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RENEWABLE ENERGY IN MONTANA: SYSTEM APPLICATIONS AND TECHNLOGY

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RENEWABLE ENERGY IN MONTANA:

SYSTEM APPLICATIONS AND TECHNLOGY

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Renewable Energy in Montana: System Applications and Technology

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Energy is a critical topic of debate today, and much interest has turned to renewable energy forms. The negative implications of fossil fuel use are outweighing their benefits, as the twenty-first century has seen environmental, economic, and social consequences unfold. Montana is in a unique position in that it has five forms of renewable energy for heating and electricity generation purposes. Solar, wind, small-scale hydro, biomass, and geothermal energies are available across the state. These energy forms have the potential to provide residences and businesses with heat and electricity year-round, using a seasonally complementary, integrated system.

The current installation of renewable energy systems was investigated to show that Montanans have been able to develop infrastructure capable of providing energy in an efficient and sustainable manner. This also demonstrates that solar, wind, small-scale hydro, biomass, and geothermal energies should be regarded as viable forms of energy, rather than high-risk and experimental options. The technological innovation of renewable energy was also investigated. Research suggests that renewable energy technology is currently able to produce energy with higher efficiencies, and at a lower cost than ever before. Lastly, innovation in the research and development phase is poised to surpass present-day technology standards and shortcomings.

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ABBREVIATIONS

Btu	British Thermal Units
DEQ	Department of Environmental Quality
DOE	Department of Energy
EIA	Energy Information Administration
EERE	Energy Efficiency and Renewable Energy
kWh	Kilowatt Hour
IPCC	International Panel on Climate Change
MWh	Mega Watt Hour
MW	Mega Watt
USB	Universal Systems Benefits

CHAPTER ONE

INTRODUCTION

The twenty-first century has brought many challenges to the American public. Central to these challenges is energy security. Montanans once had some of the lowest energy costs in the nation, but since energy deregulation in 1997, they too are experiencing rising energy costs. Other factors, including reliance on foreign oil, global warming, and an increased demand compound the energy scenario, make energy security a pressing issue. In light of this growing concern, much attention has turned to renewable forms of energy. Developments in technology, policy, and investments have grown in recent years.[1]

The diverse and expansive geography of Montana puts the state in a unique and opportune position for the potential development of many forms of renewable energy, including solar, wind, small-scale hydro, biomass, and geothermal. Montanans have long been using natural resources for energy demands, and research suggests that the aforementioned five main forms of energy could be exploited to meet all of Montana's domestic heating and electrical needs. Additionally, these forms of energy are available at varying times of year, allowing for a continual input of seasonally complementary renewables.[2]

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[1] Worldwatch Institute, "Renewables 2005 Global Status Report," *REN-21 Renewable Energy Policy Network* (2005), 5.

This paper intends to address the potential for renewable energy implementation in Montana and will answer two questions: (i) How are Montana's renewable resources currently being used to produce heat and electricity? (ii) What advances in technological innovation exist that will allow for the future development of Montana's renewable energy resources?

Renewable energy development is a viable option to help solve some of the complex energy issues facing the world. Through the investigation of Montana's renewable energy forms, successful implementation of renewable energy sources, and key technological advances, we may be one step closer to solving local and national energy issues.

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[2] Elizabeth Mulligan Hartsoch, "Renewable Energy in Montana: Resource Potential and Complementarity" (M.A. Thesis, The University of Montana, 2004), 63.

PART I

OVERVIEW

CHAPTER TWO

BACKGROUND

Montana has a unique position. The state has five forms of renewable energy available for heating and electricity generation purposes. These forms of energy include solar, wind, small-scale hydro, biomass, and geothermal sources. Furthermore, there is over fifty times as much energy present in renewable energy resources as is required to heat and provide electricity to Montanans each year (75,771 billion Btu or 22 million MWh/yr).[3] The appropriate extraction of these energies and energy conversion efficiencies deserves critical consideration, and should be considered on a site-specific, energy-specific basis. The vast availability, distribution, and diversity of Montana's renewable energy resources are quite remarkable.

Research conducted by Elizabeth Hartsoch on Montana's renewable energy potential suggests that the annual variability of these five energy forms seasonally complement one another.[4] One of the major criticisms of renewable energy is the reliability of an energy supply, given the intermittent nature of most renewable forms, and the ability to meet varying energy demands from end-users. Hartsoch's research has

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[3] The assumed energy for heating and electrical use in Montana's residential sector was taken from the Energy Information Administration (EIA). The annual energy from solar, wind, and biomass estimates come from the *Renewable Energy Atlas of the West* (2002), and are 101 million MWh, 1,020 million MWh, 6 million MWh, respectively. Geothermal output estimates are from the Montana DEQ, and total 77,000 MWht. The estimated renewable energy for Montana totals 1,127 million MWh/yr.

[4] Hartsoch, "Resource Potential and Complementarity," 2.

shown that this effect could be mitigated by using Montana's five forms of renewable energy to create seasonal complementarity.[5]

The majority of Montana's residential heating and electric demands are currently met with non-renewable energy sources.[6] In 2005, it was estimated that 64% of the electric energy consumed in Montana was produced from coal, 31% from large-scale hydropower, and 5% from petroleum.[7] Energy for heating homes comes largely from natural gas, 59%, with electric heating providing 16% and propane 13%.[8] The remaining 12% is made up from fuel oil and other sources.[9] Less than 4% of total energy production was from solar, wind, biomass, and geothermal.[10]

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[5] Complemetary energy systems are designed to make use of the opposing availability of seasonal resources that can result in higher and more continuous availability of local resources for electric and heat-energy generation.

[6] "Renewable" and "nonrenewable" are terms used to describe energy formation rates in relation to man's perception of time. Nonrenewable indicates energy sources that form at rates so slow their renewal is meaningless to humans in their lifetimes. Earl Cook, *Man, Energy, Society* (San Francisco: W.H. Freeman and Company, 1976), 51.

[7] U.S. Department of Energy, Energy Information Administration, "Consumption, Price, and Expenditure Estimates," in *State Energy Data System* [database on-line] (Washington D.C.: 2005, accessed 2 September 2008); available from http://apps1.eere.energy.gov/states/energy_summary. cfm/state=MT.

[8] U.S. Department of Energy, Energy Information Administration, "Sources of Heating in Montana Homes," *2000 Census* [database on-line] (Washington D.C.: 2005, accessed 28 August 2008); available from http://apps1.eere.energy.gov/states/residential.cfm/state=MT#sources.

[9] Ibid.

[10] U.S. Department of Energy, Energy Information Administration, "Montana," in *Individual State Data* [database on-line] (Washington D.C.: 2003, accessed 15 April 2007); available from http://www.eere.energy.gov/states/state_specific_statistics.cfm/state=MT.

The United States' reliance upon fossil fuels to provide the majority of its energy has stretched our energy portfolio thin, leaving energy security with poor, short-term, or inadequate options. The problems we are facing with energy today are similar to those challenges of the past: how to efficiently produce enough energy when and where we want it. Additionally, as the demand for energy grows, so does the challenge of continuously meeting this demand.

BRIEF HISTORY OF ENERGY IN THE UNITED STATES

Electricity has long captivated the human imagination and ingenuity. The Greek philosopher Thales of Miletus is credited with first recognizing the phenomenon of static electricity some 2600 years ago.[11] Despite this early discovery, it took two and a half millennia for the movement of electrons to be put to a practical use with the advent of the telegraph in the 1840s. However, once the electrical energy infrastructure was developed, electricity has driven the United States' economy and way of life. The ability to convert streams of electrons into a usable form of energy has been hailed as the greatest technical feat in the twentieth century.[12]

The economic growth of industrialized nations and their energy demands simultaneously grew together until the "oil shock" of the 1970s.[13] The United States experienced a national energy crisis, resulting from sharp increases in oil prices and

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[11] Richard Munson, *Edison to Enron* (Westport, Connecticut: Praeger Publishers, 2005), 1.

[12] Ibid., 15.

[13] Jose Goldemberg, *Energy for a Sustainable World* (Washington, D.C.: U. S. Department of Energy, 1987), 1.

supply in 1973-1974, as a result of the Arab oil embargo.[14] A second oil shock occurred again in 1978-1979, as a result of Iranian political and production instability.[15] The energy crises of the 1970s resulted in sudden inflation and economic recession.[16, 17]

Out of this instability grew an awareness of the vulnerability of the energy structure and progressive, alternative energy discourse ensued. A leader of this movement was Amory Lovins, considered the "godfather of alternative energy in the United States and perhaps the world."[18] Lovins advocated the future of energy to be regarded from the perspective of efficiency, conservation, and demand, and encouraged an energy system that relied upon decentralized, small-scale renewable energy.[19] He felt that the solution to the energy scenario lay with, what he termed, the "soft energy path." "The soft path is characterized by renewability, diversity, flexibility, low technology, appropriate scale and geography, and quality. It considers site-specific resource potentials, climatic patterns, energy consumption communities, population density, settlement types, and socio-cultural factors."[20]

The last three decades have undergone a series of heightened energy issues. California experienced electricity price shocks and shortages, the Enron scandal

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[14] Ibid.

[15] Ibid.

[16] U.S. Department of Energy, Energy Information Administration, "Motor Gasoline Consumption 2008: A Historical Perspective and Short−Term Projections" *Short-Term Energy Outlook* (Washington D.C.: U.S. Department of Energy, 2007), 14.

[17] It is important to note that the first energy crisis in 1973 resulted from loss of only 5% of the oil available to the U.S. at that time.

[18] Deborah R. Feder, "Beyond Conventional Energy Use: A Regionally Based End-Use Approach for the Twenty-First Century" (Ph.D. dissertation, The Pennsylvania State University, 2001), 138.

[19] Ibid., 139.

presented a side of the energy industry laden with fraud and corruption, and energy costs and future supply were deemed uncertain under energy deregulation. Terrorist acts have deepened the awareness of our "heavy dependence on energy imports, our vulnerability to oil supply disruptions or price shocks, and the possibility of terrorist attacks on key components of our energy infrastructure."[21]

Events in 2008 have further deepened the energy crisis, showing Americans exactly how vulnerable and volatile our energy practices can be. The average crude oil price was at an all-time high mid-July, 2008, at $134.44 per barrel.[22] This translated to high gasoline prices in the United States, reaching well above $4 a gallon.[23] World demand outweighed supply, straining The United States' economy and putting pressure on other energy supplies, such as natural gas. The 250,000 Montanans who use natural gas to heat their homes will face steep natural gas costs in peak winter months as natural gas prices continue to rise as a result of international demand outweighing supply.[24] June, 2008, natural gas had a peak price of $14.83 per thousand cubic feet, which

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[21] Howard Geller, *Energy Revolution* (Washington D.C.: Island Press, 2003), *ix*.

[22] U.S. Department of Energy, Energy Information Administration. "Weekly United States Spot Price FOB Weighted by Estimated Import Volume" *Petroleum* [database on-line] (Washington D.C.: 2007, accessed 7 September 2008); available from http://tonto.eia.doe.gov/dnav/pet/hist/wtotusaw.htm.

[23] U.S. Department of Energy, Energy Information Administration. "Retail Gasoline Historical Prices" [database on-line] (Washington D.C.: 2007, accessed 5 September 2008); available from http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html.

[24] Mike Dennison, "Expect Expensive Natural Gas This Winter" *The Missoulian* [archived article on-line] (Missoula, Montana: 23 August 2008, accessed on-line November 2008); available from http://www.missoulian.com/articles/2008/06/22/news/local/news02.txt.

translates into at least a 50% increase in home heating costs in the coming winter months.[25]

Furthermore, the exacerbated effects of global warming are creating global changes at an accelerated rate. According to the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC), warming of the world's climate system is "unequivocal," most of the observed increase in globally averaged temperatures since the mid-20th century is "very likely" due to the increase in greenhouse gas concentrations caused by anthropogenic emissions. Additionally, continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate that would "*very likely*" be larger than those observed during the 20th century.[26] NASA reports that there has been a 38% loss in Artic sea ice since 1979, carbon dioxide is up 384 parts per million, sea level has risen 50 mm since 1992, the global temperature is up 1.3 degrees F. since 1895, and the ozone hole now spans 8.5 million square miles.[27]

In light of these contemporary issues, it is evident that there is an increased need for the development of energy efficiency, conservation, and alternative-energy innovation. Energy efficiency and conservation measures are usually more cost-effective than developing and installing any new type of energy system, and it lessens the demand

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[25] U.S. Department of Energy, Energy Information Administration "Montana Natural Gas Residential Price" *Natural Gas* [database on-line] (Washington D.C.: 2008, accessed 15 September 2008); available from http://tonto.eia.doe.gov/dnav/ng/hist/n3010mt3m.htm.

[26] The Intergovernmental Panel on Climate Change (IPCC), "Synthesis Report, Summary for Policymakers" (Valencia, Spain: IPCC, 2007), 1-7.

[27] NASA Jet Propulsion Laboratory, California Institute of Technology, *Global Climate Change Homepage* [database on-line] (Washington, D.C.: 2008, accessed 15 September 2008); available from http://www.nasa.gov/topics/earth/index.html.

for energy, requiring fewer energy generation sites, transmission lines, and systems. There are a number of conservation and efficiency measures for machinery and building functions that deserve a considerable amount of attention, as they should play a major role in the future of energy; however, this discussion falls outside the breadth of this research.

