A New Harvest: Using Solar Power to Refine Biodiesel on Native American Reservations

By

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Abstract

Sustainability is a matter of survival. The rising cost of energy and the dwindling fossil fuel resources are disproportionally affecting Indigenous communities, making them the proverbial canary in the coalmine. Native American reservations can leapfrog past fossil fuel based energy production and assert their energy sovereignty by developing renewable energy projects. Native American tribes have already been investing in renewable energy projects with the goal of becoming energy independent. The thesis proposes that tribes invest in solar powered biodiesel refining to remove their dependence on off-reservation produced energy. I use spatial analysis and GIS to demonstrate which reservations will receive the most benefit from this technology. The goal of this project is to provide tribes with a practical, real-world solution that can elevate their energy concerns and ready for implementation.

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Chapter 1: Introduction to the Thesis

Chapter 1 Thesis Introduction

The United States is dependent on fossil fuel energy in their daily lives. According to the Department of Energy, in 2012 the United States used about 305 million gallons of gasoline, or about one gallon of gasoline per day for each person, two-thirds of which were used for transportation (U.S. Energy Information Administration, 2013). Since the 1970s, the amount of petroleum refined per person has dropped steadily (See Figure 1). The price of gasoline has trended upward since the 1970's (See figure 2). According to Brown and Yucel (2007: 2), the price of oil and natural gas are linked by "one simple rule of thumb, the 10-to-1 rule under which the natural gas price is one tenth the price of crude oil." The relationship between all of the fossil fuel prices means as the price of one fuel source increases in price, so will others.

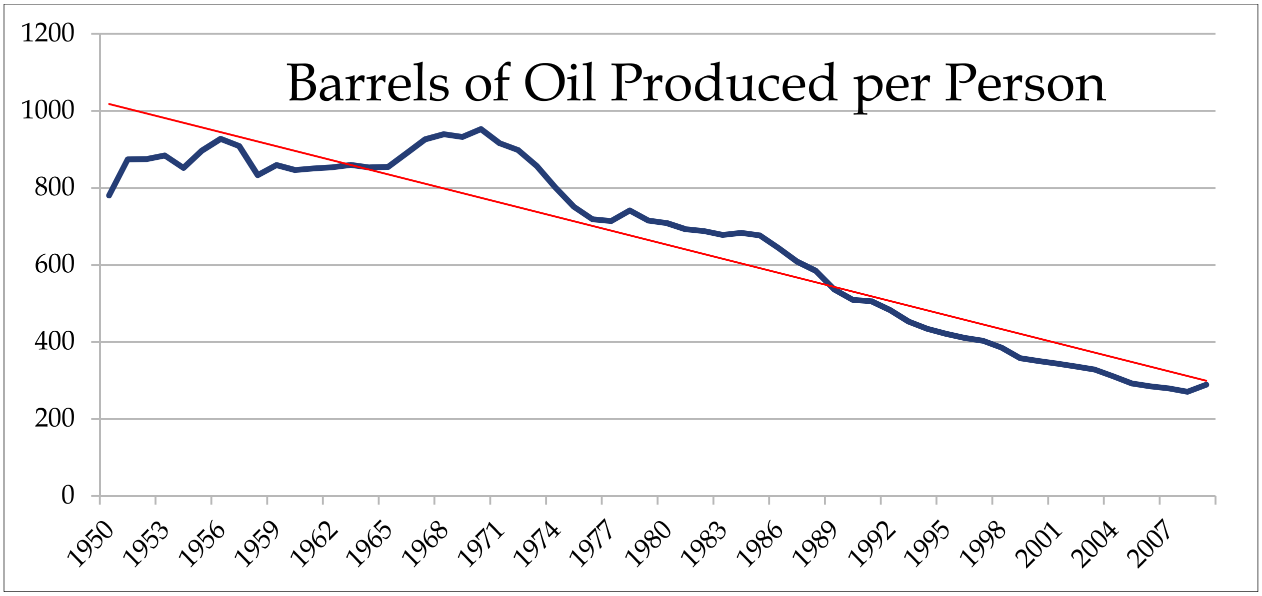


Figure 1. Oil Production Versus Population (data taken from CIA World Fact Book)

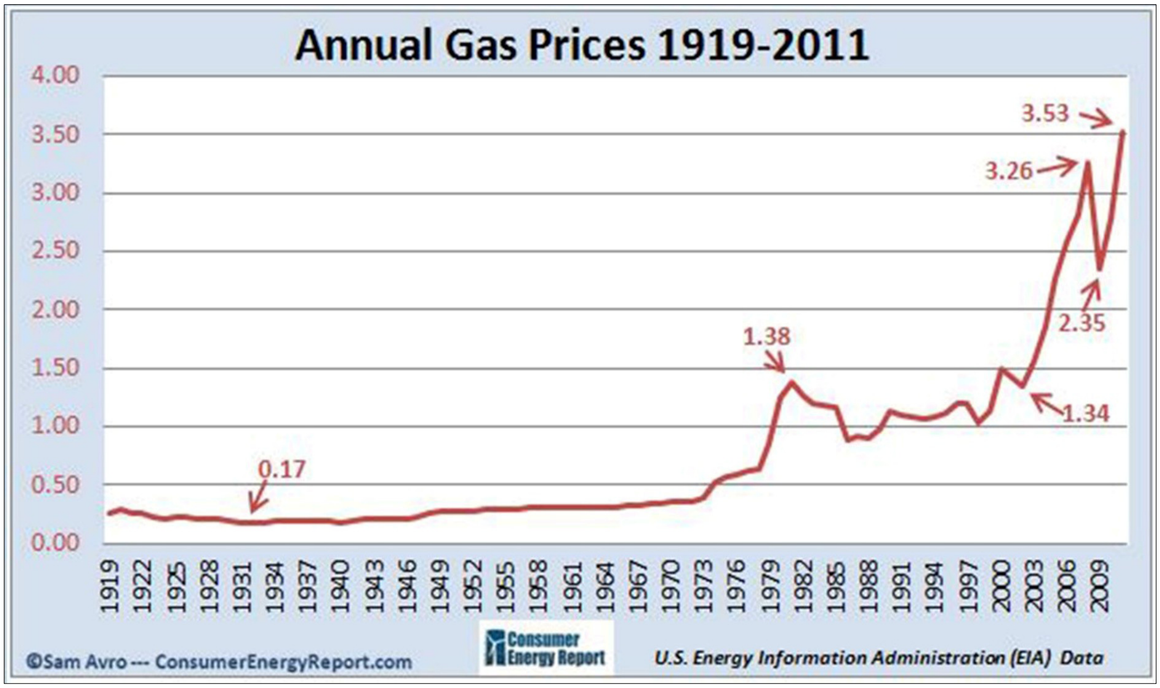


Figure 2. Average Gas Prices (http://www.energytrendsinsider.com)

The increasing cost of energy adversely affects Native American populations because Native Americans have the highest rates of poverty in the United States (U.S. Census, 2013: 3). In addition, many reservations are in rural areas. Rural reservations are the hardest hit because of longer travel distances and a lack of transportation alternatives (Mielke et al., 2008: 31). The solution to this issue that I propose in this thesis is tribes investing in solar-powered biodiesel refining as an economic development project. I am proposing small-scale (fifty gallons per day) refining systems that are small enough to be portable on the back of a pickup truck. I propose using waste vegetable oil (WVO) to convert into biodiesel. Tribal members will be able to use the biodiesel or sell it for profit.

