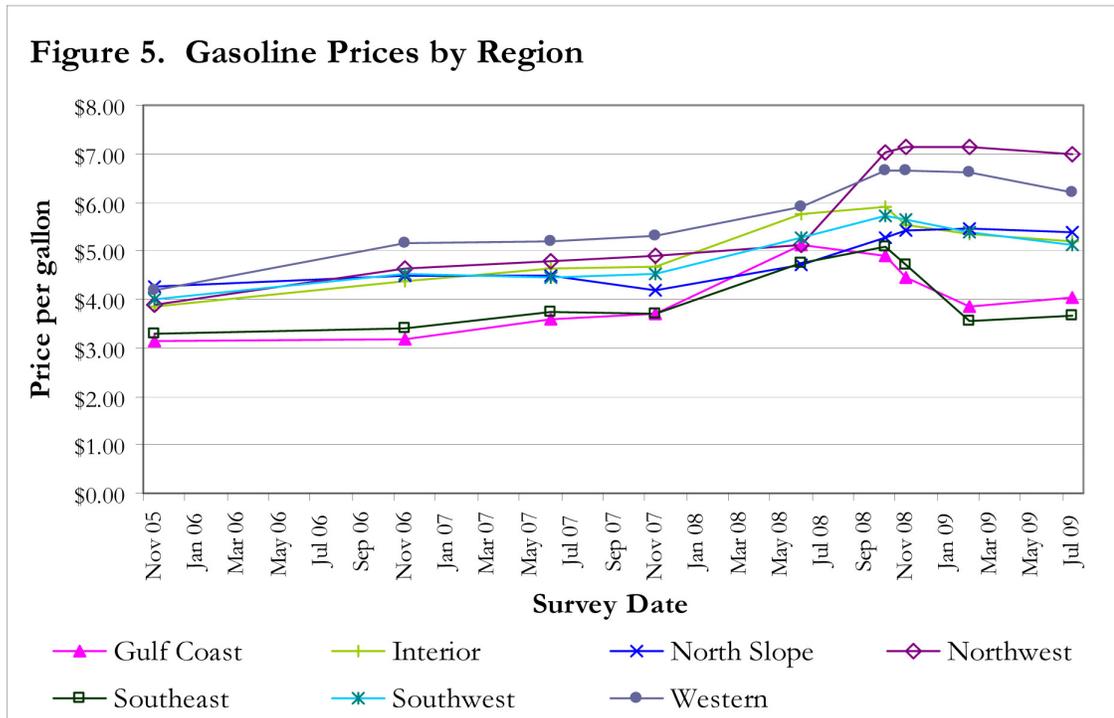


Figure 24. Regional Gasoline prices in Alaska (DCRA, 2009, p. 7).

Figures 23 and 24 above, shows the significant costs of heating and gasoline that

the Western region pays per gallon verses most of the rest of the state. Although this paper is concerned with the cost of power production for communities, Figures 22, 23, and 24 display a good visual trend of fuel prices throughout the state.

Regulations

There are numerous state regulations that need to be included in the decision process to build a geothermal power plant. Some of these regulations were identified by Bruce Buzby from the State of Alaska Department of Natural Resources Division of Oil and Gas in his presentation at the 2009 Alaska geothermal Conference, (Buzby, 2009, p. 3, 4). The following regulations were listed.

Table 4

Alaska Regulations

Article VIII, § 1. Statement of Policy	Article VIII, § 2. General Authority
AS 38.05.181 Geothermal Resources	AS 38.05.965(6) Definitions
11 AAC 82.400-475 Competitive Bidding	
11 AAC 84.700-790 Geothermal Leasing	
11 AAC 84.810-950 Geothermal Unitization	
11 AAC 87.030-050 Geothermal Exploration	
11 AAC 87.070-160 Drilling of Geothermal Wells	
11 AAC 87.210-260 Geothermal Production	

Note. Adapted from State of Alaska Department of Natural Resources Division of Oil and Gas 2009 Alaska Geothermal Conference presentation (Buzby, 2009, pp. 3, 4).

Chapter Four

Discussion

At the beginning of this study, the use of geothermic resources appeared to be a simple alternative to Emmonak's energy problem. Alaska has a significant number of active volcanoes and is therefore in a very active geologic area. With so much what appeared to be abundant geothermal resources, it was difficult to understand why this resource was not being used as a long term solution to provide low cost electric power to rural Alaskan communities.