Montana has taken action to increase renewable energy production. In 2005, Montana legislature enacted the Montana Renewables Portfolio Standard (RPS) as part of the Montana Renewable Power Production and Rural Economic Development. The RPS will require public utility companies and competitive electricity suppliers to obtain a percentage of their energy from renewables, including; wind, solar, geothermal, hydroelectric (10 MW or less), landfill, wastewater or farm based methane gas, nontoxic biomass, or fuel cells using renewable fuels. Compliance standards are set at 5% for 2008-2009, 10% from 2010-2014, and 15% by 2015 and thereafter.[28] Renewable Energy Credits may be used to satisfy the requirements and supplies may come from out-of-state. However, by 2010 a portion of the energy must be generated by community renewable energy projects less than 5 MW in size.[29] The Western Renewable Energy Generation Information System (WREGIS) will track and verify compliance. Failure to meet the required renewable energy standards will result in administration fines of $10 per

[28] Montana Department of Environmental Quality, "Montana Incentive for Renewable Energy : Renewable Portfolio Standard" (Helena, Montana: accessed February 2008); available from http://www.deq.mt.gov/energy/renewable/taxincentrenew.asp#69-8-1001.

[29] Ibid.

MWh.[30] NorthWestern Energy, a leading utility provider for Montana, is currently meeting 8% of supplied energy to its customers from an existing contract with Judith Gap Wind Farm.[31] [32]

RELATED RESEARCH

Research has been conducted exemplifying the ability of a geographic region to produce energy to meet local demand by taking advantage of renewable resources. Deborah Feder has contributed to this discussion, having authored two papers on the subject of renewable energy implementation, *A Regionally Based End-Use Strategy: Case Studies from Centre County, Pennsylvania* (2004), and *Beyond Conventional Energy Use: A Regionally Based End-Use Approach for the Twenty-First Century,* (2001).[33] Her method is a regionally based, site specific, end-use approach to energy supplies centered upon geography, resources, and unique social considerations. It is felt that the energy needs of a given region can be met by using multiple renewable energy forms, depending upon the local resources, and can mitigate the consequences of fossil fuel use.

[30] Incentives for Renewables & Efficiency, (IREC), "Renewable Resource Standard: Montana" [database on-line] (Washington D.C.: 2007, accessed February 2008); available from http://www.dsireusa.org/.

[31] Renewable supplies exceeding the required amounts for a time period can be carried forward into future requirements, allowing NorthWestern Energy to meet criteria into 2010.

[32] Personal communication with John Hines, NorthWestern Energy, Chief Supply Officer, 26 February 2008.

[33] The term "end-use" refers to an energy framework which uses the laws of thermodynamics to show how energy demand can be matched with energy supply. It focuses on the "quality" of energy levels necessary to meet an energy need and argues that by appropriately matching energy needs and energy supply, greater efficiency is reached. Feder, "Beyond Conventional Energy," 94.

This idea was taken one step further in Elizabeth Hartsoch's master's thesis, "Renewable Energy in Montana: Resource Potential and Complementarity." Hartsoch's research suggested that Montana has the potential to achieve local, diversified energy production through seasonal complementarity from solar, wind, small-scale hydro, biomass, and geothermal forms.[34] Complementary energy systems are described as "the opposing availability of seasonal resources that can result in higher and more continuous availability of local resources for electric and heat-energy generation. Insolation, which is seasonally high in the summer and low in the winter, may complement wind, which is seasonally high in the winter and low in the summer. High stream flows in the spring provide a third complement."[35] Results showed that "wind and watercourse resources are widely available, and in many cases compliment each other spatially as well as seasonally."[36]

Many studies have been conducted that analyze the potential for energy generation through an interconnected renewable energy system. Scientists at Stanford University and The Rocky Mountain Institute have shown that reliable, stable electric power can be achieved by the connection of multiple renewable production sites through transmission corridors. *Supply Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms*, by Cristina Archer and Mark Jacobson, discuss the reduction of wind power variability through geographical dispersion.[37] Their

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[34] Hartsoch, "Resource Potential and Complementarity," 2.

[35] Ibid.

[36] Ibid., 63.

analysis suggests that it is beneficial for several wind turbines to contribute to a reliable energy source. *Intermittent Renewables in the Next Generation Utility*, by Lena Hansen and Jonah Levine from the Rocky Mountain Institute, further highlight the potential for firm wind power through interconnected corridors.[38]

Economics and policy are central to the development and deployment of any energy system; however, because of the importance and complexity of a thorough investigation of these two topics, they fall outside of the scope of this paper and will not be addressed at length.

PURPOSE STATEMENT

This research project is a continuation of the research outlined by Elizabeth Hartsoch in her master's thesis "Renewable Energy in Montana: Resource Potential and Complementarity," under the guidance of Jeffrey Gritzner. The aim of the research conducted on renewable energy in Montana is to develop a comprehensive evaluation of the potential for renewable energy development within the state, based upon distributed generation facilities and seasonal complementarity.

The purpose of this research project is to investigate the innovation in renewable energy technology, and to illustrate the potential success of these implemented systems to produce reliable, clean energy. It is through diverse, sustainable energy systems that Montanans can protect their environment and health, while maintaining a high quality of life.

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[37] Christina Archer and Mark Jacobson, "Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms" *Journal of Applied Meteorology and Climatology*, vol. 46, (2007).

[38] Lena Hansen and Jonah Levine, "Intermittent Renewables in the Next Generation Utility," (Boulder, CO: Rocky Mountain Institute, 2008).

CHAPTER THREE

CURRENT PRODUCTION AND POTENTIAL

In 2005, it was estimated that Montanans used 75,771 billion BTUs for domestic electrical and heating purposes.[39] Conventional energy sources, such as coal, natural gas, petroleum, and large-scale hydropower, have been the primary sources of energy generation. However, the potential to provide more energy from alternative sources is available. The diverse geographical terrain of Montana offers several renewable energy resources across the state.[40]

Solar

Solar energy provides an enormous amount of energy. This energy is primarily unrecorded as it is radiant heat that warms the planet and supports life on earth. Solar insolation is also indirectly responsible for the natural phenomena that manifest in other forms of renewable energy, including wind, hydro, wave, and biomass.

Thermal and electrical energy from solar insolation has high potential in Montana. According to data from the National Renewable Energy Laboratory released in 2002, the

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[39] U.S. Department of Energy, Energy Information Administration, "Montana State Energy Profile" [database on-line] (Washington D.C.: 2008, accessed 16 September 2008); available from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=MT.

[40] Several studies have been conducted on the spatial availability of renewable energy resources in Montana. Refer to Hartsoch (2004) or *Renewable Energy Atlas of the West* (2002) for spatial analysis.

electricity generation potential from solar insolation in Montana is estimated to be 101 million MWh/yr.[41] Passive solar technology is also promising for energy conservation in Montana through smart home and building designs that best take advantage of solar insolation throughout the year. Active thermal collectors can also supply domestic hot water or be used for space-heating, further reducing energy demands.

Wind

The warming of equatorial air from solar insolation creates wind currents that travel from warmer to cooler regions, as a result of atmospheric pressure variation. Discrepancies in wind patterns are also affected by local conditions resulting from topological variations in oceanic and mountainous regions, as seen in the Rocky Mountains.

Wind energy has been used for over a century in Montana. Remote areas used windmills to pump water for household use and livestock. In the 1930s, rural America depended on wind power to generate energy for lighting and stored surplus energy in batteries. Today, wind is the largest contributor of renewable energy in the United States and Montana. Additionally, the horizontal axis wind turbine, HAWT, is thought to be the most mature renewable system available today (Figure, 1).[42]

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[41] Land and Water Fund of the Rockies, "Montana Renewable Energy Resource" *The Renewable Energy Atlas of the West: A Guide to the Regions Resource Potential* (Boulder: Hewlett Foundation and The Energy Foundation, 2002), 45.

[42] David Lemieux, Mechanical Engineering Specialist, Montana Department of Environmental Quality, personal communication 2 February 2008.

Figure 1. Horizontal Axis Wind Turbine (HAWT).

Wind systems contributed 1.5%, or 436,000 MWh, of the total energy produced in Montana in 2006.[43] It is estimated that the potential electrical generation from wind in Montana is 1,020 million MWh/yr.[44] The western Rocky Mountain foothills, mountains, and the eastern plains "offer abundant opportunities for small-scale and commercial-scale wind development."[45] Additionally, the *Renewable Energy Atlas of the West* also ranked Montana as the leading wind-resource state in the Western United States, with 17 million acres of windy land.[46]

Small-scale Hydro

Another source of renewable energy resulting from solar insolation is hydropower. The evaporated water is redistributed around the earth in the form of precipitation. Hydropower is currently a huge contributor to energy generated in Montana. However, the vast majority of this energy is produced from large-scale systems (>30 MW).

Like all energy systems in use today, large-scale hydro energy production facilities have their pros and cons. Since kinetic energy is converted in the process, there

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[43] U.S. Department of Energy, Energy Information Administration, "Montana Renewable Energy Electricity Profile" [database on-line] (Washington D.C.: 2008, accessed 16 September 2008); available from http://www.eia.doe.gov/cneaf/solar.renewables/page/state_profiles/montana.html.

[44] Land and Water Fund of the Rockies, *The Renewable Energy Atlas of the West*, 44.

[45] Ibid.

[46] Ibid.

is no combustion of a medium to release energy, as with fossil fuels or biomass, thereby limiting air-borne pollution and immediate CO^2 emission concerns. However, large-scale hydropower generation is not considered sustainable, owing to the environmental concerns of population displacement, ecological disturbances, the stored greenhouse gas methane, and the potential for dam failure.

Within this study small-scale hydro power will refer to all facilities with generation capacity lower than 30 MW, and is considered a renewable, sustainable resource.[47] Montana's small-scale hydropower potential is largely untapped. The Idaho National Engineering and Environmental Laboratory published a report on low head / low power resources in 2003. "Low head" indicates areas with rivers with less than thirty feet of head, while "low power" assumes a generation capacity of less than one MW.[48] The report estimates the small-scale development of the state's hydropower to be roughly 1500 MW.

Biomass

Energy derived from organic materials is referred to as "bioenergy." The earth's living matter, or biomass, is a store of the sun's energy through photosynthesis. The combustion of biomass releases heat that can be converted into a desired form of energy. Biofuels have received a lot of press recently for their potential to replace gasoline for transportation. This study focuses on bioenergy sources and products that serve domestic

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[47] Hartsoch, "Resource Potential and Complementarity," 11-12.

[48] Douglas G. Hall, Shane J. Cherry, Kelly S. Reeves, Randy D. Lee, Gregory R. Carroll, and Garold L. Sommers, *Hydropower Potential of the United States with Emphasis on Low Head/Low Power Resources* (Washington D.C.: United States Department of Energy, 2003), v, DOE/ID-11111.

heating and electrical demands. Although the use of biomass in the transportation sector is an important and timely subject, it falls outside the scope of this study. It is important to note, however, that there has been a considerable amount of research conducted on alternative fuels in the past. As is suggested by the extensive list of 1562 citations from publications found in the 1946 bulletin, *The Technical Literature of Agricultural Motor Fuels*, biofuel technology is not new, nor should it be considered as a high-risk, experimental option.[49] This can hold true for other renewable forms of energy, as their historical use and documented research should have value in today's discussions.

Biomass has long stood as the essential fuel for heat, light, and transportation. Biomass serves as the very energy that sustains human life, from both direct consumption or indirectly from animal proteins and fats. People have also long burned biomass for heat and light. Biomass is still the leading energy source for many people where the gathering of plant and waste materials provide fuels for daily activities.

The contribution of biomass to the energy portfolio could be considerable if waste from the farming, ranching, and forestry sectors were largely incorporated. In 2006, the Energy Information Administration found 66,129 thousand kWh of energy was derived from wood and fuels such as agriculture byproducts and crops, sludge waste, and other biomass solids, liquids and gases.[50] The *Renewable Energy Atlas of the West* reported that the total energy potential from biomass residue in Montana was 6 million MWh/yr.[51]

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[49] United States Department of Agriculture, *The Technical Literature of Agricultural Motor Fuels,* Bibliographical Bulletin No. 10, (Washington D.C.: Government Printing Office, 1949).

[50] Department of Energy, Energy Information Administration, "Total Renewable Net Summer Capacity by Energy Source and State" *Renewable and Alternate Fuels* [database on-line] (Washington D.C.: 2008, accessed 18 September 2008); available from http://www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends/

Geothermal

Geothermal energy is the only renewable resource available in Montana that is independent of the sun. It is produced when thermal energy from Earth's core naturally rises to Earth's surface where the crust is relatively thin: usually along fault lines or fracture zones. Steam and water make their way to the surface through these cracks in the surface.

Geothermal heat has long been used in Montana, and has been harnessed for space heating, agriculture, aquaculture, and other industrial processes. Natural hot springs are the most common application of geothermal waters in the state, with nearly twenty of Montana's recreation facilities using the hot water to heat pools and buildings.[52] It is estimated that 77,000 MWh of thermal energy could be produced from statewide geothermal resources.[53] Electricity generation can also be a product of high temperature geothermal heat.

Montana has a number of hot springs, with the majority in the mountain valleys of the southwest where many fault lines occur. Geological conditions in Montana's "hot spots" are primarily low-enthalpy resources (<100°C) and only 12% reaching temperatures above 50°C.[54] Geothermal waters with low temperatures are best applied to

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rea_prereport.html.

[51] Land and Water Fund of the Rockies, *The Renewable Energy Atlas of the West*, 46.

[52] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "GeoPowering the West: Montana State Profile" [database on-line] (Washington D.C.: 2008, accessed 22 September 2008); available from http://www1.eere.energy.gov/geothermal/gpw/profile_montana.html.

[53] Ibid.

[54] John Metesh, "Geothermal Springs and Wells in Montana" Open-file Report No. 415, (Butte: Montana Bureau of Mines and Geology, 2000), 17.

direct-use heating. However, the Geo-Heat Center identified eighteen communities in Montana that are within 5 miles of a geothermal heat source with a temperature of at least 50°C.[55] Another study, by the Montana Bureau of Mines and Geology, identified five priority spots (Bozeman, Butte, Ennis, Boulder, and Camas Prairie) with geothermal potential in close proximity to population centers.[56]

[55] U.S. Department of Energy, "GeoPowering the West: Montana State Profile," 2008.