The goal of this thesis is to investigate to what extent solar-powered biodiesel refining can strengthen tribal energy sovereignty as an economic development project. In order to do this, there are fundamental questions that need answers. What is tribal energy sovereignty and how can a renewable energy project strengthen it? How would a solar-powered biodiesel refinery work and which reservations are best suited for the technology? In addition, would solar-powered biodiesel refineries be economically feasible for specific tribes?

In Chapter 2 of this thesis, I review the literature concerning the field of Indigenous geography to show that it is a proper lens through which to examine the feasibility of tribes using renewable energy to assert their energy sovereignty. First, I examine the politics of Indigeneity, which includes topics concerning Indigenous identity, sovereignty, and self-determination. Next, I investigate the issues of Native Americans and land, resource management and sustainability. Finally, I look at how to solar-powered biodiesel refining benefits from Indigenous research methods, including the ethics of using Geographic Information Systems with Indigenous lands.

In Chapter 3, I examine the three renewable energy projects in depth. I conduct a technical analysis of each technology functions and the advantages and disadvantages of each. The analysis includes a method for comparing energy resources to each other based on the energy return on investment (EROI). The next section addresses the issues specific to using GIS to map each renewable energy technology. Finally, I describe the methodology used to map each renewable energy project. The hope is that with this chapter someone would be able to repeat the methodology to be able to create renewable resource maps for reservation areas beyond the solar, biodiesel and solar powered biodiesel resources.

I evaluate the feasibility of using solar-powered biodiesel refining on the Prairie Band Pottawatomi, Osage, and Navajo Reservations in Chapter 4. The first section takes a closer look at each of the tribes' cultures. The next section is a cost benefit analysis of solar powered biodiesel refining for each reservation. The final section set out a plan what each reservation can do with the biodiesel and its profits to continue to strengthen their energy sovereignty. The goal of Chapter 4 is to highlight the information needed by a tribe interested in investing in solar-powered biodiesel.

Chapter 2 Indigenous Geography

Chapter 2 Introduction

The field of Indigenous geography explores the intersection of Indigenous peoples and the places in which they reside. These places and attachment to them influence Indigenous cultures and worldviews. With regard to this research, Indigenous geography is a lens to examine the ways that Native Americans can use renewable energy projects to strengthen their tribal sovereignty. Indigenous geography is representative of a chorus of world views that quiet the singular voice of the Western worldview and removes its privilege at the top of the hierarchy of knowledge; as such it is a mechanism to weaken the bonds of social, political, and economic norms (Shaw et al., 2006: 273). I will explore Indigenous geography in this thesis through the politics of Indigeneity, Indigenous resource management and Indigenous research methods.

Section 2 of this chapter will examine the politics of Indigeneity and its implication for this thesis. This discussion is broken down into three main areas: who is Indigenous, what is Indigenous self-determination, and finally, what is Native American sovereignty? Each of these questions is fundamental to my research because Indigenous people, their lands, their cultures, and their resources intertwine.

Section 3 of this chapter is a discussion of issues concerning Indigenous resource management. The first area of this section further examines the relationship between Indigenous peoples and their resources. The next area focuses on the use of natural resources as an act of tribal sovereignty. The last section discusses the importance of sustainably using resources on tribal lands. Solar-powered biodiesel refining utilizes renewable resources, but if they are not responsibly used, the technology will not be sustainable.

Section 4 of this thesis explores the ethics related to doing research with Indigenous peoples. The first part discusses why it is important for research to be mutually beneficial to both tribes and researchers. The next part highlights how shared knowledge strengthens tribal sovereignty. The last part investigates the ethics of using GIS to map Indigenous lands and resources. Indigenous research methods are evolving with each Indigenous research project, and I hope that something in this project can contribute to that evolution.

Chapter 2 Section 1: The Politics of Indigeneity

Understanding the politics of Indigeneity is fundamental to the study of Indigenous geography, because Indigenous identity is the underpinning of every element of Indigenous worldviews. Indigenous identity is a complex topic that I will attempt to break down through the literature of Indigenous Geography. I do not seek to create a metric to decide who is or is not Indigenous. I mean this to be a starting point through which to discuss several elements of Indigeneity. The next discussion will be about Indigenous self-determination, focusing on the United Nations' Declaration on the Rights of Indigenous Peoples. Finally, I will conclude by engaging the literature concerning Native American Sovereignty.

Indigeneity

The first element of Indigeneity I will problematize is the spiritual and ancestral connection to the land. Indigenous peoples are people who have a spiritual and ancestral connection to a particular place prior to colonization (Shaw et al., 2006: 268). The place where a people come from is intrinsic to what it means for them to be Indigenous.That connection is difficult to define because several different groups occupied some lands. Historically, lands could have been held by many different groups, in some areas were contested even before

European contact (Tsosie, 2005: 73). In the United States, blood quantum is another element of identity. About 80% of all Choctaws are less than one-quarter Choctaw by degree of blood (Lambert, 2007: 159). Some tribes like the Choctaw include in their membership all people who can demonstrate decadency from another tribal member, however, some tribes have limits placed on the degree of blood that their tribal members can have. Blood quantum can also harm what it means to be Indigenous. An example of this comes from Tasmania, where most of the survivors of the Tasmanian genocide were women that intermarried with Europeans, and thusly, their decedents did not have enough of a degree of blood to be considered Indigenous Tasmanians (Corntassel and Primeau, 1998: 146). Indigeneity is complex and cannot be defined by any one element, even though a ancestral connection to place is important to Indigeneity, it is not the only element in which Indigeneity can be discussed.

Indigenous ancestry does not automatically mean that they understand or participate in their culture. Even though many tribes in the United States have blood-quantum thresholds, cultural proficiency is not a requirement (Corntassel and Primeau, 1998: 145). This has led to Indigenous people who do not speak their language or know the history of their people. Alfred and Corntassel (2005) argue that by continuing to rely on blood-quantum only as a means of determining Indigeneity it will lead to more people becoming “incidentally Indigenous.” All cultures evolve over time, and to freeze what it means to be Indigenous in the past limits its ability to grow and evolve. Indigeneity is a process with a constantly evolving history and will continue to grow and change in unexpected ways (De la Cadena and Starn, 2007: 3). Indigenous people need to find a balance between lineage and culture to define what it means to be Indigenous.