It became evident early on, that certain geographic areas within Alaska were not good candidates for geothermal power production, Emmonak is located within one of these areas. From the data collected, the area around Emmonak is not recognized by any of the geographic survey maps as being a resource for geothermal energy production. The data further explained that geothermal resources were available to practically any area if one is willing to drill deep enough to reach the desired temperature. Under this scenario, cost becomes a major deciding factor. Another factor is the cost savings of installing a geothermal power plant.

In the case of Emmonak, there are only 277 paying customers out of a population of 800. The Calista Cooperation funded \$65,000 in 2003 to AVEC to provide electrical power for Emmonak. No data was discovered that gave a more recent cost figure. Given that the population has remained fairly stable at 800, any increase in allotment to AVEC would not warrant the cost of installing a 1 MW geothermal power plant. The Chena Hot Springs plant cost over \$2,000,000 for only a 400kWe plant in a known geological hot spot. Emmonak would require twice as much power as Chena Hot Springs.

The literature on geothermal energy production is extensive. One difficulty in researching this paper was that there are so many different variations and applications of geothermal technology that it tended to get confusing at times. A future researcher might consider identifying various costs for a specific power output that could be applied to a known community's population.

Limitations of study

This study did not consider the local interest of the community. Nor did it research at what depth viable geothermal resources could expect to be found. Again, the cost of action verses the expectation of return is the significant factor in deciding whether or not to pursue drilling exploratory boreholes. At \$100-\$300 per foot for a population of 277 paying customers, the smart economic decision is not to pursue geothermal power production.

Not mentioned in this paper is the need to address government regulations and required permits for land use and construction. There was a good guideline in the Alaska Geothermal Conference held on April 28, 2009 that outlined geothermal statures and regulations for Alaska.

My lack of knowledge on the subject of power production from geothermal resources was immense. I basically had no idea of what really was involved to harness geothermic energy. To educate myself on this topic took more time than I anticipated. The more I learned the more I needed to learn. Filtering what was pertinent to the research and needed to be included in the paper verses what was just interesting proved difficult.

Recommendations

My recommendations for future researchers on geothermal energy are to first educate themselves on the technology. By first becoming familiar with the technology and current applications, they can better decide how to direct their efforts. Another item to consider is the cost of geothermal energy verses that of other energy sources, both finite and renewable.

Conclusion

This paper asked the research question "... Can geothermal energy production be produced on a small enough scale with energy yields that are cost affective for application in the rural Alaskan community of Emmonak?" Data was collected and analyzed from several online sources and books.

Initially, the technology was explained followed by a description of the geology required to produce a viable geothermal resource. Regions around the world and Alaska that were producing power from geothermal resources or appeared to have the potential to be a geothermal resource were identified.

The area around Emmonak was compared to the geothermal maps with Alaska's geothermal hotspots. Emmonak is not located in an active or promising geothermal area. Geothermal power production is possible most anywhere if one is willing to make the investment. However, given Emmonak's population size and ability to generate revenue, it is not a viable candidate for geothermal power production.

Alaska Pacific University's Senior Project process helped me to synthesize my collective studies at the university. I found myself time and time again reflecting on the lessons from various classes. This Senior Project reinforced the lessons from one of my first classes, Critical Thinking. Critical Thinking taught to search for the root cause or elements of a particular subject, topic, or event to establish a foundation to build an understanding of the subject. This project forced me to activate the critical thinking process, to take the research question and really delve into what was being asked and what would be required to answer it.

The three segments that make up the Senior Project, the Literature Review, Research Methods, and Final Paper and Presentation, were difficult to understand their connections with one another at the beginning of the project. However, looking back, I now understand their interrelationships. We were advised by the faculty to think about and choose a topic that we had a strong interest in. In doing so, we would find the topic easier to research. Part of my problem was that I did not have a burning desire to understand a particular subject. I have strong interests in several topics, choosing a specific one was difficult. However, power production from geothermal energy is one of my current interests. I thought that researching a topic from a pool of equals would be a good test of my ability to analyze a particular topic.

In my current position as a manager with a telecommunication company, I am often given tasks that are new to me. Having gone through the Senior Project process has given me confidence that I have the tools required to build foundations to accomplish difficult or uninteresting assignments. In my personal life, I now have the satisfaction of knowing where to find the resources to learn about topics that interest me.