[56] Metesh, "Geothermal Springs and Wells in Montana," 21-3.

CHAPTER FOUR

RENEWABLE ENERGY AT WORK: CASE STUDIES

Renewable resources have served the energy needs of civilizations for centuries. It is through continued discoveries and technological advances that energy systems have evolved into what they are today. The advancement of energy systems developed from a body of knowledge fed from past successes and failures. Renewable systems are no different. The technology has developed over the centuries, compounded by information and technology from numerous sources.

To understand the current state of renewable energy technology and how it can best fit Montana's needs, we can look to a variety of resources. Existing infrastructure is an excellent reference. It allows us to critique an energy system without the capital investment. Second, existing systems using current technology are often highly successful for the end-user. These systems can serve as a guide for considerations when determining many aspects of a facility, from the technology incorporated to geospatial placement. Lastly, when consideration is given to changing the energy system that thousands of people and businesses count on, it is responsible to have tested, reliable systems as models.

This chapter will provide examples of energy systems supplied by solar, wind, small-scale hydro, biomass, and geothermal resources currently found within Montana.

These systems can serve as guides for future energy generation sites, produced for Montanans from local resources.

Solar

Montanans are finding solar energy a viable source of energy for their homes, businesses, schools, community centers, farms, and ranches. Montana Green Power has recorded nearly two-hundred solar energy systems in operation across the state as a result of the Universal Systems Benefits (USB) fund administered by NorthWestern Energy; including power generation from twenty-seven schools, ten community buildings, twenty fire stations, ten senior meals facilities, at least one-hundred homes, and six stock watering systems.[57] Sixteen residential solar hot water systems, seven solar thermal units, and at least ten other non-specified applications are also in operation.[58] Community solar projects have been developed across the state to demonstrate the feasibility of working solar energy systems. These projects have provided experience with net metering, contributed to green energy production, and therefore lessen the demand for non-renewable forms of energy, and serve as learning tools for communities. The Sun4Schools and Fire Station Solar Electric Demonstration are two examples of USB funded projects developed to promote green electricity production in the Montana Power Company territory.

The Sun4Schools project resulted in the installation of 2 kW PV systems at twenty-seven schools. The installed PV panels are flat-plate multicrystalline silicon cells,

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[57] Montana Green Power, *Solar USB Installations: USB Solar Installation Numbers Growing* [database on-line] (Butte: NCAT, accessed 25 February 2008.), available from http://www.montanagreenpower.com/USB_installations.html.

[58] Ibid.

with the peak output of approximately 2 kW. The PV panels are roof or pole mounted at a 45 degree angle facing south and capable of withstanding winds of 90 mph. The modules have a UL 1703 test rating and are guaranteed by the manufacturer to produce 90% of the rated power for ten years and 80% for twenty. Each system is expected to generate roughly 3,000 kWh/year, of which 1000 kWh will be provided to the grid and 2,000 kWh will be used directly by the schools. The cost of energy produced is about $0.24 per kWh.

In addition to the solar panels, the system is comprised of corrosion-resistant steel or aluminum mounts, and disconnect switches. It also has an inverter that allows for grid connection. The system contains maximum power point tracking (for maximum energy production from the cells), islanding protection (to prevent the inverter from shutting down if it does not detect the grid in error), over or under voltage disconnect, over or under frequency disconnect, automatic fault condition reset for loss of grid and voltage or frequency variations, ground fault interrupter (GFI) protection (to prevent shock), AC and DC disconnect switches (to shut down the system for maintenance or in emergencies), communications adapter for PC connection/monitoring, as well as a five-year warranty.[59]

The Fire Station Solar Electric Demonstration Project resulted in twenty fire stations outfitted with solar power between 2001 and 2005. The solar energy systems are beneficial for several reasons; they save taxpayers money by eliminating the need for fossil fuel consumption; they serve as an educational tool for firefighters and their

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[59] Montana Green Power, *Sun 4 Schools Project* [database on-line] (Butte: NCAT, accessed 25 February 2008); available from http://www.montanagreenpower.com/solar/schools/sun4schools.html.

communities; and they have back-up batteries that would operate in the occurrence of a power outage. Additionally, the systems are grid integrated, range in capacity size from 1.98 – 4.8 kW, and are located across the state.

Missoula Fire Station No. 4 was the first facility installation and produces approximately 6,500 kWh annually.[60] There are 40 Kyocera 120 watt panels, thirty-two of which are roof mounted and eight are pole mounted on a Zomeworks tracker. To keep the batteries charged, energy is routed through four RV Solar Boost 3048 charge controllers. The power is then routed through the inverter and made available for the stations electrical needs. The excess energy is passed on to the grid. The batteries are high capacity Surrete 4KS – 21 PS 4-volt batteries. Twelve of these batteries make up the battery pack, to supply 1104 amp hours at 48 volts, and is enough energy to operate critical station functions of opening doors, operating lights, radios, and computers for six hours.[61] Diesel power will back up the system in the occurrence of an extended outage.

Ranchers are also able to adapt solar power to serve their needs in remote areas. Two Lower Musselshell Ranches in eastern Montana have adapted gas stock water pumps to use solar power. Solar Jack SDS-Q-128 pumps were installed, along with PCA10-30B controllers (to protect the pump from high or low voltage conditions and maximizes the amount of water pumped in less than ideal light conditions).[62] One site uses two 80-watt Kyocera panels and is able to produce 1,000 gallons a day for the eight

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[60] Ed Brunvold "Missoula Fire Station Goes Solar" *Montana Green Power* [article on-line] (Butte: NCAT, accessed 15 October, 2008), available from ttp://www.montanagreenpower.com/solar/projects/missoulafs.html.

[61] Ibid.

[62] Montana Green Power, "Solar Pumps Replace Gas Power on Lower Musselshell Ranches" [article on-line] (Butte: NCAT, accessed 15 October 2008); available from http://www.montanagreenpower.com/solar/projects/musselshell.html.

available grazing months.[63] The other site uses two 100-watt panels and can produce at least 2,000 gallons a day.[64] Both sites are reported as working well for their purposes.

Wind

Wind power is currently being generated at large-scale commercial sites and from private or community systems across Montana. Montana Green Power, a Montana renewable energy website hosted by NCAT, acknowledges that wind power installation capacity is nearly 900 kW from 86 systems owned and operated by homeowners, businesses, ranchers, farmers, and communities across the state. [65] Many of these systems were partially financed through the Universal System Benefits (USB) fund administered by NorthWestern Energy. Additionally, roughly 900 MW of wind energy developments are being perused, primarily along a swath of central Montana, stretching from Big Timber north to Shelby, an area buffeted by strong winds coming off the Rocky Mountains and onto the Great Plains. [66]

Among the utility-scale wind farms are Judith Gap, with a maximum capacity of 9 MW in Wheatland County, and Cascade County's Horseshoe Bend Wind Park, with an operating capacity of 9 MW. Other utility scale sites are also under serious consideration for development. The Martinsdale Wind Power Project in central Montana,

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[63] Ibid.

[64] Ibid.

[65] Montana Green Power, "Montana Wind Installations Near 900 Kilowatts" [database on-line] (Butte: NCAT, accessed 6 October 2008); available from http://www.montanagreenpower.com/wind/mtinstallations.html.

[66] Matthew Brown, "Wind Farm Proposed for Central Montana," *San Francisco Chronicle*, 3 February 2008), sec. B, 1.

approximately 20 miles west of Harlowton, would initially consist of thirty turbines, and could possibly expand to one-hundred turbines, and generate up to 300MW. Additionally, the would-be Springdale Wind Farm proposes to install six to ten turbines on State School Trust Land in Eastern Sweet Grass County. Research on community response and environmental impact statements are being conducted.[67]

The Blackfeet Reservation experiences powerful winds, with an estimated wind energy potential of 3,900 MW.[68] The remote location and lack of transmission lines in this region make it difficult for utility installations, but two local projects are proving to be beneficial for local applications and demonstrate the potential for future developments. Both projects were funded by the Department of Energy as demonstration projects for utility scale installations.

The Blackfeet Community College was awarded a $225,000 grant from the DOE in 1995 for a wind turbine. A grid-connected V-17 100 kW Vestas turbine was erected as a demonstration project, learning tool, and employment stimulus. The project lasted from 1995-1998 and generated 181,824 kWh, providing most of the college's electricity needs for the time.[69] The power generated from the turbine was purchased by Glacier Electric Cooperative, Inc.(GEC), at a rate of $0.027 per kWh, half of the retail price of energy in GEC territory.[70] The system is still in operation today and the electricity generated by the

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[67] Montana Department of Natural Resource Conservation, "Springdale Wind Farm" [database on-line] (Helena: Montana's Official State Website MT.GOV, accessed 6 October 2008); available from http://dnrc.mt.gov/trust/wind/springdale.asp.

[68] Native American Wind Interest Group Newsletter, "Blackfeet Wind Projects Provide Foundation for Future Development" *Wind Powering America* (Washington D.C.: U.S. Department of Energy, Spring 2004), 2-3.

[69] Ibid, 2.

turbine is now purchased at avoided cost (the cost the utility would have incurred had it supplied the power itself or obtained it from another source) and is credited against the Blackfeet Community College's electric bills.

The second demonstration project was set up at the Browning Wastewater Treatment Center. The installation of four Bergey Excel 10-kW wind turbines was also funded in part by a grant from the DOE. This pilot study ran from 1999-2000 and was installed with local labor and is used to generate power directly for the city's sewage treatment center. The turbines are grid-tied, but the project was directed to have the facility as the primary consumer of the wind power on-site. One-quarter of the power needed to run the waste treatment plant is supplied from the turbines, displacing energy otherwise obtained from the grid.[71]

Small-Scale Hydro

As previously noted, hydropower accounts for a considerable amount of energy produced and consumed in Montana. Water systems have historically provided power for irrigation and mining, turned sawmill blades, and generated electricity for remote farms, homesteads, and factories within the state.[72] While most large hydropower sources have been tapped, small-scale sites still exist across Montana with varying degrees of energy potential and end uses.

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[70] Ibid.

[71] Ibid.

[72] Montana Green Power, *Hydropower* [database on-line] (Butte: NCAT, accessed 9 December 2008); available from http://www.montanagreenpower.com/renewables/hydropower/index.html.

Figure 2. Run of the River Facility (DOE: EERE).

A great example of a small-hydro system can be found north of Vancouver, British Columbia, outside of Squamish. The Upper Mamquam project is a run of the river system that relies on the natural downward flow of a controlled water source, over a vertical drop, which ultimately turns turbines to produce electricity (Figure 2). (Refer to "Small-Scale Hydropower" in Chapter Five for a more in-depth explanation of hydropower technology and run of the river systems.) The facility has a generating capacity of 25 MW, and produces 103,000 MWh a year.[73] The site has an intake upstream from a 50 foot waterfall, and is capable of handling 513 million gallons of water per day (27 cubic meters per second).[74] Small holes on the intake screen prevent fish from passing through the intake. The water travels through 4,166 feet of low pressure penstock, and is then fed into a high pressure vertical penstock, with 442 feet of it tunneled under a rock wall to the powerhouse down stream. The powerhouse is equipped with two Horizontal Francis turbines ideal for the 357 feet of head (vertical distance of water travels). The water returns to the river after passing through the powerhouse. The facility is unique in that it is upstream from another run of

[73] Canadian Hydro Developers, Inc, *Upper Mamquam Hydroelectric Plant* [database on-line] (Alberta: Canadian Hydro Developers, Inc., accesses 9 December 2008); available from http://www.canhydro.com/pdf/PlantProfiles/Upper_Mamquam.pdf.

[74] Tony Kryanowski, "A River Runs Through It" [article on-line] (Vancouver: *ener G: Alternative Sources Magazine*, Issue 8, accessed 9 December 2008); available from http://www.altenerg.com/issue08art04.aspx.

the river hydro plant, and is in close proximity to the urban area Sqaumish, approximately six miles away.

The Upper Mamquam Hydroelectric Plant was developed by Canadian Hydro Developers, Inc. for $33 million.[75] The plant has a twenty-year agreement to supply power to BC Hydro, the third largest utility company in Canada. Another interesting aspect of this small developer is that Canadian Hydro uses a business model to ensure project economic sustainability by operating on a 65% debt to 35% equity ratio.[76] This ensures that a project will stay afloat even if hydrologic systems have low output years.

Biomass

Many industries in Montana result in waste products with little or no market value. Several domestic wastes are being investigated for their energy generation potential, which in turn add value to waste materials and create an alternative, emission neutral energy source. Agriculture, ranching, forestry, municipal, and industrial wastes are all showing promise for energy exploitation in the state. Additionally, the geographic dispersion of these many industries across Montana allows communities to appropriately develop local resources. Forestry slash, crop residue, livestock waste, landfill methane, and industrial byproducts can all provide fuel sources capable of providing heat and electricity for consumers with many different end-uses.

The use of biomass as a heating source is proving to be highly beneficial in Montana. The Montana State Fuels for Schools and Beyond program has initiated the use of forest biomass waste to heat eleven public buildings. The program arose from the

[75] Canadian Hydro Developers, Inc., *Upper Mamquam Hydroelectric Plant.*

[76] Kryzanowski, "A River Runs Through It," 2.

need to reduce fire hazard in Montana's forested regions after the devastating wildfires in 2000, which burned 350,000 acres and 70 structures in the Bitterroot Valley.[77] Small diameter and under-utilized woody material are the primary waste materials used to heat nine public school buildings across the state. Two additional buildings are underway and are projected to be completed in 2008 and 2010.