Being Indigenous is also a political distinction that has national and international legal implications. Who is considered to be Indigenous, and how much influence over their lands and resources the Indigenous people have, varies by country (Alfred, 2009: 3). In the United States, a tribe is "federally recognized" through treaties, congressional acts or presidential executive orders that affirm that a tribe is politically sovereign within the United State federal system (Cornell and Kalt, 2010: 3). Even though there are hundreds of "federally recognized" tribes, there are tribes that are not recognized or only recognized by a state government. There are over 200 tribes that are seeking federal recognition by the United States government, which the recognition progress that only approves or denies one to two tribes per year, however, there are sixty-two tribes that through their ongoing presence within a state are acknowledged as tribes by the state, but not by the federal government (Koenig and Stein, 2008: 81-82). In addition to state recognized tribes, there are tribes that the federal government has removed their federal recognition. A terminated tribe is a tribe that once had dealings with the United States government but the government dissolved their recognition. Some of these tribes have blended into local non-Native populations, some now have state recognition, some have since been re-recognized by the federal government, while others have been absorbed into other federally recognized tribes (Myers, 2001: 275). Communities can also self-identify as "Indigenous." Self-identification should not be the sole criteria for Indigeneity (Corntassel and Primeau, 2006: 60). Indigeneity is a balance between cultural, ancestral, and political ties to a place.

For the purposes of this thesis, when I refer to Native Americans, American Indians, or tribes, I mean federally recognized tribes by the United States government. This thesis focuses on using a renewable energy project on Native American reservations. It is important to note that not all federally recognized tribes have reservations, i.e. most of the tribes in Oklahoma.

Furthermore, when I refer to “Indigenous peoples”, I mean communities that: 1) have a ancestral tie to a land, even if they do not have legal claim to that land, 2) still have cultural ties to that land (language, religion, etc.) that go back to before European contact and 3) identify themselves Indigenous, even if their national government does not recognize them as such. Indigeneity is complex and the factors that go into Indigenous identity multiply when one examines what it means to be Native American, Maori, or Aborigine. It becomes even more complex when one looks at the specifics of what it means to be Osage, Navajo, or Choctaw. This part of the thesis is a brief look at the major issues that face all Indigenous people in varying degrees. De la Cadena and Starn (2007) point out, “[t]racing the trajectories of Indigeneity should be about enablement, not endless destruction.” In that vein, I hope that this thesis enriches the definition of Indigeneity.

Indigenous Self-Determination

One of the main reasons that it is important to define which groups are Indigenous, is that Indigenous people have specific rights both at the national and international level. One of the fundamental rights that Indigenous people have is the right to self-determination. The United Nations Declaration on the Rights of Indigenous Peoples of 2007 (hereafter referred to as the Declaration) outlines Indigenous peoples’ right of self-determination. In the United States, tribal self-determination has been a government policy of self-governance and economic self-sufficiency since the 1970’s (Cornell and Kalt, 2010: 19). Even though this thesis focuses on tribal reservations, it is important to look at Indigenous self-determination as a broader global Indigenous right. The United States signed onto the Declaration in 2010 and was the last country to support the Declaration (Obama, 2010). Even though the Declaration is a non-binding, and thus not enforceable through international law, it is has international moral and political weight.

For this thesis, I will focus on Article 31 of the Declaration because it provides a definition for Indigenous self-determination. During the fourth Working Group on Indigenous Populations produced the first draft of the Declaration. The Section on self-determination reads as follows:

> All Indigenous peoples have the right of self-determination, by virtue of which they have the right of **whatever degree of autonomy they choose**. This includes the right to freely determine their political status, the right to freely pursue their own economic, social, religious, and cultural development and determine their own membership and/or citizenship **without external interference** (Pritchard, 1998: 45).

The draft of the declaration written in 1996, and had softer language than the 1985 draft. The Article 31 of the 1996 draft Declaration reads as follows:

> Article 31
>
> Indigenous peoples, as a specific form of exercising their right to self-determination, have the right to autonomy or self-government in matters relating to their internal and local affairs, including culture, religion, education, information, media, health, housing, employment, social welfare, economic activities, **land and resources management, environment and entry by non-members**, as well as **ways and means for financing these autonomous functions** (Burger, 1996).

In this draft, self-determination has several inherent rights including land, control over who are able to come onto that land, and the economic means to govern their lands. The declaration tied self-determination to land as well as culture and governance. The final draft of Article 31 reads as follows:

> Article 31
>
> 1. Indigenous peoples have the right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures, including human and genetic resources, seeds, medicines, knowledge of the properties of

> fauna and flora, oral traditions, literatures, designs, sports and traditional games and visual and performing arts. They also have the right to maintain, control, protect and develop their intellectual property over such cultural heritage, traditional knowledge, and traditional cultural expressions (UN General Assembly, 2000: 11).

All mention of land, rights to land, land ownership, or governance removed from Article 31. The main driver for the changes in the definition of self-determination came because of pressure from governments concerned about Indigenous government using self-determination to declare complete autonomy from their governments, for example the Nordic countries were concerned about the Sami parliament, whose territory spans across Denmark, Sweden, Finland and Russia (Errico, 2007: 9). Erica-Irene A. Daes (2001: 7), a Special Rapporteur and drafter of the 1996 draft, stated "It is difficult to separate the concept of indigenous peoples' relationship with their lands, territories and resources from that of their cultural differences and values. The relationship with the land and all living things is at the core of indigenous societies." Corntassel (2008: 108) argues that Indigenous self-determination is more than just a set of rights, and for it to exist for future generations has to "economically, environmentally, and culturally viable and inextricably linked to indigenous relationships to the natural world." The United Nations established rights of Indigenous peoples to exist and to maintain culture, but did not extend those rights to economy and the environment.

This thesis focuses on using renewable resources as an economic development strategy for Native American tribes. The United Nations' definition of self-determination does not include economic development, even though it does mention intellectual property rights. There may come a day that self-determination will include rights to land, resources and economic development, that day has not yet come. For this reason, I do not think that self-determination is an appropriate term to use in this thesis. I do hope that projects, like solar-powered biodiesel refining, will help to create a dialogue that will lead to Indigenous peoples' right to self-determination to include economic development. When that day comes, this thesis can serve as a blueprint of how to use renewable energy resources for Indigenous peoples to exercise that right.

Native American Sovereignty

The concept of sovereignty is a European concept. The legal definition of sovereignty is a people's right to create and enforce the laws within their territory (Deloria, 1996: 118). In Western culture, originally sovereignty was a divine right, in that God was sovereign over heaven and earth (Dan.7:14). As such, God could bequeath sovereignty to certain people, monarchs or the Pope for example (Dan. 7:27). Native Americans had sovereignty over their lands at the time of European contact, and have continue to exercise it to this day (Johnson, 2008: 31; Corntassel and Primeau, 1995: 56-57). The United States government has sought to control to what extent tribes are able to exercise their sovereignty. The United States government has limited or shared sovereignty with Native tribes through treaties, acts of Congress, executive orders and court cases, creating degrees of sovereignty instead of strict definition of either having sovereignty or not having it (Cornell, 2006: 15). Tribal sovereignty was inherent to all tribes before contact, but now it is highly dependent on the tribe's relationship and history with the United States government.