I was fortunate to travel to Emmonak this past March, 2010, in connection with my job. Seeing the village first hand and talking with some of the residents was enlightening. The comment from the residents was that the weather was exceptionally nice for my visit with no wind. They said that Emmonak was usually windy. After leaving Emmonak, I went to Numan Iqua. Some maps refer to it as Sheldon Point. It was renamed to its original Yup'ik name Numan Iqua by its residents in 2000. There I saw several wind generators in place with a couple working. At this point, I see wind generators as being the best option for Emmonak. Calista Corporation, Emmonak's

parent Native corporation, has a biennial energy plan for 2008-2010 that is studying the possibility of using geothermal resources in the villages of Aniak and Stoney River. With the knowledge that I have gained from this Senior Project, I see the possibility of two items of action on my part. First is to contact Emmonak's village council and ask them what they see as their energy needs. And second, contact the Calista Corporation and inquire on the status of Emmonak's inclusion in their wind and geothermal projects.

References

- Advameg, Inc. (2003-2008). *Emmonak, Alaska*. Retrieved from <http://www.city-data.com/city/Emmonak-Alaska.html>
- A hungry dragon. (2004). *Economist*, 372(8395), 12-14. Retrieved from <http://proxy.consortiumlibrary.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=14600647&site=ehost-live>
- Alaska Energy Authority. (2008). *Statistical report of the power cost equalization program*. Retrieved from <http://www.akenergyauthority.org/PDF%20files/FY09%20PCE%20Statistical%20Report.pdf>
- Alaska Forum Inc. (2008). *Alaska forum on the environment*. Retrieved from http://murkowski.senate.gov/public/index.cfm?p=Speeches&ContentRecord_id=662fb28c-9f3a-ac0b-77b3-28320ee31a18&ContentType_id=a254d6e4-28a1-416a-a475-cded48504549&19760459-7424-403a-8038-666e11ddb515&Group_id=59643e03-a6a4-4b6a-bc33-52e166e4c462&MonthDisplay=2&YearDisplay=2008
- Alaska Public Radio Network (Producer). (2009, January 13). Extreme cold forcing Emmonak residents to choose fuel over food. Podcast retrieved from <http://aprn.org/2009/01/13/extreme-cold-forcing-emmonak-residents-to-choose-fuel-over-food/>
- Alaska State Chamber of Commerce. (n.d.). Southcentral Energy Forum. Retrieved from http://www.alaskachamber.com/content/index.php?option=com_frontpage&Itemid=1

Alaska Village Electric Cooperative, (AVEC). (2010). Welcome to Alaska Village Electric Cooperative. Retrieved from <http://www.avec.org/>

Alaska Volcano Observatory. (2010). Volcano Information, Retrieved from [http://www.avo.alaska.edu/volcanoes/eruptsearchresults.php?fromsearch=1&yearstart=1900&yearend=2010&year=&volcano=-1&eruptiondesc\[\]=28](http://www.avo.alaska.edu/volcanoes/eruptsearchresults.php?fromsearch=1&yearstart=1900&yearend=2010&year=&volcano=-1&eruptiondesc[]=28)

All about Science. (2010). Second law of thermodynamics. Retrieved from <http://www.allaboutscience.org/second-law-of-thermodynamics.htm>

Alternative energy sources. (2008). *Congressional Digest*, 87(7), 196-224.

Retrieved from

<http://web.ebscohost.com.proxy.consortiumlibrary.org/ehost/detail?vid=15&hid=105&sid=9ca1eb8f-0eff-431f-bf2a-34cd3d275e47%40sessionmgr109&bdata=JnNpdGU9ZWZWhvc3QtbGl2ZQ%3d%3d#db=aph&AN=34222716>

Avakian, M. D., Dellinger, B., Fiedler, H., Gullet, B., Koshland, C., Marklund, S.,...& Sulk, W. A. (2002). The origin, fate, and health effects of combustion by-products: A research framework. *Environmental Health Perspectives*, 110(11), 1155-1162.

Retrieved from <http://www.jstor.org/stable/3455441>

Barfield, A. (2008). Hybrid geothermal for hotel. *American Society of Heating, Refrigeration and Air-Conditioning Engineers, INC, (ASHRAE) Journal*.

Retrieved from

http://www.ashrae.org/members/doc/barfield_8090903.pdf

Bartholomew, J., & Bartholomew, J. C. (1982). *World atlas* (12th ed.). Edinburgh, Great Britain: John Bartholomew & Son LTD.