The first pilot project took place in the Darby public schools in 2003. Funding and assistance from the Economic Action Program, Biomass Energy Resource Center, and the US Forest Service Forest Products Laboratory resulted in the installation of a biomass broiler system. The estimated annual savings for the Darby schools has paid off. The switch from fuel oil to forest waste has resulted in huge annual savings of $90,000 from fuel and operational costs.

The Montana Fuels for Schools and Beyond Projects operated in three phases, providing an excellent model for deployment and success of a renewable energy conversion project. The initial project in Darby, and two other installations in Victor and Philipsburg school systems, were part of "Phase 1: Demonstration," were fully funded, and served as demonstration projects to illustrate operational successes. This phase also included the expansion of biomass in several more public buildings to show different applications of biomass heat including, the first college campus at UM Western in Dillion, two demonstrations that would burn 'all tree' pellets made from slash wood waste, and the first new government construction project to incorporate biomass systems

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[77] Montana Department of Natural Resource Conservation, "The Fuels for Schools and Beyond Program" [database on-line] (Helena: The Official Montana Website, accessed 7 October 2008); available from http://dnrc.mt.gov/forestry/Assistance/Biomass/AboutProgram.asp, 1.

into its design.[78] The second round of grants for "Phase 1" was for $400,000 or 50% of the construction and installation costs.[79] The second phase, "Phase 2: Expansion," sought to increase interest and the incorporation of biomass boiler systems in a wider geographical area. A larger geographical distribution would help make "the processing and delivery of wood fuels more economically viable and efficient."[80] Grants were awarded for 25-35% of the project costs in Phase 2. Outside or private funding has also been identified during this phase to provide additional financial support for these systems. The project is transitioning to "Phase 3: Privatization" in 2008. This phase intends to phase out grant funding from the Forest Service, but they continue to provide technical assistance and support. It is anticipated that private funding will replace government grants and prove profitable, as well as serve as a wise investment for all parties. The overall estimated and actual annual savings from all eleven facilities is $669,500, with approximately 12,750 tons of biomass replacing fuel oil, natural gas, and propane energy sources.[81]

A second form of bioenergy showing promise in Montana is landfill methane generated from municipal waste facilities. The city of Billings and the Montana-Dakota Utilities (MDU) are working to extract landfill methane for utility purposes. Instead of spending close to $1 million a year to remove the poisonous methane gas from its

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[78] Ibid.

[79] Ibid, 2-3.

[80] Ibid, 3.

[81] *The Fuels for Schools and Beyond Program*, "Table of Projects" [database on-line] (Helena: Department of Natural Resource Conservation, Forestry Division, accessed on 7 October 2008); available from http://dnrc.mt.gov/forestry/Assistance/Biomass/Projects/MTprojectstable80608.pdf.

landfill, Billings would in turn be paid fifteen-percent of the gas sales.[82] This could amount to $500,000 a year or more if gas prices hold steady or increase.[83] This deal could prove economically beneficial for both the City of Billings and MDU, as well as make use of an otherwise harmful waste. The contract is pending the results of tests from landfill well sites to ensure methane supply.

Geothermal

The U.S. Department of Energy and The Montana Department of Environmental Quality have developed programs to research and explore geothermal resources across Montana. Researchers feel there is great potential for expanded heating applications and electricity generation. It is estimated the state has 25,000 square miles of high-potential sites and areas for both surface and sub-terrain geothermal water.[84] Over fifty geothermal areas, with more than 300 springs or wells, have been identified and assessed, including at least fifteen high-temperature sites (> 149° C).[85] Low temperature (<100° C) geothermal water near the surface is the most developed source, with nearly twenty

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[82] Matt Hagengruber, "Billings, Montana, City Council OKs Deal for Landfill Gas" *Billings Gazette* 26 August, 2008.

[83] Ibid.

[84] Montana Department of Environmental Quality, *Montana Geothermal* [database on-line] (Helena; Montana's Official State Website, accessed 11 October 2008); available from http://www.deq.mt.gov/energy/geothermal/.

[85] Montana Department of Environmental Quality. "Geothermal Energy Sites" *Montana Geothermal* [database on-line] (Helena; Montana's Official State Website, accessed 11 October 2008); available from http://www.deq.mt.gov/energy/geothermal/sites.asp.

commercial hot spring recreational facilities. Greenhouses, aquaculture, and space heating are also prevalent in high potential areas.[86]

Fairmont Hot Springs is one of the largest hot spring developments in Montana, which uses geothermal heat to warm all of the 106,000 square feet of the resort's four pools, two restaurants, lounge, 158 guest rooms, and 7000 square foot conference center.[87] It is located in Western Montana between Butte and Anaconda, nestled up against the Pintler Wilderness. The water is sourced from several springs discharged into ponds near the resort. The hot water is a result of the Tertiary volcanics associated with the Boulder batholith.[88] An additional source of geothermal water used by the resort comes from a 600 foot well, drilled in 1985. The spring water is discharged from the source at about 760 gallons per minute (gpm) at 62° C (143° F) and the well supplies 180 gpm at 77° C.[89] The water temperature can vary ten degrees, and the flow is reduced in summer months. Water flow rate is controlled by restricting the flow into the pump pipeline using a valve and temperatures are maintained during cold periods, when necessary, by a fuel oil fired broiler.

A 50-hp line shaft pump is used to access the well water, which is then pumped to a central broiler room. From here a forced air system supplies heat to individual rooms. A plate heat exchanger is used to circulate a secondary closed loop system (Figure 3).

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[86] Idaho National Laboratory has produced a geothermal potential and application map of Montana that highlights many of the known developments and resources across the state. It is available online from http://geothermal.inl.gov/maps/mt.jpg.

[87] Geo-Heat Center: Oregon Institute of Technology, "Geothermal Direct Use Case Studies" (Kalamath Falls: Oregon Institute of Technology, October 2005); 21.

[88] Ibid., 21.

[89] Ibid., 21-22.

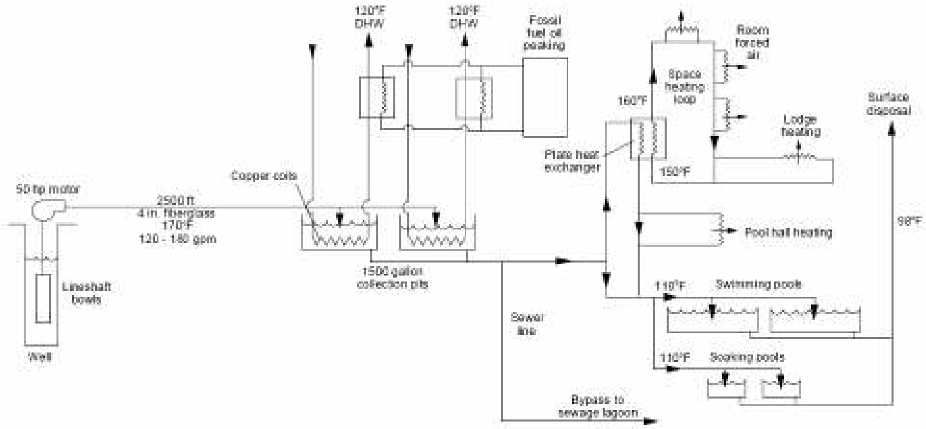

Figure 3. Fairmont Hot Springs Geothermal System Diagram (Geo Heat Center).

Additionally, domestic hot water is supplied from copper coils in the bottom of the collection ponds, typically kept above 49° C. The geothermal water also heats the pools directly. The water is pumped into the four pools at about 43° C (110° F) and exits at approximately 37° C (98° F). Water is discharged into a collection pool near the resort and is used for irrigation. Excess water not used by the facility is bypassed to the local sewer line where it ends in a sewage lagoon.

Fairmont Hot Springs has an estimated $500,000 savings a year from using geothermal heat instead of fuel oil.[90] Electricity needed to operate the pumps and fans necessary to disperse the heat, as well as annual maintenance costs of the system, are both annual expenses incurred. However, considering most operational expenses would

[90] Ibid., 22.

be the same regardless of the energy source, the annual operational costs of the geothermal system alone are about $30,800.[91]

The exploitation of geothermal energy for the generation of electricity also has potential in Montana. High temperatures (>149° C) are favorable for power generation; however, temperatures as low as 103° C (218° F) can also be economical.[92] Interest in developing geothermal resources to produce electricity has gained attention at existing hot spring facilities, as well as the Berkley Pit in Butte, with geothermal heat emanating from deep wells drilled during the days of the Anaconda copper mining complex.[93]

A system better suited for low-temperature resources is known as a Binary Power Plant, which uses a secondary medium that vaporizes at a lower temperature than water. A new 400 kW binary power plant outside Fairbanks, Alaska is an example of a successful geothermal system that uses low-temperature water to produce electricity. The water resource at Chena, Alaska is only 165° F, making it the lowest temperature commercial power plant in the world. A secondary fluid is vaporized by the geothermal heat, which then drives a turbine to produce power. The Chena geothermal power plant has reduced the cost of power production from $0.30 (using a diesel generator) to less than $0.06 per kWh.[94] The key to success for moderate-temperature systems is to make it economical. United Technologies Corporation (UTC) worked with Chena Hot Springs to

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[91] Ibid., 22.

[92] Kim Lyons, "A Regulatory Guide to Geothermal Direct Use Development: Montana" (Olympia: Washington State University Extension Energy Program, 2003), 1.

[93] National Renewable Energy Laboratory, *Geothermal Technologies Program: Montana* (Washington D.C.; U.S. Department of Energy, November 2005), 1.

[94] Chena Hot Springs Resort, "Fact Sheet on the Chena Geothermal Power Plant" [database on-line] (Fairbanks, Alaska: accessed 15 October 2008); available from http://www.chenahotsprings.com/fileadmin/chena/Renewables/power_plant/Power.pdf.

manufacture a system that uses a reverse refrigeration system, from mass produced Carrier chiller components, to dramatically reduce the cost of production while allowing for modular construction.[95] Previously, mid-temperature geothermal systems were tailor made, using custom designed components that increased the cost of development, often making them economically unfeasible. Chapter Five explains the Binary Power Plant in greater depth.

Integrated Systems

In addition to single form energy supplies, integrated systems are also in place around the state. These systems serve to diversify energy sources, thus firming renewable energy supplies year round, and appropriately applying energy to an end-use. For example, a solar PV system may be best applied to generating electricity to run a computer, while the heat energy produced from a biomass broiler may be best used to space heating applications.

Cascade County incorporated conservation, efficiency, and renewable energy into its road and bridge facility, near Vaughn, Montana. The new building replaces a complex "plagued by environmental damage with a modern energy efficient facility."[96] To meet electric and heating needs, the county installed an Entegrity Wind Systems 50 kW wind turbine and a 2 kW solar energy system. It is estimated that the wind turbine will produce 85% of the electricity needed to run the shop and the solar panel will contribute

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[95] Ibid.

[96] Cascade County Wind, "Cascade County Owned Wind Turbine at the New Road Department" *Cascade County Wind Website: Current Projects* [database on-line] (Great Falls: Cascade County Commission, accessed 20 October 2008); available from http://cascadecountywind.com/Projects.html.

to power to operate the sewer pumps for the sewer district.[97] Additionally, waste oil from the county's maintenance shop is used to fuel Laniar HI-260 heaters. These will generate roughly 260,000 BTUH (75 kW) of heat.[98]

Spa Hot Springs Motel in White Sulfur Springs is a business that incorporates several renewable forms of energy available to them. Among the contributing sources are wind, solar, and geothermal energies. The owners of the resort installed a 3 kW Whisper 175 wind turbine, a sixteen-panel solar electric system, and geothermal heat exchangers. The wind turbine produces over 500 kWh each month, in wind speeds averaging around 12 mph.[99] The solar energy system includes two Kyocera 120 W solar modules mounted on Zomeworks tracking systems. Both the wind and solar energy systems are net metered, but are also backed up by twelve batteries capable of running the well pump in the event of a power outage. This is a valuable feature, as it would prevent the water from backing up, potentially contaminating the motel's well. Spa Hot Springs Motel also uses geothermal energy to heat guest rooms, facility space, domestic water, and its hot spring pools.

In addition to public and commercial integrated systems, homeowners are also making use of multiple renewable forms of energy to meet their domestic electric and heating needs. Montana Green Power reports a large family in Manhattan has incorporated solar and hydro systems to contribute to their power supply, in addition to

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[97] Ibid.

[98] Ibid.

[99] Montana Green Power, "Solar, Wind, Geothermal Power on Display at Spa Hot Springs" [article on-line] (Butte: NCAT, accessed 20 October 2008); available from http://www.montanagreenpower.com/solar/projects/WSS.html.

energy conservation measures. Two sets of twelve 100 W Siemens PV panels were installed on Zomeworks trackers, and two 24 V submersible generator Aquair hydro turbines were immersed in a ditch behind the family's home.[100] Compact florescent light bulbs, and new energy-efficient appliances contributed to this household's energy conservation efforts, lessening their energy demands. This family of five was using 33 kWh of grid-fed electricity daily, but now has reduced that consumption to 2.5 kWh a day.[101]

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[100] Montana Green Power, "Manhattan Family Uses Sun, Water to Achieve Near Grid Independence" [database on-line] (Butte: NCAT, accessed 20 October 2008); available from http://www.montanagreenpower.com/solar/projects/manhattan.html.

[101] Ibid.