The first major impact to tribal sovereignty was the Marshall Trilogy decisions. The Marshal Trilogy is comprised of three Supreme Court cases that are the foundation of United States and Native American relations. In the first case, *Johnson v. M'Intosh* (1823), Marshall's opinion concluded that the United States government had sole authority to acquire Native

American lands. This meant that Native Americans could only deal with the United States government when it came to the sale of their lands. In the next case, *Cherokee Nation v. Georgia* (1831)*,* Marshall's opinion declared Native American tribes as "domestic dependent nations" that needed to be protected like "wards of the state" (Wilkins, 1997: 116-117). This not only placed tribal sovereignty under the dominion of the United States, it also set the standard that legally Native Americans are not able to take care of their own affairs. This also led to the concept of "trust responsibility" which stated that the dealings between tribes and the U.S. government be done in good faith for the protection of the tribe, and was elaborated on through Marshall's opinion in *Worcester v. Georgia* (1832)*,* where Marshall concluded that tribes had complete authority over their lands but the United States had a duty to protect tribal lands (Tsosie, 2003: 273). This meant that the tribes had the ability to make and enforce their laws within their borders, but it was a federal responsibility to protect those borders, even from state's actions.

On the heels of the Worcester decision, President Andrew Jackson began his policy of Indian removal. Jackson proceeded to remove Native Americans even though the Indian Removal Act did not dissolve treaties concerning tribal boundaries, nor did it authorize for tribes to be forcibly removed from their lands (Cave, 2003: 1330). Some tribes negotiated through treaties their own removal. The Choctaws signed the Treaty of Dancing Rabbit Creek in 1830, and ceded their lands east of the Mississippi River for federal protection (Black, 2009: 69). Jackson's Indian removal policy set a dangerous precedent. Indian removal from their homelands became a part of federal Indian policy throughout the 1800's however, ultimately failed because westward expansion was too rapid for negotiating deals, so force was used to remove tribes' rights to land and resources (Cross, 1998: 443). The forced removal of tribes through military action demonstrated the United States' dominion over Native American lands and forced the tribes to become the "domestic dependent nations" that Marshall labeled the tribes.

There are also instances where the United States government has strengthened tribal sovereignty through support or partnership with tribes. The Boldt decision led to the partnership of Northwestern tribes and, federal and state agencies to manage the salmon population. In his ruling Judge Boldt (U. S. v. State of Washington, 1974) said "[t]here is no indication that the Indians intended or understood the language 'in common with all citizens of the Territory' to limit their right to fish in any way." There is a clear asymmetry between the tribes and the state that led the twenty Western Washington tribes to band together and form the Northwest Indian Fisheries Commission (Singleton, 2001: 149). Judge Boldt determined that not only did the tribes have a right to half of the harvestable salmon, but also that they were to be co-managers of the watersheds (NWIFC, 2012). In making the tribes co-managers of the salmon harvest, Judge Boldt not only recognized the right of the tribes to the salmon, but the right to be stewards of the salmon. As a result, the NWIFC's co-management led to a dramatic increase in the available salmon for both the tribes and for fishing corporations. By the late 1980's, over 40,000 steelhead were harvested and over 1.5 million Coho and Chinook salmon were able to be harvested (NWIFC, 2011: 13). T federal court decision strengthened the sovereignty of the Northwestern tribes, and increase the availability of a cultural and economic resource.

As with the case of the Northwest tribes and salmon fishing, tribes can use their renewable energy resources as a way to develop their economies. They need to exercise "practical sovereignty", which means that tribes need to make their own economic development decisions in order to increase the odds that their projects will be successful (Cornell and Kalt, 2006: 12). The Indian Tribal Energy Development and Self-Determination Act of 2002

(ITEDSDA) allows tribes to create Tribal Energy Resource Agreements (TERAs) which will allow tribes to enter into lease agreements for their energy resources. These TERA leases are similar to the mineral resource leases that cut the tribe out of the negotiations taking the decision making out of the hands of the tribe (Royster, 2008: 1085). Currently, a proposed amendment to the ITEDSDA would take the Secretary out of the approval process. The amendment reads as follows:

> (B) by striking paragraph (2) and inserting the following:
> (2) A lease or business agreement described in paragraph (1) **shall not require review by, or the approval of, the Secretary** under section 2103 of the Revised Statutes (25 U.S.C. 81), or any other provision of law… (Indian Tribal Energy Development and Self-Determination Act Amendments of 2014, proposed May 21, 2014)

This would allow tribes to create TERAs and be in control of the negotiations bypassing the Secretary. This would also allow tribes to exercise their energy sovereignty in a practical way. “Energy sovereignty” is based on several factors including: 1) ownership of the energy projects by the people, 2) sustainable use of the resources, and 3) investment in renewable energies (Muhammad, 2014: 66). If tribes are able to exercise their “practical sovereignty” through the amended ITEDSDA, they will be able to use solar-powered biodiesel refining to exercise their energy sovereignty.

Chapter 2 Section 2: Natural Resources and Native American Lands

Native American resource management is fundamental to the study of Indigenous geography because tribes’ relationship with the natural world affects their worldview. Researchers need to be aware of the unique factors that go into mapping Indigenous resources. The tribalization process has reduced Indian people to wards of the Federal government (Cross, 2000: 895). As “domestic dependent Nations,” Native Americans were tribes were managed as wards of the state instead of being treated as true equals (Cherokee v. Georgia, 1831). As wards of the United States government, Tribes have limited options when it comes to resource management. Resources sit at the intersection of Indigenous cultures, sovereignty and sustainability, because how a people use resources is the foundation of their way of life. Climate change is making water, plant and animal resources harder to utilize and manage for the majority of Native American reservations (U.S. National Assessment Synthesis Team, 2009: 101). How are the reservations going to continue with their way of life without sacred plants, or access to water?

The Blurred Line Between Native Communities and Resources

The interdependency of Native people and their environments has been problematic for researchers who approach American Indian issues from a singularly Western academic point of view (Coombes et al., 2014: 2). As geographers learn that the connections between humans and nature are entwined, their studies of human cultures will extend past merely the understanding of the people, but the natural worlds that those cultures are forged in (Panelli, 2010: 79-80). Berkes (2004: 622) suggests that the study of a “socio-ecological system” should examine the dynamic interactions of humans and the environment by looking at humans as more than “stressors” or “managers.” When a researcher focuses on the human-nature dynamic in this way, it removes humans as superior to, or custodians of, nature and places humanity within the broader context of nature. Wildcat (2009: 99) sums up this concept thus, “The nature-cultural nexus is the unique interaction between a people and place.” The “nature-cultural nexus” demonstrates the dynamic relationship between the environment and culture. The impacts of anthropogenic climate change are an example of how culture can influence nature on a global scale. As the climate continues to change, the research nexus between culture and nature will become increasingly important.

Native American survival depends on a deep connection with their environment and the ability to manage natural balances (Pierotti and Wildcat, 2000: 1334). Culture has to be flexible and varied to survive. Native American's survival is determined by their ability to adapt to changing external factors (Berkes et al., 1998: 149). My project will allow tribes to adapt to increasing energy prices as well as be able to reduce their carbon footprint. This project focuses on utilizing small-scale refineries, instead of one large refinery, and thus, it will allow tribes to be able to be more flexible with their energy development. My research utilizes renewable energy with waste vegetable oil as a feedstock. This allows a waste product to be useful, and beneficial. Solar powered biodiesel refining helps to balance the drivers of climate change by reducing the net carbon that goes into the atmosphere, which will be gone into with more detail in the following chapters.