Benoit, W., Blackwell, D., Erkan, K., & Holdmann, G. (2008). Understanding the Chena Hot Springs, Alaska geothermal system using temperature and pressure data from exploration boreholes. *Geothermics*, 37, 565-585.

doi:10.1016/j.geothermics.2008.09.001

Berman, A. (2009). The dirt on clean coal. *Nation*, 17-21. Retrieved from <https://my.alaskapacific.edu/sandfcd621e31f6f6be25427f4ef538c05/sandf0/SecureExternalMYPortalHomePage/>

Bertani, R. (2005). World geothermal power generation in the period 2001-2005. *Geothermics*, 34(6), 651-690.

doi:10.1016/j.geothermics.2005.09.005

Bogo, J. (2008). Alaska Energy Surprise. *Popular Mechanics*, 185(2), 64-69.

Retrieved from

<https://my.alaskapacific.edu/sandfcd621e31f6f6be25427f4ef538c05/sandf0/SecureExternalMYPortalHomePage/>

Bogo, J. (2008). Geothermal power in Alaska holds hidden model for clean energy.

Popular Mechanics. Retrieved from

<http://www.popularmechanics.com/science/earth/4245896.html?page=1>

Brigham, E. F., & Houston, J. F. (2007). Interest rates. *Fundamentals of financial management*, (pp. 174-206). Mason, OH: Thomson South-Western.

British Broadcasting Corporation (2005). *Clean coal technology: How it works*.

Retrieved from <http://news.bbc.co.uk/2/hi/sci/tech/4468076.stm>

Buzby, B. (2009). *Alaska geothermal conference*. Retrieved from

http://www.bcsmain.com/mlists/files/chena09/documents//Session%202_Regulations_Buzby.ppt

Calista Corporation. (2009). *Calista Corporation*. Retrieved from

<http://www.calistacorp.com/default.asp>

Chena Power Company. (2007). *400kw geothermal power plant at Chena Hot Springs, Alaska*. Retrieved from

[http://docs.google.com/viewer?a=v&q=cache:HYKcCeAyNYcJ:www.yourownpower.com/Downloads/PowerPlantReport.pdf+chena+geothermal+power+plant+project&hl=en&gl=us&pid=bl&srcid=ADGEESizs-](http://docs.google.com/viewer?a=v&q=cache:HYKcCeAyNYcJ:www.yourownpower.com/Downloads/PowerPlantReport.pdf+chena+geothermal+power+plant+project&hl=en&gl=us&pid=bl&srcid=ADGEESizs-CiFNjeBwBJsrMuYJ2sYW5CBFaDoi_1zTIS4H2Pol9PTBOvFMSHyQb6ZqOxsT6ne7L_DOULfa1OY2tNL2dOBqVTbtb4H9gcA0ux14XMc2T5RbgcL0pBh7PAyjj1Y91RBh2N&sig=AHIEtbR5X6M0GNyd7RuBzKtMdSz4hNrtdA)

[CiFNjeBwBJsrMuYJ2sYW5CBFaDoi_1zTIS4H2Pol9PTBOvFMSHyQb6ZqOxsT6ne7L_DOULfa1OY2tNL2dOBqVTbtb4H9gcA0ux14XMc2T5RbgcL0pBh7PAyjj1Y91RBh2N&sig=AHIEtbR5X6M0GNyd7RuBzKtMdSz4hNrtdA](http://docs.google.com/viewer?a=v&q=cache:HYKcCeAyNYcJ:www.yourownpower.com/Downloads/PowerPlantReport.pdf+chena+geothermal+power+plant+project&hl=en&gl=us&pid=bl&srcid=ADGEESizs-CiFNjeBwBJsrMuYJ2sYW5CBFaDoi_1zTIS4H2Pol9PTBOvFMSHyQb6ZqOxsT6ne7L_DOULfa1OY2tNL2dOBqVTbtb4H9gcA0ux14XMc2T5RbgcL0pBh7PAyjj1Y91RBh2N&sig=AHIEtbR5X6M0GNyd7RuBzKtMdSz4hNrtdA)

Clearinghouse on Adult, Career, and Vocational Education. (2002, Winter). Qualitative

Research in Adult, Career and Career-Technical Education. *The Practitioner File*, p. 1.

Cox, W. M., & Alm, R. (2008). *China and India: Two paths to economic power*.