CHAPTER FIVE

TECHNOLOGY

The advancement of renewable energy technology continues to evolve as the collective understanding of renewable energies advances. To meet the growing demand for renewable energy integration, companies are designing technology to efficiently harness energy, while ensuring safe, sustainable, and cost-effective energy systems. Present day technology used to convert solar, wind, hydro, biomass, and geothermal sources are effectively generating clean, reliable power around the world. With continued investment in research and development, these systems and emerging technologies will become more competitive with traditional energy systems. Furthermore, as the industry matures, cost reductions will be seen as a result of learning effects, marginal technology improvements, and economies of scale.[102]

This chapter intends to address advances in renewable energy technology that has, or is intended to, improve energy generation potential from a given source as it is best applied to Montana's resources. There are many aspects to renewable energy technology development and integration. This paper focuses is on energy conversion technology. Solar, wind, small-scale hydro, biomass, and geothermal technologies are assessed with the purpose of identifying key technical innovations in the energy conversion process that would ensure their successful implementation. This chapter also intends to show that the

[102] José Goldemberg et. Al, "Overview" *World Energy Assessment: Energy and the Challenge of Sustainability* (Washington D.C.: United Nations Development, September 2000), 14.

current state of renewable energy technology is appropriate to use to meet Montanans' energy needs.

Solar

Solar energy is used for heating and electricity generation purposes. Low temperature solar energy can be used to heat water for domestic use or for swimming pools, and can provide space heating through a variety of active and passive methods, making use of a variety of technologies. There are several technological advances and engineering concepts that make solar heating applicable in Montana; however, the focus of this study is on the electricity generation technologies of photovoltaics (PV), and PV's ability to supply energy for residential and remote access uses. Therefore, PV technology has been highlighted for its ability to currently supply energy, as well as for its highly promising future.

Photovoltaics (PV) are a direct method of generating electricity from solar radiation. A PV system uses PV cells to create an electrical stream from the photons that comprise sunlight. PV cells are made of semiconducting materials, most commonly silicon, to create an electric field between two layers of the semiconductor materials. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce an electric current.

There are three phases of solar cell technology development, know as the first, second, and third generations. Presently there is concurrent research in all three phases, but the first generation silicon based PV cells are the most common, accounting for nearly 90% of PV production.[103] Cost and efficiency are two main issues that the solar industry is having difficulty with. Currently, high quality silicon semiconductors are capable of efficiencies of 30%; however, the cost of $3.50 per watt makes these systems less competitive with fossil fuels. On the other hand, easier and cheaper manufacturing techniques, such as polycrystalline silicon, lower costs at the expense of efficiency.

The first generation PV cells consist of large-area wafer solar cells, high quality silicon based semiconductors, and single junction devices (only one electric field). These are characterized as having high energy and labor inputs, with long payback times, thereby limiting their cost reduction potential. Efficiency for first-generation PV cells is anywhere from 10% to 15%, assuming standard conditions.[104] Crystalline silicon solar cells are the most common solar modules sold today and are the type of solar modules most commonly found in Montana. These are the rectangular rooftop and pole mounts we know as solar panels. The silicon that is most often obtained from the microelectronics industry as "off-grade silicon," is inadequate for use in electronics, but is appropriate for solar cells. The silicon is purified and crystallized to form "solar grade" silicon. This process can be highly energy intensive and has a payback time of four years to recover the energy necessary to manufacture the solar cell.[105]

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[103] Alvin D. Compaan, "Photovoltaics: Clean Power for the 21st Century" (New York: Elsevier, *Solar Energy Materials & Solar Cells*, vol. 90, 2006), 2170-2180.

[104] Wim C. Turkenburg, "Renewable Energy Technologies" *World Energy Assessment: Energy and the Challenge of Sustainability* (Washington D.C.: United Nations Development, September 2000), 236.

[105] U.S. Department of Energy: Energy Efficiency and Renewable Energy, "PV Faqs" [database on-line] (Washington D.C.: DOE, 2004, accessed 11 November 2008); available from http://www.nrel.gov/docs/fy05osti/37322.pdf.

Second generation PV is characterized by "thin-film" technology that has been developed to address energy requirements and production costs of solar cells. Thin film cells are comprised of semiconductors made from a variety of materials capable of conducting an electrical current and are made from thin material layers ranging from fractions of a nanometre to several micrometres in thickness. A film of the semiconductors is deposited directly onto a substrate (glass, stainless steel, plastic), thus reducing manufacturing costs from the reduction of semiconductor material costs. Second generation thin-film solar cells can produce energy for less than $1 per watt, but the efficiencies are typically less than 10%, owing to the imperfections characteristic of semiconductor material and application methods (Figure 4).[106] However, the payback period for thin film could be as low as 1 to 2 years.[107] Emerging technologies are testing cadmium telluride, copper indium gallium selenide, amorphous silicon, and micromorphous silicon as semiconductor materials, with a few available on the market. The variability and flexibility of substrate materials is also promising for the many new locations available for non-traditional solar modules, such as building siding.

Third-generation solar cells aim to combine the cost effective manufacturing techniques of the second-generation with the high efficiencies seen by the first-generation of solar cells. It is hoped efficiencies of 20% to 60% could be achieved, while lower manufacturing costs to see less than $0.50 per watt (Figure 4). Several techniques being pursued in third-generation research aim to increase the efficiency of a system by absorbing sunlight photons on many levels using different semiconductors. Single

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[106] Note that the efficiencies recorded were achieved in lab conditions.

[107] DOE, "PV Faqs."

semiconductors will only absorb photon energies within their spectrum range, creating losses on both sides of the absorbed spectrum (for silicon the higher energy photons on the blue end of the spectrum are absorbed). Silicon looses high frequency photons as heat in the device. Researchers are developing “hot carrier cells” to absorb this energy before it is lost. On the other end, low frequency photons near the red end of the spectrum are not absorbed at all and are completely wasted. Devices to “up-convert” low frequency photons are also under development. In third-generation solar developments, much attention is being given to solor collector innovation at the nano and microscopic levels, through nanotechnology. Third-generation products could be included into several mediums, making the potential for solor collector placement endless. Cloth, paint, and other flexible materials are just some of the possibilies.

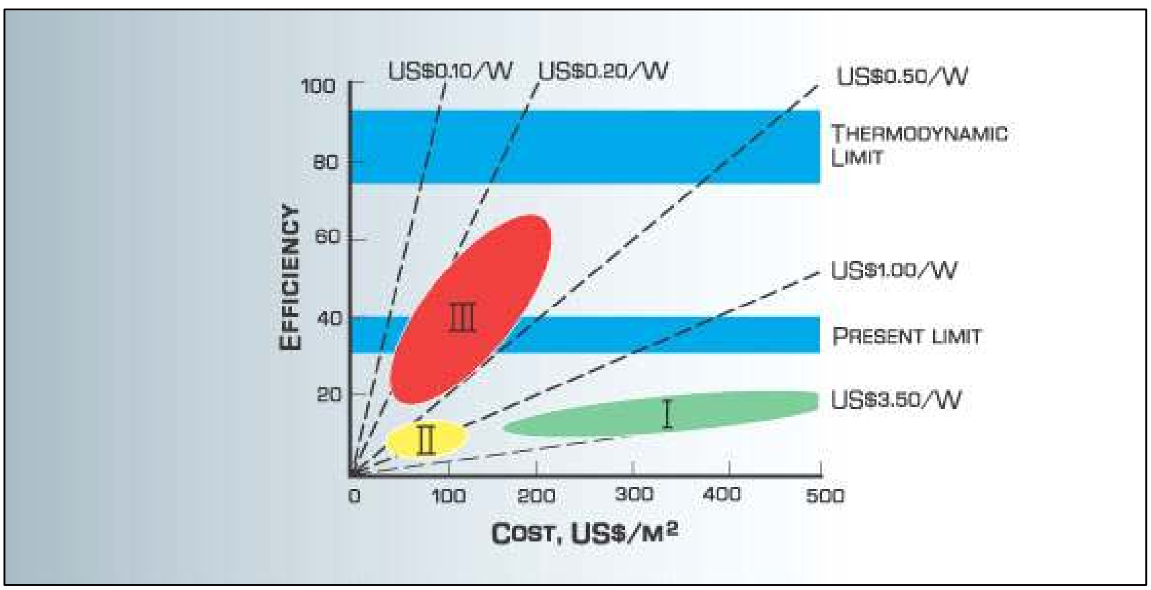

Figure 4. Efficiency and Cost Projections for First, Second, and Third-Generation PV Technology (School of PV and Renewable Energy Engineering).

Another type of solar energy system that is promising is the solar concentrator that uses a Stirling engine to convert solar energy into mechanical or electrical power. The solar concentrators are often dish or trough shaped to reflect solar radiation to a single receiving point or line, where a medium is heated to power an engine. The medium used in a Stirling engine is a gas such as air, helium, hydrogen, or nitrogen.

Benefits of the Stirling engine are that it is easily maintained, it operates quietly, and it has high efficiencies. Another benefit of the Stirling engine, as opposed to an internal combustion engine, is that it has the potential to use any heat source that is immediately available. This makes it highly compatible with renewable energy sources such as solar, geothermal, or biomass forms. Stirling engines can be supplied with heat from the combustion of a fuel source, but any heat source can be used including solar, geothermal, or waste heat from combustion in a cogeneration scenario. Therefore, emissions can be lowered or eliminated.

The Stirling engine relies on a heat source to heat the gas inside the heating chamber where the work is done in the Stirling engine. The gas then expands, creating pressure in the chamber. The heated gas then forces the piston down in the cooling chamber and consequently up in the heating chamber. The gas is then cooled in the cooling chamber, typically from an ambient temperature air or water source. The piston in the cooling chamber then forces the cooled gas back into the heating chamber, where it is once again heated and the cycle repeats itself. As the pistons move up and down, they turn a crankshaft that runs a generator to produce electricity or produces mechanical power.

Wind

Montana has a long standing relationship with wind energy, and many forms and applications of its technology have been used in the past. Historically, wind power has been used for for many purposes, including timber milling, rural electrical production, as seen in the 1940's, and remote water pumping stations that used windmills. Today, off-line and net-metered electricity generating turbines further demonstrate the evolution of wind technology and the continued efforts to develop this ample renewable resource.

Wind energy technology has continued to advance, as it has experienced a "continuous chain of incremental improvements based on experience."[108] In the 1970s, wind energy was first seriously considered for utility-scale production of electricity. Since then, great improvements in performance and efficiencies have been made through innovation in design. Wind turbine rotor efficiency is up at least 20% since the 1980s and the technical availability of a turbine to operate is at 98%.[109] Maximizing the turbine's ability to convert wind energy is the key driver in wind technology research and design. Improvments in wind pattern prediction models are an important part of maximizing energy obtained from the wind, but owing to the complexity and importance of a thorough inquiry into the subject, wind system site planning falls outside the scope of this research project.

Turbine size is related to the intended purpose of the energy produced. Residential scale (400 W to 50 kW per turbine), industrial scale (50 kW to 250 kW), and utility scale (900 kW to 2 MW) all have potential for further development in Montana.

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[108] Ahmet Duran Şahin, "Progress and Recent Trends in Wind Energy" *Progress in Energy and Combustion Science*, vol. 30, (2004): 501.

[109] Ibid.

Similarly, the requirements of the technology used at a particular site are ideally determined by its ability to extract the greatest amount of energy from the available wind resource; however, it is generally accepted that the larger the turbine, the greater the energy output. This is due to greater availability of wind resources at higher measurements and the efficiency of blade length to capture a resource (Figures 5 and 6).

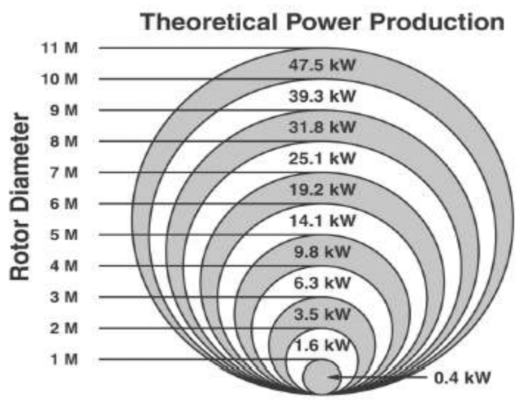

Figure 5. Theoretical Power Production for Small Wind Turbines When the Wind Speed is 10 m/s (DOE).

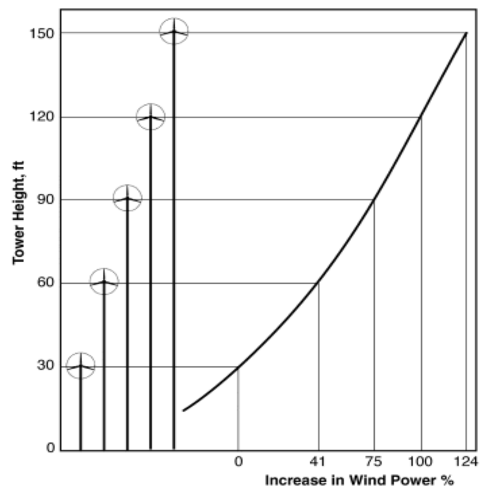

Figure 6. Wind Speed Increases with Height (DOE).

There are several types of wind turbines in use today; however, the horizontal axis, three blade turbine has been widely adopted as the system of choice. Wind turbines produce power at wind speeds between 9 mph and 56 mph, and a good wind energy site will produce its total operating capacity 35%, averaged over a year.[110] The goal of future developments is to increase wind capture and decrease or eliminate loads (mechanical stress).[111]

[110] New York State Energy Research and Development Authority, "Wind Turbine Technology" (Albany: NYS Energy Research & Development Authority, 2005), 5.

[111] Sahin, "Progress and Recent Trends in Wind Energy," 501.

Control systems within the turbines have been employed to maximize wind capture. Since wind resources are not constant, techniques for capturing variable wind speeds have been developed. Each turbine is designed with an optimal efficiency based on the angle at which the wind hits the angle of the blade. To reach optimal efficiency a greater percentage of the time, control systems are incorporated into the rotors. These control systems can be variable-speed, passive-stall, or active-stall . Variable-speed controls allow the rotor to adjust the "pitch" (or angle), of the blade along its longitudinal axis to best extract the wind energy resource at variable wind speeds. On a pitch controlled wind turbine, the turbine's electronic controller checks the power output several times per second. When the power output becomes too high, as a result of strong winds, it sends an order to the blade pitch mechanism which immediately pitches, or turns, the rotor blades slightly out of the wind. This will prevent the generator from being overloaded, allowing the excess energy to move through the blades without being converted. Conversely, the blades are turned back into the wind whenever the wind drops again.