Resource Management as Sovereignty

The basis of Native sovereignty is the tribes' connection to the land, unfortunately though many Indigenous communities have no legal claim to the land. Globally, each settler-state (i.e. former European colonies) has its own history with Indigenous peoples and its own way of dealing with Indigenous land claims. There are three common problems that Indigenous peoples face globally: 1) ontological disconnection, or a fundamental difference in the way that the Indigenous peoples and the government see the world, 2) limits to communicative rationality, or just talking about monetary compensation instead of reconciliation, 3) transactional costs, or lengthy processes designed to frustrate and exhaust Indigenous efforts to (re)claim land (Coombes et al., 2011: 4-5). Native Americans have experienced this through the Land Claims Commission process. In the case of the Sioux claim to the Black Hills, which are sacred to the tribe, the government instead saw land and resources that could be turned into money.

Accordingly, the government assessed the value of the land (which at the time had no monetary value) and placed a $105 million price tag on the compensation for the loss of the land, a process that took more than a decade to adjudicate (Lazarus, 1999: 269, 374). This is only one Native American land claim case, but it does highlight the issues that Indigenous people have when trying to (re)claim their homelands.

Even if a tribe has a reservation and thusly some control over its resources, there are still major issues that they face. Tribes do not have control over their mineral rights and still need to go through the federal government for mineral leases. In the case of the Peabody Coal Mine on the Navajo reservation, the Secretary of the Interior supplied the mining company with information that allowed them to underpay the Navajo resulting in losses of up to $600 million, and the Supreme Court ruled that the Secretary's actions were not a breach of the United States' trust responsibility (Royster, 2008: 1085). The fight for tribal sovereignty requires that tribes reassert their own legal controls based on their own cultural worldviews in accordance with the interests of tribal members, but within the context of non-native laws, courts and governing agencies (Cross, 2000: 958-959). Tribes have to walk a thin line between the preservation of their culture, and the fight for their sovereignty. Native Americans need to strive towards their own definitions of sovereignty and self-determination, which will include how best to use natural and cultural resources to the benefit of tribal members.

Tribes are starting to utilize renewable energy projects to strengthen their sovereignty. An example of tribes using renewable energy to strengthen their own sovereignty is the Intertribal Council on Utility Policy (COUP) that connected Midwestern United States Tribes so they could collectively empower themselves by developing renewable energy projects like industrial wind turbines on the Sioux Reservations (Middlemiss and Parrish, 2010: 7564). Solar powered biodiesel refining, increases a tribe's ability to write its own destiny by creating a project that gives control over the means of production, the management of the resources, and the ownership of the product. The utilization of resources to promote sovereignty is not a new idea. The Algonquin Confederacy in the north and the Five Civilized Tribes in the south disrupted the European power bases until the latter half of the 18th century by utilizing strong partnerships with European allies that would not have been possible without practical economics and resource management (Cross, 1998: 430). These tribal groups were able to exercise their sovereignty through utilization of their resources. Renewable energy projects help Native Americans not only create economic benefits, but also strengthen ties to a place, while increasing its value.

Sustainable Use of Resources

Tribal resources are most beneficial to tribal members when tribal members can sustainably use the resources. On a broader global scale communal property ownership is the basis of sustainable use of resources, which is opposite from private property ownership. Indigenous property claims force Indigenous people to sacrifice cultural recognition of property rights (Coombes et al., 2011: 7). The establishment of a private property system establishes monetary land values and aids in controlling Indigenous populations (Demarest, 1993: 27). Privatization of Indigenous lands allows the dominant government to control Indigenous resources through taxation and other means. A way that Native Americans can mitigate the impacts land privatization is through sustainably using renewable energy technologies, like solar-powered biodiesel refining. There are three main aspects for evaluating the sustainable use of resources on a Native American reservation: 1) seven generations thinking, the understanding that decisions today impact the next seven generations, 2) natural intelligence, the usage and discovery of technology that is best suited for the people and place, 3) seeing relationships in complex harmony, the striving toward life enhancement, for the people and the planet (Wildcat, 2009: 124-125;131). Wildcat's recommendation is radically different from the mainstream recommendation for usage of resources in the United States, which focuses on maximizing profit margins. Tribes are also facing dwindling resources on their lands. Sustainable use is intrinsically at odds with conservation efforts, because sustainable use means that people use the resources in a responsible way, while conservation is seen as setting resources aside, removing them from use entirely (Berkes, 2004: 628). It is important for American Indians to be able to use resources responsibly, because their resources are limited to begin with, and they cannot afford to use up all of their resources and there are not enough resources to conserve.

The goal of refining biodiesel using solar energy is to assist tribes with sustaining their life-ways as well as being economically sustainable. The nature of Native American pedagogies is the implementation of sustained intergenerational knowledge that is passed from elder to child, through ceremonies, stories, songs, etc. (Berkes et al., 2000: 1257). This energy project can make use of its own waste products, for example, soap is made with lye and glycerin which are both associated with biodiesel refining. Because of the multiple benefits that this project can produce, it opens the way for each family member to be a part of it, by learning the process, and passing the knowledge down to the next generation. The development of Native American sustainability starts with the family then extends through extended families, clans, and finally tribes, and promotes division of labor, sharing of resources, social awareness and a respect for all life (Clarkson et al., 1992: 14). The nature of my renewable energy project helps to bring communities together to produce an energy resource that all the tribal members can benefit from. The eventual goal is that the biodiesel refineries profit the community as a whole, and not for personal profit.

Chapter 2 Section 3: Indigenous Research Methodology

Neitschmann (1995: 5) observed, “[m]ore indigenous territory has been claimed by maps than by guns. This assertion has its corollary: more indigenous territory can be reclaimed and defended by maps than by guns.” The same holds true for Indigenous knowledge and researchers. This is especially important for Indigenous geographers because their focus is on working with Indigenous communities. It comes down to who holds the gun, or in this case, the pen. Research, like a gun or a pen, is a powerful tool and it requires respect because its impacts can be devastating.

In my research, I have held a simple, yet strong, stance: if my work does not empower Indigenous people, then it is not worth doing. The goal of this thesis is that it as beneficial to Native American tribes as it is to myself as a researcher. In addition, I designed this thesis to direct geographic information to Native American tribes, not take information from them. One of the ways that I do this is through the usage of a Geographic Information System (GIS), recognizing that this technology raises ethical issues specifically for Indigenous communities.

Mutual Benefit

I am receiving funding, a degree, a stepping stone to my future, what can I give back that is anywhere close to equal to the community that I am working with? Smith (1999: 120) recommends hosting the people and being generous. Research with Indigenous communities should ideally co-produce respectful and empowering knowledge (Castleden et al., 2012: 173). One of the ways that researchers can give back is by doing research that strengthens Indigenous sovereignty and self-determination. Researchers need to take a multi-layered reflexive look how their research affects themselves, the Indigenous people that they work with, and the Indigenous community as a whole in equal measure (Nicholls, 2009: 22) It is easy for researchers to look at how their research will benefit themselves, but that can blind a researcher to potential harms that the research can do to the Indigenous community.