Retrieved from <http://www.dallasfed.org/research/eclett/2008/el0808.html>

Davies, S. (2009). Going underground. *Engineering & Technology*, 4(6), 48-51.

doi:10.1049/et.2009.0608

DiPippo, R. (2004). Second law assessment of binary plants generating power from low-temperature geothermal fluids. *Geothermics*, 33, 565-586.

doi:10.1016/j.geothermics.2003.10.003

Divisional of Community and Regional Affairs (2009). *Current community conditions:*

Fuel prices across Alaska July 2009 update. Retrieved from

http://www.dced.state.ak.us/dca/pub/Fuel_Report_July_2009_web.pdf

Duffield, W. A., & Sass, J. H. (2003). Geothermal energy clean power from the earth's

heat. Retrieved from <http://pubs.usgs.gov/circ/2004/c1249/>

Emmonak. (2009). *Alaska community database community information summaries (CIS)*,

Retrieved from

http://www.commerce.state.ak.us/dca/commdb/CIS.cfm?Comm_Boro_name=Emmonak

Energy Information Administration. (2009). *State Energy Profiles - Alaska.*

Retrieved from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=AK

Energy units. (2010). *American Physical Science*, Retrieved from

<http://www.aps.org/policy/reports/popa-reports/energy/units.cfm>

Farlex, Inc (2010). *The free dictionary.* Retrieved from

<http://encyclopedia2.thefreedictionary.com/joule>

Foell, W. K. (Ed.). (1979). *Management of energy/environment systems.* London: Wiley.

Geo-Heat Center (2008). Oregon Institute of Technology. Retrieved from

<http://geoheat.oit.edu/>

Gokcen, G., Ozturk, H. K., & Hepbasli, A. (2004). Geothermal fields suitable for power generation. *Energy Sources*, 26, 441-451.

Graves, P. E. (2007). *Environmental Economics - a critique of benefit-cost analysis.*

Lanham, MD: Rowman & Littlefield Publishers, Inc.

Gross, D. (2008, April 14, 2008). Iceland has power to burn. *Newsweek*, 151(15), 1-5.

Halcro, A. (2010). *Map of Alaska with Emmonak inset*. Retrieved from

<http://www.andrewhalcro.com/blog/admin?from=28>

Idaho National Laboratory. (2010). *Geothermal energy: Maps*. Retrieved from

[https://inlportal.inl.gov/portal/server.pt?open=512&objID=422&&PageID=3487
&mode=2&in_hi_userid=200&cached=true](https://inlportal.inl.gov/portal/server.pt?open=512&objID=422&&PageID=3487&mode=2&in_hi_userid=200&cached=true)

Idaho National Laboratory. (2010). *Production of geothermal energy*. Retrieved from

https://inlportal.inl.gov/portal/server.pt/community/geothermal/422/what_is_geothermal_energy_/3453

Journal of Commerce. (2006). Rural Alaska stuck with high fuel prices through winter.

Retrieved from

http://www.alaskajournal.com/stories/110506/hom_20061105008.shtml

Lund, J. W. (2003). Direct-use of geothermal energy in the USA. *Applied Energy*, 74, 33-42.

Marshall, C., & Rossman, G. B. (2006). *Designing qualitative research*. Thousand Oaks, CA: Sage Publications, Inc.

Mays, N., & Pope, C. (1995). Reaching the parts other methods cannot reach: an

introduction to qualitative methods in health and health services research. *British Medical Journal*, 311, 42-45. Retrieved from

<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2550091/pdf/bmj00599-0046.pdf>

Montara Energy Ventures. (2008). *What's in a name?*. Retrieved from

<http://www.google.com/imgres?imgurl=http://montaraventures.com/energy/wp-content/uploads/2008/05/rankine-cycle->

[diagram.jpg&imgrefurl=http://montaraventures.com/energy/category/research/&h](http://montaraventures.com/energy/category/research/&h)

=414&w=650&sz=60&tbnid=IOqvbaJSCuKSNM:&tbnh=87&tbnw=137&prev=/
 images%3Fq%3Drankine%2Bcycle&hl=en&usg=__QWgJPQN4uSS1cWWneGh
 qIfo1VFE=&ei=Lu2qS7unEo_-
 tQPUnYnkDQ&sa=X&oi=image_result&resnum=7&ct=image&ved=0CB0Q9Q
 EwBg

Motavalli, J. (2008). Iceland's abundance of energy. *E Magazine*, 19(2), 14-16.