Passive, or stall controlled wind turbines, have the rotor blades bolted onto the hub of the rotor at a fixed angle. These have fewer moving parts, and are therefore less expensive to manufacture. The rotor blade has been aerodynamically designed to ensure that the moment the wind speed becomes too high it creates turbulence on the side of the rotor blade not facing the wind. This creates a stall that prevents the lifting force of the rotor blade from acting on the rotor. These are the most common type of systems installed today. These systems are slightly less efficient than controlled systems, but make up for it in the relative cost reduction from their simplified mechanisms and cost of manufacturing.

Active-stalled systems work much like active control systems, where they make use of mechanical movements of the blades. However, in the event of strong or gusty winds, an active-stall system will increase the angle at which the wind hits the blade, making the blade go into a deeper stall, creating turbulence on the backside of the blade as seen in the passive-stall system.

Small-Scale Hydropower

Hydropower systems have numerous methods for extracting energy from water systems, and several developed technologies exist with varying degrees of environmental disturbance. The classification of hydropower systems as a renewable resource can also widely vary. Although some classify all hydropower facilities as "renewable," this study will only consider low-impact hydroelectric schemes, with less than 30 MW capacity, as renewable hydropower. Impounded hydroelectric schemes used by large-scale dams are not considered "renewable" because of the social and environmental consequences discussed below. The classification of hydroelectric facilities are generally rated by their installed capacities. As previously stated, this study will use the term *large-scale hydro* to refer to facilities with installed capacity greater than 30 megawatts (MW). *Small-scale hydro* can be used to reference those facilities between 0.1MW (100kW) and 30 MW, and *micro-hydro* often classifies systems with a capacity of less than 0.1 MW.[112] This paper uses *small-scale hydro* to refer to all systems with less than 30 MW operating capacity, unless otherwise stated.

[112] Hartsoch, "Resource Potential and Complementarity," 11.

Montana has a long history of hydroelectricity, and currently derives 31% of its electricity from large-scale hydro facilities, primarily produced from large dams.[113] However, Montana is also presently facing the environmental consequences of large dams, as seen in the Milltown Dam Cleanup Project on the Clarkfork River, in Western Montana. Large-scale dams pose problems with sediment buildup, the potential storage of harmful heavy metals from mining, the buildup of the greenhouse gas methane, ecological disturbances to flora and fauna, the potential of dam failure, and the implications to the safety of human development down river.[114] Hydropower on a small-scale can exploit a river's hydroelectric potential without significant damming and "is one of the most environmentally benign energy options available."[115] It is also a source of energy with high efficiency (70% to 90%), and long lasting and robust technology engineered to last fifty-years or more.[116]

Hydroelectric power requires adequate "head" and "flow" from a water source for the practical development of a hydro system. Head is the maximum vertical distance water falls in a system. The higher the head, the less water that is required to produce a given amount of power, resulting in the need for smaller, less expensive equipment. Flow, or the flow rate, is the volume of water passing per second, and is usually measured in cubic feet per second, or liters per second. Flow is important to determine

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[113] U.S. Department of Energy, Energy Information Administration, "Consumption, Price, and Expenditure Estimates."

[114] Godfrey Boyle, *Renewable Energy: Power for a Sustainable Future* (Oxford: Oxford University Press and The Open University, 2004), 177-182.

[115] O Paish, "Micro-hydropower: Status and Prospects" (London: Proceedings of the Institute of Mechanical Engineers: Part A, vol. 216, 2001), 31.

[116] British Hydropower Association, "A Guide to UK Mini-Hydro Developments" (Wimborne: British Hydropower Association, version 1.2, January 2005), 2.

the volume of water available to generate energy year round. Low flow rates in dry seasons may limit or prohibit hydropower generation. Together flow and head determine the potential power of a site. Ultimately, the head and flow values will determine the size, scheme, and type of turbine installed.

There are several hydroelectric schemes, including impounded, run of the river, pumped storage, and direct submersion. Impounded facilities make use of dams to directly store water for electricity generation purposes. Pumped storage uses two water reservoirs, one at a higher elevation than the second. The water from the lower reservoir is pumped to the higher reservoir, using electricity, and then is released from the higher reserve to the lower in order to generate electricity when it is needed. The pumped storage systems generally serve as on-demand energy sources for peak energy use or to supplement other sources of energy, such as wind. Direct submersion systems place the turbines directly into the water where the force of the moving water turns the blades of the turbine. This system can operate in streams with as little as thirteen inches of water, but efficiency is low.

Run of the river systems are the most common small-scale hydro schemes in the United States. This system diverts a portion of a stream's water through an intake to the leat (Figure 7). The water is channeled horizontally to the forebay, where the water is dramatically slowed down and the suspended particles settle out. The water is conveyed vertically to the turbine through a penstock. A powerhouse encloses the turbine, generator, and control equipment, and is where the water's kinetic energy is converted to mechanical energy for the production of electricity. Electric wires then feed the electricity to the grid or to end-users. From the powerhouse the water is returned to the

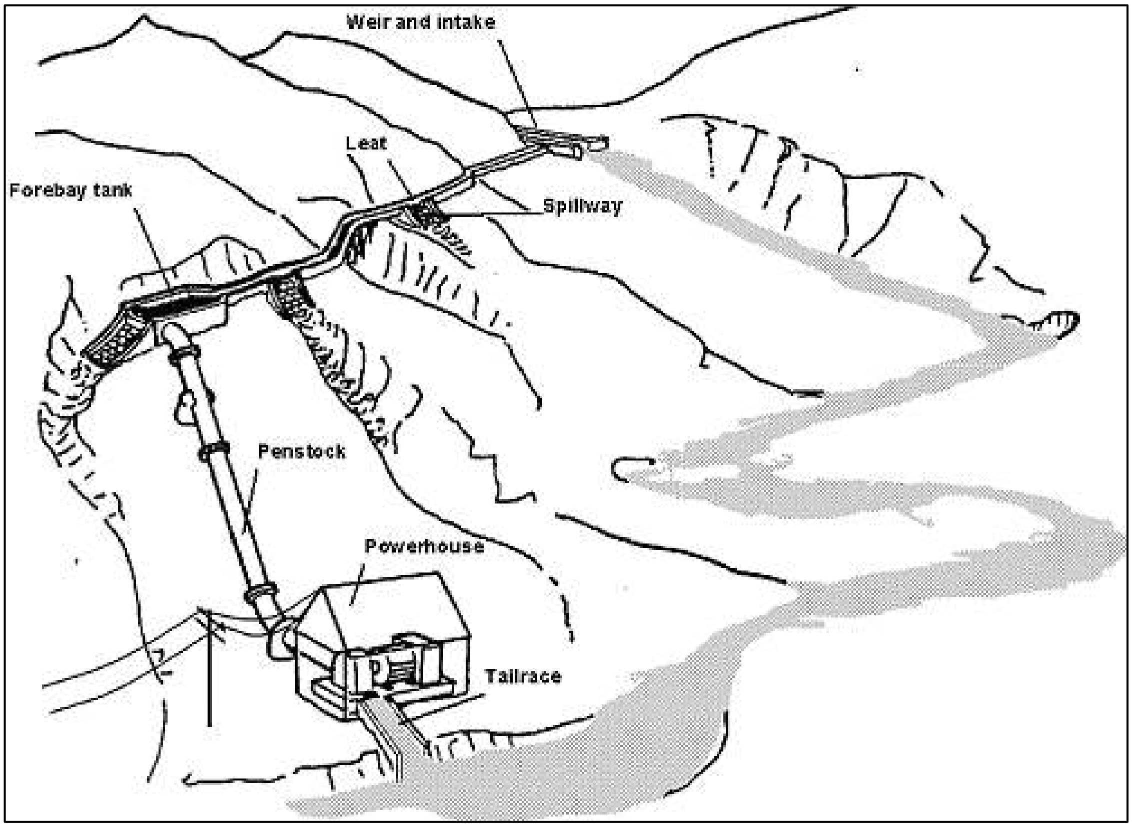

Figure 7. Run of the River Component Diagram (British Hydropower Association).

river. Variations of the run-of-the-river scheme exist to adjust for sources with low-head, environmentally sensitive areas, or terrain development constraints. Adaptations of this systems also exist at places with discharged water, such as waste-water treatment plants or sewer works.

The type of turbine used at a particular site is determined by the head classification of a source. Impulse and reaction turbines are the two main categories turbines. Reaction turbines rely on pressure rather than velocity, and are commonly used at impounded facilities. Impulse turbines are fairly simple in design and are most commonly used for high head micro-hydro systems. Impulse turbines use the velocity of the falling water (head) to turn the turbine wheel. Two common types of impulse turbines are the Pelton and Turgo wheels; both rely on jet force to generate energy. The water is funneled into a pressurized pipeline and directed through a narrow nozzle where the water's force is maximized. The water emerges as a jet spray, hitting the buckets of the turbine wheel, and forcing the wheel to rotate (Figure 8). Pelton wheels have high efficiencies of 70% to 90%, and are best suited for high head, low flow applications.[117] A Turgo turbine is another impulse system, but it works well for high head, high flow sites. It too uses the jet force system, but instead of hitting a single bucket, a Turgo supplies water to hit three buckets at once, moving the turbine wheel twice as fast. The advantage of this system is it is smaller, needs few or no gears, has higher output potential for high-head sites, and "has a good reputation for trouble-free operation."[118]

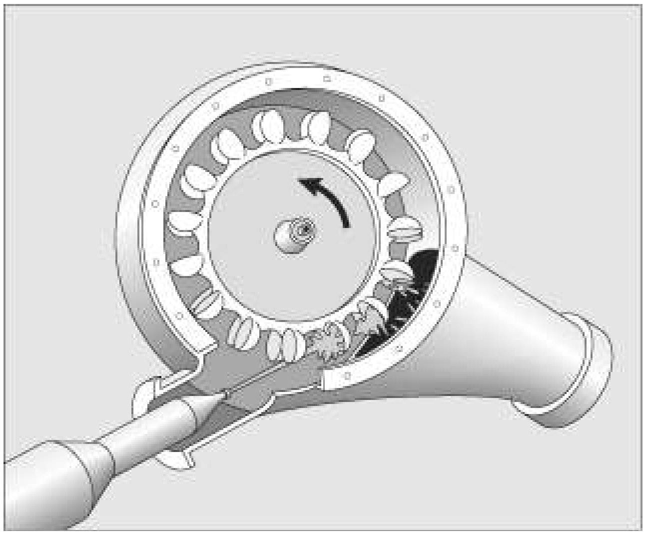

Figure 8. Pelton Wheel (DOE).

Biomass

The use of biofuels to produce heat is not new in Montana; however, innovation in technology has improved conversion efficiencies, making them economically competitive with fossil fuel sources. Additionally, research on the requirements of various bioenergy sources to become a reliable, efficient energy source has incorporated

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[117] U.S. Department of Energy: Energy Efficiency and Renewable Energy, "Small Hydropower Systems" (Washington D.C.: DOE, July 2001), 1.

[118] Ibid., 6.

forestry, agricultural, and municipal wastes, and energy crops as viable energy sources for heat and electricity. Various methods for preparing a fuel for the energy conversion system have been developed. Methods for size uniformity, reduction in water content, use of specific plant materials, and the reduction of rock and dirt contamination, are processes that insure system operation efficiency and increase energy output efficiencies.

The combustion of biomass is the means of extracting the energy stored in the fuel source. Several technologies exist to produce energy from biofuels. Biomass combustion and gasification are the two primary biomass energy technologies appropriate for heating and the generation of electricity. Additional technologies make use of biomass to produce fuels for the transportation sector, but this falls outside the scope of this research project.

Combustion technologies convert biomass into several forms of useful energy, such as hot air, hot water, steam, and electricity. A biomass-fired boiler is a common system that has many applications. This technology uses a broiler to produce steam from the combustion of biomass (Figure 9). This steam can be used for direct heating applications (via piping in a building), or to produce electricity. Once the combustion of the biomass takes place in the boiler, steam is produced, which then turns a turbine to generate electricity. Many types of biomass-fired boilers exist, including the pile burner, stationary combustor (or traveling grate combustor), and fluidized-bed combustors. Stationary combustors made the pile burner obsolete since the pile burner requires the manual removal of ash, while the gate combustors do not. In a stationary or traveling gate combustor an automatic feeder distributes the biofuel onto a grate inside the boiler chamber. Combustion air enters the chamber from below the grate, releasing the

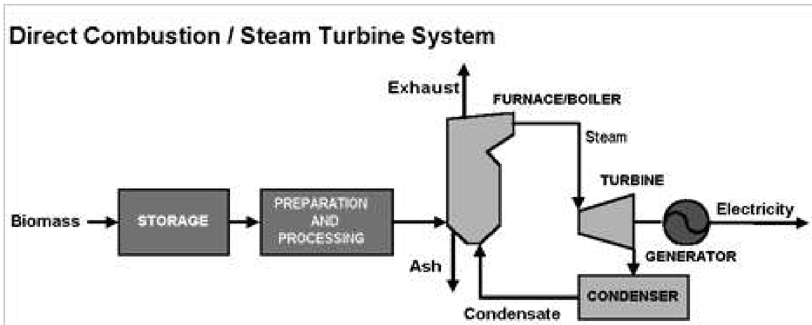

Figure 9. Electricity Generation from Biomass Combustion System (EERE).

bioenegy from the fuel source. Stationary grate ash falls into a collector, while traveling grate combustors move the ash to a hopper. Technological efficiencies for biomass grate combustors is about 33.9% with the use of dryers, and higher pressure and temperature conditions.[119]

Fluidized-bed combustors burn biofuel in a hot bed of free-flowing granular material, such as sand or limestone. Air is forced up through the material creating a turbulence that resembles a boiling liquid. The granular material distributes and suspends the fuel during combustion, and the turbulent action “scrubs” away the burned residue surrounding the fuel particles, allowing for a more complete combustion; thus, increasing efficiency. The heat is transferred to a collection device, typically water tubes. These systems allow for a variety of fuel sources, and can be used for both coal and biomass. Furthermore, this design allows for greater heat transfer at a lower temperature, reducing the emissions of the greenhouse gas nitrogen oxide.[120]

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[119] U.S. Department of Energy: Energy Efficiency and Renewable Energy, “Direct-Fired Biomass” (Washington D.C.: DOE, November 2007), 22.