There are several ways that small scale solar-powered biodiesel refining can benefit a tribal community. First, this project examines the feasibility of using a renewable energy project as an economic development project. By investing in renewable energy projects, tribes can strengthen their sovereignty (Cornell et al., 1992: 12). In addition, this thesis focuses on smaller scale units that allow for more local community involvement. Small-scale renewable energy projects are best suited for reservations because the tribe is in a better position to access the needs of the community and deal with local issues (Dreveskracht, 2011: 153). Finally, Solar-powered biodiesel refineries are small-scale systems that do not alter land usage and are small enough to be portable and using waste vegetable oil (which is not a mineral or a fuel crop). This means that the solar-powered biodiesel refining systems can be built without the need for a lease approved by the Secretary of the Interior (Royster, 2012: 102-105). Solar-powered biodiesel refining strengthens tribal sovereignty by demonstrating how tribes can invest in a renewable energy resource, encouraging local involvement with the project, and places the powered to invest in a renewable energy project back into tribal hands.

Directionality of Knowledge

A goal of this research is to share knowledge with tribal communities, not just take knowledge from them. By looking at the research experience as knowledge sharing, knowledge cannot be owned (Wilson, 2001: 177). I want to share my knowledge with native communities, not just have receive knowledge from them. If tribal research projects are successful, in the end, tribes will no longer need researchers because the tribes will be able to do the research themselves (Coombes, 2012: 290). Research should not just provide knowledge to tribal groups, but it should give useful knowledge. Researchers that use research to reclaim tribal knowledge should keep in mind the relationships between the researcher, the community, and the larger political motives of decolonization (Smith, 2007: 117). My desire for the research in this thesis is to provide tribes with practical knowledge that strengthens their tribal sovereignty and ultimately leads to tribes being in charge of their own agenda.

The first way in which my research changes the directionality of knowledge is through the GIS maps that I created for this thesis. The data came from the National Renewable Energy Laboratory and the United States Census, both of which are government entities. I reinterpreted the data and presented it in a format that privileges tribal reservations. By mapping renewable energy resources, it allows tribes to assert their control over those resources and prevent environmental disputes. Coombes et al. (2011: 9) states, “Indigenous motivations in environmental disputes are connected to broader projects of recognition, reclamation of sovereignty and resistance to capitalism; they are not mere resource conflicts.” Tribal control over their resources, even renewable energy resources, assist in tribal claims to the land. Mapping renewable energy resources is the first step to establishing tribal control over those resources. Even if tribes do not use the maps for the solar-powered biodiesel refining, tribes can still use the data to evaluate which renewable energy option would be best suited for their tribe.

Indigenous Issues with GIS

There are conflicting views concerning the usage of GIS when mapping Indigenous lands. Rundstrom (1995: 45) asserts that GIS is incompatible with Indigenous ways of knowing, and is a tool for “epistemological assimilation” which threatens Indigenous cultures. Pearce and Louis (2008: 108) state that “[m]aps are now fundamental to Indigenous self-determination and perceived to be essential tools for portraying Indigenous environmental, political, cultural, and socioeconomic landscapes.” How can GIS both be a tool for assimilation and a tool to protect sovereignty? For Indigenous peoples the chief failing of the technology is that it does not take into account Indigenous ways of seeing space and place and prioritizes Western ontologies (Turnbull, 2007: 144). When Indigenous peoples utilize GIS to protect their cultural and terrestrial rights, they may have to sacrifice cultural ways of preserving knowledge (stories, songs, dances, etc.) finding the technology unreceptive to incorporating Indigenous epistemology within its construct. Indigenous peoples have begun forcing GIS to assimilate to their culture. An example of this is the Bdote Memory Map, which embeds videos of elders telling stories about important cultural places to the Dakota people (www.minnesotahumanities.org).

Beyond the ontological issues that Native Americans have with GIS, government agencies like the Bureau of Indian Affairs (BIA) are the main providers GIS software and infrastructure to tribes. The BIA first began to be interested in using GIS in 1975 and wanted to use it to evaluate resources on reservations by archiving information on resources without the notification or consultation of the tribes (Palmer, 2012: 84). Widespread use of GIS by federal agencies did not begin until the 1980s. In 1983, the Indian Integrated Resource Information Program (IIRIP) began to acquire and archiving spatial data on Native American Reservations (Palmer and Rundstrom, 2012: 1149). The main problems with the IIRIP were that tribal members had little to no access to the data, and that the achieved data quantified and commodified Native American resources. In recent years, several tribal integrated GIS into their governments, but the expertise to use GIS technology is still highly dependent frequently on the

BIA and government agencies, or university researchers. The proliferation of GIS infrastructure and the rationing of expertise from the United States government creates and maintains "networks of dependency" (Palmer, 2009: 37). If tribes want to use maps to protect their resources, they need to use GIS, even though the BIA has and is continuing to use GIS to chip away at tribal sovereignty. The use of GIS is another compromise that tribes and researchers have to make in order to protect tribal resources.

The BIA-created GIS infrastructure also compromises tribal sovereignty by not keeping tribal spatial data secure. Tribes have historically felt abused by the United States' attempts to collect information, and subjecting Indigenous peoples to remote sensing without the guarantee of privacy will increase the abuse felt by tribes (Madsen, 1995: 1). According to the decision in *Department of Interior v. Klamath Water Users Protective Assn. (2001),* the Supreme Court decided that information shared between the BIA and tribes was not protected under the Freedom of Information Act (FOIA). If tribes use BIA provided computers or GIS, the data may be subject to FOIA (Shanley, 2005: 2). In the BIA Quality Information Guidelines, it states, "[m]aking data and methodology publicly available will assist in determining whether analytic results are reproducible. Tthe objectivity standard does not override other compelling interests such as privacy, trade secrets, intellectual property, and other confidentiality protections established by law." (Interior, 2002: 2). The BIA in providing tribes with GIS infrastructure has made it so anyone can request private tribal spatial data. By mapping sacred sites to protect them, tribes may accidently reveal locations of cultural importance to outsiders by utilizing GIS equipment provided by the BIA (Smith, 2008: 140). Data security comes down to who has control to the infrastructure and access to spatial data.

Even though this thesis uses GIS, it is only one cartographic tool. GIS is not the tool to solve every cartographic problem. GIS is a powerful tool and ethical usage of it helps tribes to protect their land and resources. GIS is a double edge sword and can equally help or hurt tribal claims to land and resources. If GIS users and tribes are not careful, in another decade the Neitschmann quote may become "[m]ore indigenous territory has been claimed by GIS than by guns."

Chapter 2 Conclusion

Solar-powered biodiesel refineries on reservations are fundamentally an Indigenous geography issue. The goal of the project is to strengthen Native American energy sovereignty. The first step was to establish what I mean when I use the term Native American. Next, I established what sovereignty means when applied to Native Americans, which in defining energy sovereignty from a tribal perspective. Renewable resources fuel the refineries, so I provided closer examination of issues dealing with Indigenous resources and land. Finally, I examined Indigenous research ethics in the field of Indigenous geography to ensure that my project would empower tribes.