Neufeldt, V. & Guralnik, D. B. (Eds.). (1996). *Webster's new world college dictionary* (3rd ed.). New York: Simon & Schuster, Inc.

Nowak, W., & Stachel, A. A. (2005). Assessment of operation of an underground closed-loop geothermal heat exchanger. *Journal of Engineering Physics and Thermophysics*, 78(1), 136-143.

doi:10.1007/s10891-005-0039-0

Olijnyk, Z. (2005). Full steam ahead. *Canadian Business*, 78(18). Retrieved from
 file://E:\APU\Full steam ahead.htm

Our-Energy. (2007). *Geothermal energy facts*. Retrieved from http://www.our-energy.com/energy_facts/geothermal_energy_facts.html

Ozgener, L., & Ozgener, O. (2008). Thermomechanical exergy and thermoeconomic analysis of geothermal district heating systems. *Institution of Mechanical Engineers*, 222, 167-177.

Rowlett, R. (2005). *A dictionary of units of measurements*. Retrieved from
<http://www.unc.edu/~rowlett/units/index.html>

Sanner, B., Mands, E., & Sauer, M. K. (2003). Larger geothermal heat pump plants in the central region of Germany. *Geothermics*, 32, 589-602.

Serrano, J. E. (1998). Mexican geothermal development and the future. *Energy Sources*, 20, 743-751.

Sierra Geothermal Power. (2009). *What is the average lifespan of geothermal power plant?*. Retrieved from <http://www.sierrageopower.com/index.php/investors/investor-faq>

Smil, V. (2009). 21st century energy: Some sobering thoughts. *oecd Observer*. Retrieved from <http://www.oecdobserver.org/news/fullstory.php/aid/2083/>

Southern Methodist University. (2004). *Alaska surface heat flow*. Retrieved from <http://smu.edu/geothermal/heatflow/heatflow.htm>

Stefansson, V. (2002). Investment cost for geothermal power plants. *Geothermics*, 31, 263-272.

Stevens, R. E., & Sherwood, P. K. (1982). *How to prepare a feasibility study*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Stimac, J., Nordquist, G., Suminar, A., & Sirad-Azwar, L. (2008). An overview of the Awibengkok geothermal system, Indonesia. *Geothermics*, 4(4), 300-331.

Tenenbaum, D. (1995). Tapping the fire down below. *Technology Review*. 98(1), Retrieved from file://E:\APU\Tapping fire below.htm

Thain, I. A., & Carey, B. (2008). Fifty years of geothermal power generation at Wairakei. *Geothermics*, 38, 48-63.

Tucker, N., (2009). Emmonak man seeks food airlift to combat economic crisis, *Bristol Bay Times*. Retrieved from http://thebristolbaytimes.com/article/0903emmonak_man_seeks_food_airlift_to_combat

- Turboden. (2010). *Organic Rankine cycle*. Retrieved from <http://www.turboden.eu/en/rankine/rankine-history.php>
- United States Census Bureau. (2000). *Profile of general demographic characteristics: 2000*. Retrieved from <http://censtats.census.gov/data/US/01000.pdf>
- U.S. Census Bureau. (2003). *Statistical Abstract of the United States: 2003*. Retrieved from <http://www.census.gov/statab/hist/HS-01.pdf>
- U.S. Department of Energy. (2006). *Geothermal technologies program*. Retrieved from <http://www1.eere.energy.gov/geothermal/technologies.html>
- U.S. Department of Energy. (2008). *Geothermal technologies program: Geothermal resources of 13 western U.S. States*. Retrieved from <http://www1.eere.energy.gov/geothermal/maps.html>
- U.S. Department of the Interior, U.S. Geological Survey (2003). *Geothermal energy: Clean power from the earth's heat*. Retrieved from <http://pubs.usgs.gov/circ/2004/c1249/c1249.pdf>
- University of Houston. (2009). *The twentieth century the United States in 1900*. Retrieved from http://www.digitalhistory.uh.edu/database/article_display.cfm?HHID=205
- Wagner, L. A. (n.d.). *Productive capacity indicator 5-1: consumption of materials and energy over time*. Retrieved from http://www.unr.edu/mines/smr/workshopfiles_Dec2002/PC_5.1.pdf
- Wicker, K. (2005). Geothermal: hotter than ever. *Power*, 149(1), 1-8.