[120] Oregon State Biomass Energy Homepage, *Biomass Energy Technology* [database online] (Salem: Oregon.gov, accessed 8 December 2008); available from http://www.oregon.gov/ENERGY/RENEW/Biomass/bioenergy.shtml.

Cogeneration, or combined heat and power (CHP), is another type of biomass combustion technology that produces both heat and electricity from a single system, thus increasing efficiency up to 85%.[121] Steam is produced in a boiler and is used to generate electricity. The steam exhaust is then used to heat water, or for space heating, also known as district heating. District heating is a common practice in European areas with dense populations near a power source.

Gasification is a new technology that converts biomass into a combustible gas through a thermochemical process, and has a conversion efficiency of 70% to 80%.[122] Gasification technology requires biomass fuels to be dry, with a moisture content of no higher than 20%, and of uniform size.[123] This requires a pretreatment process to ready the fuel source. The first stage of gasification is call pyrolysis, where the volatile components of the fuel (carbon monoxide, hydrogen, methane, volatile tars, carbon monoxide, and water) are vaporized at a relatively low temperature. The remaining material is only 10% to 20% of the original matter mass and is a charcoal.[124] The second stage is the combustion of the charcoal matter in which carbon monoxide is produced. The pyrolysis vapor and carbon monoxide are retained in their gaseous form, collectively known as producer gas, to be used for combustion to produce heat or steam for electricity.

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[121] Ibid., "Cogeneration."

[122] Ibid., "Gasification."

[123] Ibid.

[124] Ibid.

Geothermal

Geothermal heat can be used for direct heating applications, electricity generation, or combined heat and power in cogeneration and hybrid applications. Additionally, geothermal systems can use the earth as a heat source or sink in heat pump systems. Owing to the dispersed availability of mid to low-temperature geothermal heat sources across the state, binary power stations are of great interest in Montana. Geothermal heat pumps are another application of thermal energy highly viable in Montana, as these systems can be used virtually anywhere.

Binary power facilities have been identified by the Department of Environmental Quality as highly advantageous because they can be used at sites with mid to low-temperature water sources and are small in scale; therefore, can be located near urban or recreational areas with little notice.[125] They can also be modular in designs so that they could be added onto in the future, thus avoiding high capital investments up front. Binary power facilities are also capable of operating automatically, therefore, reducing operation costs.[126] The challenge for moderate temperature, small-scale geothermal development has been to bring facility costs to a level that is economical to develop small geothermal sites.[127] Chapter Four discussed the installation of a Binary Power Plant at Chena Hot Springs Resort in Alaska. This facility was the first geothermal site to use

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[125] Geothermal Energy Program, *Montana Geothermal: Electrical Power Generation Cost-Benefit Analysis for Geothermal Systems* [database on-line] (Helena: Montana Department of Environmental Quality, May 2007, accessed 22 October 2008); available from http://www.deq.state.mt.us/energy/geothermal/electric.asp.

[126] Ibid.

[127] Chena Hot Springs Resort, “Fact Sheet,” 1.

moderate temperature water to produce electricity using a modified, mass-produced refrigerant chiller, thus dramatically lowering the cost of production.

The Chena Hot Springs Resort teamed up with United Technologies Corporation (UTC) to demonstrate the use of modified refrigeration equipment to generate power from low-temperature thermal heat. Chena Hot Springs Resort installed two 200 kW Organic Rankin Cycle (ORC) power plant modules, designed by UTC and its sister corporations, Carrier and UTC Power. The concept of running a refrigeration cycle in reverse to generate power has been known for a long time, but it wasn't until 2003 when Carrier released the PureCycle 225, for power generation from waste heat, that the model was put into practice. In a traditional system the chiller removes heat from a medium with the aide of the compressor, but in the case of the reverse system, the chiller is used to transfer heat to power a turbine (Figure 10).

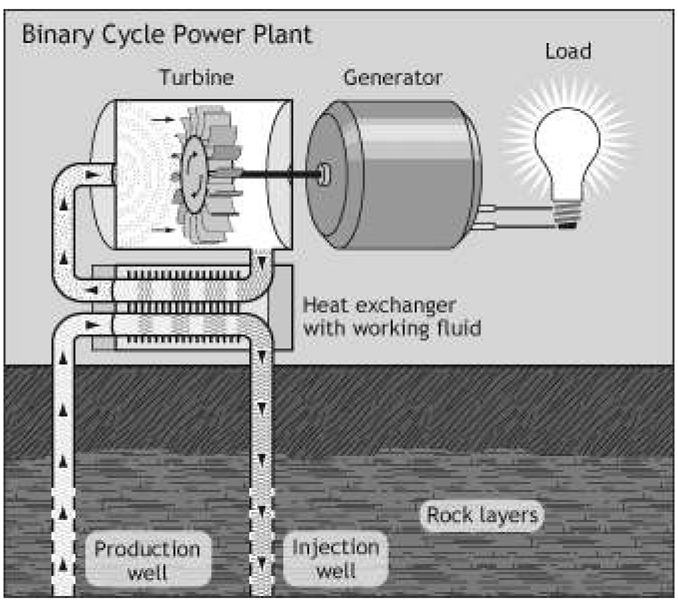

Figure 10. Binary Cycle Power Plant (Alternative Forms of Energy).

The success of the Chena facility is largely a result of the relative economic benefit of using the Carrier chiller system. The temperature of the geothermal heat source is only 165° F. Low thermal temperatures inherently mean low thermal efficiency; and low thermal efficiency means increased power plant equipment size.[128] This can make development of moderate temperature sites cost prohibitive using standard power plant equipment. By using modified mass-produced air conditioning equipment to generate power, upfront costs were greatly reduced. The power generation equipment can feasibly produce electricity for less than \$0.05 kWh from a 165° F. source with 98% availability.[129] In 2006, the facility logged over 3000 hours from the first installation of a 200 kW unit with 95% availability, saving over 44,500 gallons of diesel fuel. It was projected that 3 million kWh would be generated in 2007, with the second unit up and running, replacing 224,000 gallons of diesel, and saving \$550,000 in energy costs.[130]

Geothermal heat pumps (GHPs) are another system that uses geothermal energy in Montana. A GHP is a system that uses the Earth's relatively consistent temperatures as either a heat source, when operating in heating mode, or a heat sink, when operating in cooling mode. GHPs can be used in almost any part of the country where subsurface temperatures are relatively consistent.

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[128] Ibid., 1.

[129] Gwen Holdmann. "The Chena Hot Springs 400 kW Geothermal Power Plant: Experience Gained During the First Year of Operation" (Fairbanks: Chena Hot Springs and Chena Power, June 2007), 2.

[130] Ibid., 6.

PART II

DISCUSSION

CHAPTER SIX

POTENTIAL FOR RENEWABLE ENERGY DEVELOPMENT

Renewable energy sources are abundant across Montana and are capable of providing reliable, efficient energy for heating and electric needs. Research conducted for this paper has shown that solar, wind, small-scale hydro, biomass, and geothermal energy forms are currently supplying various utility, commercial, governmental, and residential end users with clean power. These five forms of energy have proven to be viable forms of energy, rather than high-risk, experimental energy production options. The technology for capturing renewable energy is also in use across the state, as is demonstrated in the case studies provided in Chapter Four. Additionally, emerging technological innovation is addressing shortcomings of existing systems to continue to improve reliability, efficiency, economic feasibility, and competitive viability of renewable energy. Chapter Five addressed the various forms of technology used to capture and convert energy forms into appropriate end products for electrical and heating needs. Various technologies were also discussed that demonstrate the direction of research and design underway to produce the next generation of energy systems.

Solar

Solar energy is a valuable contributor to Montana's energy portfolio. As discussed in Chapter Four, it is currently supplying clean energy to hundreds of homes and businesses across the state. The potential development of solar power is also considerable; electrical generation could be as high as 101 million MWh/yr.[131] Several projects, including Sun4Schools and the Fire Station Solar Electric Demonstration Project, show how solar energy can be a useful addition to the energy mix, is reliable, and can act as a backup power source. Ranchers are also finding solar power a dependable, cost-competitive alternative to gas generators for remote stock tanks.

Solar technology research and development is alive and well, with three generations of technology simultaneously under development. The first generation of solar cell wafers is capable of producing electricity for a variety of purposes, as seen in the case studies. Chapter Five summarized the cost and efficiency of this generation, and showed how the development of the second generation thin film technology can reduce production costs. Thin film also is advantageous for incorporation into larger design schemes because of the various substrate materials used to develop thin film (glass, plastic, stainless steel, etc). Some second generation thin film systems are available on the market. The third generation of solar power aims to increase efficiency and decrease production costs through manufacturing techniques. The products that will emerge from this generation may be highly competitive with current fossil fuel electricity generation. As solar technology advances, it may become a larger contributor to utility power; maybe even in states like Montana, where seasonal availability varies greatly throughout the year.

There are several additional advantages to solar energy. First, it is a relatively inexpensive system for homeowners and small businesses, especially with USB grants and tax incentives. Second, it can be a private method of energy generation for off-grid

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[131] Land and Water Fund of the Rockies, *The Renewable Energy Atlas of the West*, 45.

and grid-tied sites with ample sunlight. For example, a home owner within city limits can produce their own power, needing only a southern facing area to place the system (roof or yard). And finally, the future of solar energy systems is as big as our imaginations. The promise of solar technology that can be integrated into building designs as siding, shingles, paint, and window coatings is exciting. Furthermore, solar technology allows for multiple land uses, as it can be placed on, or above, existing infrastructure, such as buildings, or mounted on towers above livestock grazing land.

Considerations for solar energy development include the availability of the resources needed for production. This is important, because the development of solar technology is energy intensive in itself and any installation should consider the energy payback period compared to the lifetime of the system. If an installation produces less energy than it took to manufacture, deliver, and install, the value of developing the renewable resource may be negated. The future availability of solar radiation conversion materials, such as silicon, may be less than the supply, if solar cell production continues to grow, the industry will then need to find another source of silicon other than microelectronics off-grade silicon.

Overall, the continued development of solar power is beneficial. The addition of solar to a seasonally complementary infrastructure would be highly valuable, especially in the summer months. As this research project has shown, solar technology is working for Montanans and the conversion techniques are currently viable, and have a promising future.

Wind

Wind power is definitely working for Montana. Currently, it is the most widely developed renewable energy form in the United States. This is also true in Montana, and the potential for increased development is huge, with 17 million acres of windy land.[132] Chapter Four described several wind energy sites that have been developed for commercial and small-scale applications. Judith Gap, Horseshoe Bend Wind Park, the Blackfeet Reservation projects, and the integrated systems in Cascade county and Spa Hot Springs Motel, have all seen positive results in their ability to produce electricity appropriate for their end-use.

The state of wind energy technology is arguably the most advanced renewable energy technology available today. This has come from a long history of developments and innovation in the industry. The ability of a turbine to maximize efficiency was discussed in Chapter Five. Techniques found in variable speed, passive-stall, and active-stall systems improve system performance, and increase efficiency through a variety of methods. Utility size installations are growing in number, and the productivity of the wind turbines are growing with size. This is an important contribution, since the greater the output from a single machine, the less land area that is needed to produce a given amount of energy, and the less strain it will have on the natural environment.

Wind energy has had bad press for what some consider negative visual impacts. Therefore, the locations of wind turbines are often located away from population centers. However, this then requires a greater distance between the energy generation sites and the end-users. Furthermore, the power lines needed to carry large loads of electricity have a

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[132] Land and Water Fund of the Rockies, *The Renewable Energy Atlas of the West*, 44.

visual and environmental impact. Turbine noise, electromagnetic interference, and glare are some of the other criticisms of wind energy. Although the extent to which these pose are real problem are questionable, these are considerations that should be taken into account when planning a site. Furthermore, environmental impacts are a huge criticism given to wind development. Careful site planning can lessen these concerns, and they should be also be located away from bird migration routes and protected areas.

Through a continuation in research and development, wind energy stands to be a highly valuable and important contributor to the energy mix. It also would be a considerable addition to any integrated system. Seasonally it would have a big impact in the winter and spring months; however, some regions show relative consistency year round. The long history of Montana's use of wind power is not coincidental; it is one of the states largest natural resources and with appropriate development it could be one of its most valuable resources.

Small-Scale Hydro

Small-scale hydropower stands to be a valuable contributor, on a responsible, environmentally sustainable level. Large-scale hydropower currently is a major contributor to Montana's energy portfolio at 31%.[133] However, as previously discussed, it has major environmental and social consequences of use. Small applications of hydropower have made significant contributions historically, for irrigation, forestry, and mining, as well as electricity production for remote locations. Hydro technology is considered efficient and robust, with minimal maintenance costs. Additionally, the power available from water sources is available twenty-four hours a day, and variability

[133] DOE, "Consumption, Price, and Expenditure Estimates."

in supply patterns are much more predictable, and less sudden, when compared to other renewable sources.