Even if tribes do not invest in solar-powered biodiesel refining, or any other renewable energy project, they will need to be careful using their land and resources. As Indigenous resources disappear, so will elements of Indigenous culture. In order to prevent this, tribes need to exercise control over their resources to manage them sustainably. Intelligent management of Indigenous resources helps tribes to preserve their natural resources, their cultures, and their political integrity. Solar-powered biodiesel refineries are one way that tribes can sustain their resources and their economies.

Solar-powered biodiesel refining is only one example of a renewable energy project for tribal investment. Each technology has its advantages and drawbacks, but it is important for tribes to take into account how the technology can strengthen their sovereignty. The field of Indigenous geography provides the tools to examine renewable energy projects, and emerging renewable technologies. In addition, ethical research within the field of Indigenous geography creates a standard that tribes can apply to any research project concerning their people, lands, or resources. Ethical Indigenous research should empower Indigenous peoples to the point that they are the ones in control of what research they want conducted on their lands to solve the practical problems of their people.

Chapter 3 Renewable Energy

Chapter 3 Introduction

Geographic Information Systems (GIS) are computer programs that lets us see and interpret geographic data to understand spatial relationships. GIS is also a tool that tribes can use to assess the availability of renewable energy resources for their reservation. If tribes would like to use renewable energy to exercise their energy sovereignty, they will need to use tools, like GIS, to investigate the feasibility of a specific technology on their reservation. In this chapter, I will investigate the technical aspects of solar energy, biodiesel refining, and a hybrid solar power/biodiesel refining system. Each energy technology has its own Energy Return on Investment (EROI). I will use spatially analyze renewable energy resources for reservations. A comparison of reservations will show which renewable energy project will be best suited for geography of each reservation.

This chapter will look at three different renewable energy options: 1) solar energy, 2) biodiesel refining, and 3) a hybrid solar power/biodiesel refining system. Each section of this chapter will examine the technical aspects of each technology, the specific issues when using GIS to map these sources of the renewable energy system, and the methodology to map the renewable energy resources for each reservation. Every tribal energy development project will have trade-offs that will need to be considered. For example, the Garrison Dam in North Dakota is a hydroelectric dam that produces a lot of electricity. Unfortunately, it also flooded the three affiliated tribes' reservation (Cross, 1998: 485). The loss of arable farmland to build a reservoir as a renewable energy is a trade-off not worth tribal investment. Hydroelectric dams are not as efficient compared to other renewable energy resource projects. PV panels' biggest drawback is that the energy production is variable and subject to available sunlight (Lewis, 2007: 800). Biodiesel still relies heavily on fossil fuels to transport the biodiesel and to build and power the refinery (Hill et al., 2006: 11206). Even though both solar and biodiesel technologies are considered renewable, they may not be sustainable. Tribes need to be aware of both the positive and negative aspects of each technology before investing their time and money into a renewable energy project.

Researchers need to understand the technical aspects of both solar energy and biodiesel before the implementation of the technologies on reservations. Biodiesel uses concepts of chemistry to turn triglyceride oils into biodiesel. In this thesis, the feedstock for the biodiesel refining will be used cooking oil, also known as waste vegetable oil (WVO). Solar energy operates on principles of physics to convert energy in sunlight into electrical energy. In this thesis, the solar energy will be provided through photovoltaic (PV) panels, even though there are other options for producing solar energy, for example passive solar, thin films, etc. Solar powered biodiesel refining utilizes both chemistry and physics principles in its operation. The primary reason for examining solar powered biodiesel refining utilizing WVO and PV panels is simplicity. The less training that is required for tribal members means that they are more likely to use the technology. There are other more complex ways to refine biodiesel and highly technical solar energy technologies, but both would require specialized training. There needs to be enough human resources on a reservation for a renewable energy project to be feasible.

This chapter will use Energy Return on Investment (EROI) as a measure energy into a system compared to the amount of energy put into a system. The EROI is figured by taking the energy output and dividing it by the amount of energy into the system (Murphy and Hall, 2010: 102-103). The energy into the system includes fixed energy (like energy used to construct a building) and variable energy (like the energy used to transport feedstocks). If the EROI is less than 1, the system does not produce more energy that it takes to produce the energy. Any energy project that does not have an EROI greater than 1 is not worth investing in. Moreover, conventional fossil fuels have an EROI up to 18, and if a renewable energy system does not meet or exceed fossil fuels' EROI, there is less of a chance that it will be able to replace fossil fuels (Hall et al., 2008: 118). Different renewable energy projects have different EROIs, which means some renewable energy systems are more efficient than others are. A tribe would want to maximize their EROI because that means that the technology is less dependent on fossil fuels.

Chapter 3 Section 1 Biodiesel Refining

Tribes have already begun considering biodiesel as a viable renewable energy source. The Nez Perce tribe built a biodiesel refinery in 1986, and has already changed its tribal government vehicle's to diesel so they can run on the tribe's biodiesel, produced from several different feedstock sources (Kipp, 2013). In 2011, tribal colleges and high schools competed to build biodiesel refining projects (Lerner, 2011). In 2012, the Council of Energy Resource Tribes, a group of 27 California tribes, decided to develop biodiesel projects on their reservations (Cheeseman, 2012). It is clear that tribes want to develop biodiesel on their reservations, even though biodiesel is still heavily dependent on fossil fuels to refine. If tribes are going to consider using WVO as a feedstock, they will require maps that show the refining potential of their reservation.

A chemical process called transesterification converts triglycerides into methyl esters (figure 1). Any plant oil can be refined into biodiesel using this process, even used cooking oil. The basic process of refining biodiesel is as follows: 1) mix the triglyceride with methanol and a catalyst (such as potassium hydroxide) 2) separate the mixture (the glycerol is heavier and settles to the bottom, 3) mix water into the bio diesel (the water will separate taking excess methanol as methanol hydroxide with it), 4) allow the biodiesel to evaporate excess water by setting in an open container for 24 hours (Figure 2). Even though the chemistry may seem complex, the actual refining of the biodiesel requires little training.

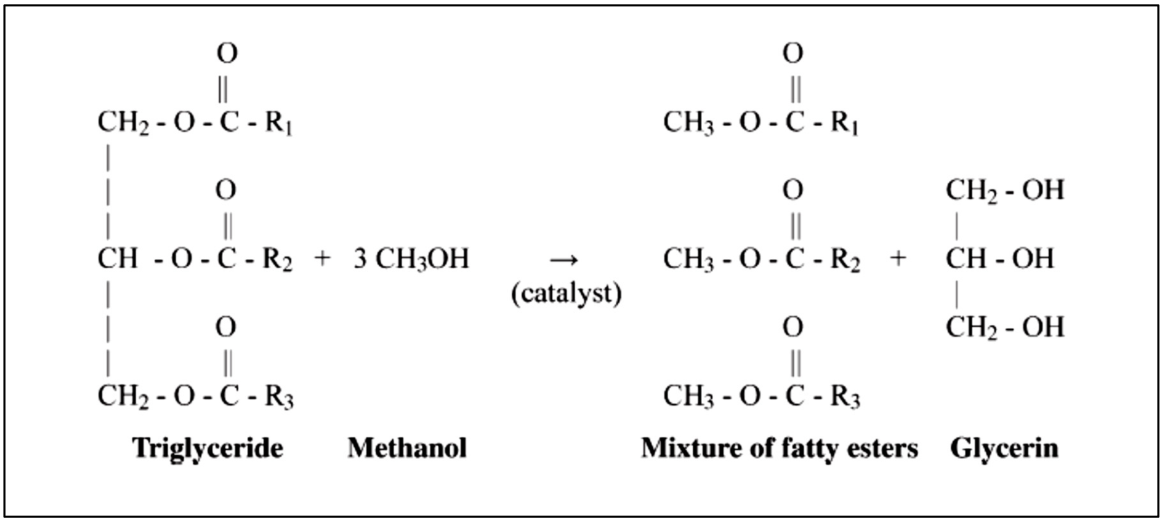


Figure 1. The chemical process of refining biodiesel. (Gerpen, 2005: 1099)