Several small-scale hydro systems exist across Montana as contributing sources of energy on private land. The Upper Mamquam project, discussed in Chapter Four, is a great example of a working hydro system capable of delivering reliable, clean energy to a nearby city. The different types of systems were discussed in Chapter Five. Submergible turbines are of interest in locations with low or mid head, with consistent flow. Run of the river facilities require a water course to have an abrupt change in elevation, such as a waterfall, or steep terrain, and are the most common low impact hydro power installations. Other hydro developments might come from discarded waste water.

There is not always a clear distinction between renewable hydropower and non-renewable, so the resources found on this topic were often limiting. Several renewable energy studies found did not include hydropower as a renewable, while other studies did not discern a difference between large and small installations. Through the course of this research project it seems that small-scale hydro is a practical, reliable use of the resource when it limits the disruption to the local environment and is within near proximity to end users. Fish migration is always a concern with hydro developments. It seems that screens on intakes could limit the access of fish into the system, while the majority of the water proceeds on its natural course.

In the right locations, small hydro can be a great source of energy. In the spring and early summer, tributaries are bursting with snowmelt runoff and this would be the time of year when small-scale hydro power could shine in a seasonally complementary system.

Biomass

There are many biofuel sources available in Montana. It was reported that six million MWh of electricity could be generated annually from Montana's forestry, agriculture, and industrial sectors.[134] Chapter Four discussed how biomass is providing heat to community buildings through converted broiler systems and pellet stoves. The Montana State Fuels for Schools and Beyond program is an excellent example of how biomass can be used in heating applications. The program also was organized in a way that fostered a learning environment from which other projects were able to successfully model their own biomass system. This project and the three phases of development outlined by the DNRC exemplifies how demonstration projects, organized with clear objectives and detailed guidelines, can make a huge impact on the successful inclusion of renewable energy resources into the energy mix. This type of methodology may be appropriate for other forms of renewable energy and their associated technology. Municipal waste can also be a great asset to energy production, as well as an economical benefit. Chapter Four described the arrangement underway between the City of Billings and MUD to capture methane gas emitted from the landfill and use it to produce electricity.

In Chapter Five the biomass conversion technologies available for heating and electricity generation purposes were identified. Several combustion and gasification techniques are used to extract stored energy from the biofuels. Improvements in technology aim to increase the amount of useable energy that can be converted from biomass from complete combustion.

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[134] Land and Water Fund of the Rockies, *The Renewable Energy Atlas of the West*, 46.

Benefits of biomass include the ability to use waste that otherwise has no market value. Often the disposal of residual waste from industrial practices can be costly to remove, as seen in the case of the Billings landfill. Another plus is that the combustion of biofuels is carbon neutral, as the amount of CO^2 emitted is equal to the amount of CO^2 absorbed by the plant during photosynthesis.[135] As previously stated, there are several sources of bioenergy, within each region of Montana capable of producing/ harvesting its own. Furthermore, biomass is available year round, can be transported fairly easily, and in most cases, it can be annually or seasonally quantified. A stock pile of biofuel has an approximate energy value from which supply and production decisions can be made.

There is some controversy surrounding the use of biofuels for energy production. Fuel crops threaten the availability of land used to grow food for consumption. This can also increase the demand for farmland; resulting in the conversion of forest and grasslands, thus, releasing CO^2 stored in the soil and ultimately increasing the amount of greenhouse gases released into the atmosphere. The removal of forest residue is also criticized, as a healthy ecosystem relies on biodegradable materials naturally found in a forest.

Biomass should be considered for any type of energy matrix in locations where biomass waste materials are in excess. Given the dependable source of energy, biofuels should also play an important role in firming energy supplies when other renewable energy availabilities are low. The capability to store biomass is relatively easy and would allow biomass to be a component in an integrated system year round.

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[135] This of course does not take into account the carbon emissions from the farming the biomass or he transportation from the source to the power facility.

Geothermal

Geothermal systems used for heating purposes are well established by commercial and residential end users in Montana. Greenhouses, aquaculture, and space heating practices have been used for over a century. There is also a considerable amount of energy potential that can be explored in Montana. The U.S. Department of Energy has estimated that 77,000 MWh of thermal energy could be produced statewide.[136] Electricity can also be produced at high temperature geothermal areas, and at least fifteen prime geo-power generation sites have been identified by the Geo-Heat Center.[137]

Fairmont Hot Springs was highlighted in Chapter Four for its dynamic use of geothermal waters to heat over 106,000 square feet of the facility buildings, heat four hot-spring pools, and provide domestic hot water. Chena Hot Springs Resort is another hot springs facility that has developed its geothermal waters to not only provide heating demands to the facility, but to also generate electricity. In Chapter Five, the binary power plant technology implemented at Chena has been described. This site is an exciting breakthrough in low-temperature geothermal resource development, as it is the lowest temperature commercial facility to generate electricity. The key to the success at Chena is that it adapted refrigeration components to drastically reduce system costs. The Montana Department of Environmental Quality has identified this type of facility to be highly advantageous for development in Montana because they can be used at low to mid temperature geothermal sites and are small in scale, and therefore, can be located closer to end users.

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[136] DOE, "Geopowering the West."

[137] Geo-Heat Center, "Geothermal Direct Use Case Studies," 21.

There are a number of benefits to using geothermal energy to produce heat and electricity. First, geothermal resources are the only renewable energy form available in Montana that is independent of the sun. It is also a resource that is available year-round, and anytime of the day. In addition to the commercial exploitation of the resource for over seventy years, the extraction techniques for geothermal heat are similar to the well established practices for oil and gas. Lastly, the relatively constant rate of geothermal energy supplies makes it an ideal candidate as a baseload energy source in a complementary system.

There are some drawbacks to geothermal energy that should be considered before developing a site. Geothermal heat reserves can be extracted at non-sustainable rates, depleting the resource faster than it can be naturally replenished. There can be issues of ground subsidence from long-term extraction and the potential for induced seismic activity in some areas if underground reservoir pressures are not maintained.[138] Gaseous pollution and waste water disposal, are other areas of concern for some sites.

The development of geothermal energy in Montana deserves further consideration, especially in locations near population centers. Binary power plant technology, district heating, and combined heat and power systems could become significant contributors to Montana's energy portfolio. Ground heat pumps are another option for buildings, and can be located anywhere with a relatively constant sub-surface temperature. The constant nature of geothermal sources makes it an excellent source for reliable, predictable energy. And, with proper management, geothermal heat can be one of the most sustainable, environmentally benign energies available.

[138] There is debate over the influence geothermal water extraction has on seismic activity, as it is acknowledged most hot spot locations already have geologic activity.

CHAPTER SEVEN

DIVERSITY AND LOCALIZATION

It is important to highlight the importance of diversity and localization in an energy system. A diverse renewable energy portfolio can improve environmental and human health. The dominance of a single energy system can lead to an excessive burden on a particular aspect of the environment, thus posing a risk to human and environmental health.[139] There is not one energy system that does not have an adverse impact on the environment, as dictated by the second law of thermodynamics.[140] As Xianguo Li points out in "Diversification And Localization of Energy Systems for Sustainable Development and Energy Security"(2005), diversification also increases security and reliability. For example, analogies found in other fields, such as forestry, or finance, rely on diversity to achieve stability in a system.[141] Forestry considers biodiversity the key to the health of an ecosystem, and reduces the risk of crop or ecosystem failure to pests or diseases. Financial portfolios are similar. The more diverse a portfolio, with high to low-risk holdings, the lower the potential for loss and higher the potential returns.

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[139] Xianguo Li, "Diversification and localization of energy systems for sustainable development and energy security" (Ontario: Energy Policy, vol. 33, 2005), 2237.

[140] Ibid.

[141] Ibid., 2240-1.

The same holds true with energy systems. Additionally, the use of renewable, sustainable energy systems has minimal to neutral impacts. The utilization of various forms of energy have differing degrees of impact on the environment and through careful consideration of the technology used, the placement of systems, and sensitive environmental factors disturbance on an area can be reduced or eliminated.

Localized energy production, on a regional, community, or residential level can also ensure energy security. There is currently not one energy source, renewable or not, that can fully meet the needs of communities in all geographic regions of the United States, regardless of the incidental implications of its use. By developing decentralized, regional or residential-scale energy systems that take advantage of available, abundant local resources, resident experts and local citizens have the ability to highlight environmental concerns, as well as minimize the potential for disruption of service in the event of a large-scale power outage. The interconnection of many energy generation sites through short, robust links to the grid protect against the large loss of power from central hubs. Another advantage of small-scale energy production is it requires a trained workforce, and most often employs local citizens.[142]

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[142] Amory Lovins, *Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (Snowmass: Rocky Mountain Institute, 2002), 15.

CHAPTER EIGHT

INTEGRATION

One of the biggest considerations in developing utility scale renewable energy in Montana is how to deliver power to the end-users in a cost-effective way. Often a great energy generation site is hundreds of miles from the necessary power lines capable of delivering such large loads. This would require the construction of transmission lines to deliver the power to the grid, and financing such a venture is often the largest obstacle faced by developers.

A second challenge to the development of most renewable energy forms is the intermittent nature of the resource's availability. The wind does not always blow, the sun shine, or the rivers surge. Biomass does have storage potential, but long term storage mitigates the quality of the resource because of disintegration.[143] Geothermal resources also fluctuate seasonally.[144] The utility grid system requires energy sources be available when people need them, and Americans have come to rely on that consistency.

Several studies have addressed the variability in renewables and have suggested that interconnected systems decrease the cost of and increase the total amount of renewables that can be integrated on to an electrical grid.[145] The geographical

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[143] U.S. Department of Energy: Energy Efficiency and Renewable Energy, "Direct-Fired Biomass."

[144] Geo-Heat Center: Oregon Institute of Technology, "Geothermal Direct Use Case Studies," 21.

distribution of generation sites also "show a reduction in portfolio variability compared to any individual site."[146] Transmission requirements can be reduced by interlinking multiple generation sites together and substantially improving the overall performance of the interconnected system when compared with that of any individual site.[147]

This research project suggests that "geographical corridors" of distributed generation sites, could ease concerns of variability and transmission requirements when multiple energy forms are contributing to the energy supply. It is proposed that a geographical area in Montana, with high potential for development of at least two or more renewable energy forms, could be built in conjunction with a central transmission line that would connect to the grid. For example, the northwestern region of Montana, off the eastern slopes of the Rocky Mountains, could be a hypothetical renewable energy corridor.[148] According to Hartsoch's estimations, this region has medium to high aggregated annual energy potential for all five energy forms. Through further geographical analysis, a specific area appropriate for development of two or more renewable energy forms could be determined. Areas with multiple generation sites from one energy source should also be included. Specific sites could then be identified based on potential, land use policies, and existing infrastructure.

Research suggests that the benefits of interconnection continue to increase with more and more interconnected sites, and the down time of a given energy form is

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[145] Hansen and Levine, "Next Generation Utility" (2008), and Archer and Jacobson, "Baseload Power" (2007).

[146] Hansen and Levine, "Next Generation Utility," 1.

[147] Archer and Jacobson, "Baseload Power," 1702.

[148] Reference the series of annual availability maps produced by, Hartsoch (2004) for comparisons.

drastically reduced with multiple generation sites.[149] Further research on this subject is recommended to determine the feasibility of such a project in Montana; however, it seems beneficial to contribute to the discussion of transmission and variability of renewable energies, as it is often the largest obstacle in the development process.

This type of approach can be and is applied to small-scale systems, where residences or buildings off-the-grid use more than one energy form to supplement their energy demands. This could also be taken one step further and applied to a community, a series of government buildings, or a single high-demand end user, such as a factory.

[149] Archer and Jacobson, "Baseload Power," 1702.

CHAPTER NINE

FUTURE RESEARCH

The topic of renewable energy is a timely and rapidly growing field. In the time that has passed from the beginning of this research project to its end, an enormous amount of attention has been given to renewable energy by academic, political, and civil agencies. It is a contemporary issue with an ever-growing body of research devoted to its understanding. Any project that aims at developing a renewable energy source should investigate the most current technologies available on the market, as well as consider current policies and economic benefits available at the time of development.

Research that would undoubtedly add to this body of work would be a thorough investigation into policy and economics. Policy surrounding the advancement and protection of Montana's citizens, economy, and environment is an important part of any development project. These policies that govern the development of renewable resources in Montana should be clearly understood, and if appropriate, improved to support the future of economic progress, energy security, and environmental protection of the state and its resources.

Montana has a long history of using natural resources to provide economic gain, and energy production, both renewable and non-renewable, has been part of that history. The pros and cons of further developing Montana's renewable energy and the impact that it could have on the economy should be researched. A clear understanding of the economic advantage and commitment necessary to produce efficient energy would also be valuable. Costs associated with installation, operation, and projected output should obviously be considered whenever developing a site. Also, projected cost comparisons of future energy production and market prices for fossil fuels and renewable energy would be an interesting topic. The cost of environmental impacts from continued use of fossil fuel cannot be entirely measured in dollars, but, the cost of environmental restoration, associated health care needs, and cost of securing foreign oil sources would be a fascinating and important area to research.

Lastly, research on Montanans' perception of renewable energy development should be considered. Concerns, support, and misconceptions about its implementation should be investigated. It is well known that Montanans are passionate about their state and their land, and the exploitation of any resource should be beneficial to and supported by Montanans.

APPENDIX

1. Energy Consumption by End Use in Watts per Second.

Use	watts / second
Light bulb (60 watt)	60
Computer	100 - 200
Television	300
Furnace (1 hp)	875
Microwave	1,000
Window Air Conditioner	1,500
Oven	2,000
Electric Clothes Dryer	5,000
Annual U.S. Household Average*	3,180
Energy consumption widely varies based on settings, brands, and usage. *Based on ~28 MWh annually (DOE)	

2. Basic Energy Conversion Chart.

watt	kilowatt	megawatt
1	0.001	0.000001
1000	1	0.001
1000000	1000	1

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