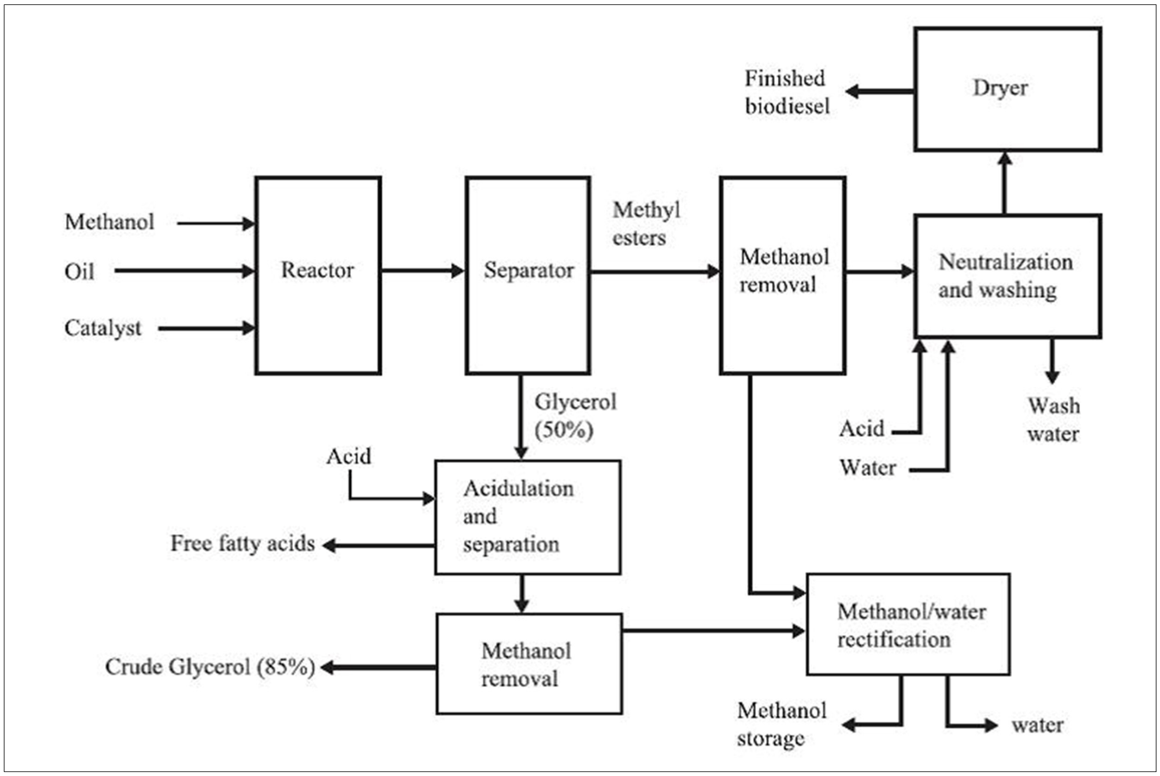


Figure 2. The physical process of refining biodiesel. (Gerpen, 2005: 1101)

The Advantages and Disadvantages of Biodiesel Refining

There are several advantages to investing in biodiesel refining. The chief of which is that the waste from biodiesel refining does not need to be thrown out, but can be useful in several ways. Glycerin is a common component in soaps, shampoos, and conditioners. Soap is made by combining WVO, NaOH and water, which are all ingredients used in refining biodiesel (Hill, 2004: 1659). In 1983, a patent was drafted showing a technique to make soap bars that include glycerin (a biodiesel byproduct) in soap making (Nyquist et al., 1983). The glycerin helps to condition skin as the soap is used. Glycerin is a commodity that there is an emerging market due to the influx of glycerin from biodiesel refining new uses for glycerin will continue to be developed (Kenar, 2007: 253). Glycerin, a waste product, is a marketable product that can increase the profits from refining biodiesel.

In addition to creating multiple revenue streams, investing in biodiesel also has other advantages. If they already run on diesel, vehicles and machines do not need to be modified to operate on biodiesel, because biodiesel is chemically similar to traditional fossil fuel-based diesel (Demirbas, 2009: 25). Tribes can gather biodiesel feedstock locally, instead of across the nation or the globe, which is the case with fossil fuel energy. One of the main reasons that biodiesel is being pursued by the United States is because it can reduce the dependence on foreign oil, which is becoming increasingly more expensive to extract and refine, while being dominated by a few countries, some of which are located in unstable regions like the Middle East (Lin et al., 2011: 1026). Carbon released by biodiesel is carbon recently sequestered by the plants, which can reduce a tribe’s carbon footprint. Biodiesel is renewable fuel that reduces unwanted emissions in the environment (Yusuf et al., 2011: 2746). Biodiesel is not only a renewable resource, it is has less of a carbon footprint than traditional diesel. By investing a biodiesel refinery, a reservation could have a renewable resource that does not require modifications to vehicles, provides a local source of liquid fuel, and reduces carbon emissions into the atmosphere. All of which, add to the value of investing in biodiesel refining.

This thesis also addressed the disadvantages of biodiesel refining. Biodiesel is not a replacement for gasoline. Right now, almost all passenger cars run on gasoline. Most heavy equipment, large trucks, and busses that run on diesel also run on biodiesel. In addition, SUVs, light trucks and passenger cars are expected to transition to diesel engines, because biodiesel production is becoming more prevalent and creates a cheaper fuel than fossil fuel based diesel (Ohlrogge et al., 2009: 1020). Right now people in the United States use about one gallon of gasoline a day, this thesis will assume that for biodiesel to be viable to provide the liquid fuel needs of a reservation that one person will use one gallon of biodiesel per day (U.S. Energy Information Administration, 2013). There is not enough land for the United States to feed everyone and to turn crops into biofuels. For this thesis, the feedstock will be waste vegetable oil, which is an inedible waste product. In addition, there may not be enough land to support all of the United States' fuel needs, but there is enough to provide for reservations. Biodiesel does have structural differences from fossil fuel based diesel. Biodiesel has a higher viscosity, lower energy and more frequently clogs fuel injectors than traditional diesel (Demirbas, 2007: 4666). The chemical structural differences between biodiesel and diesel can result in less fuel efficiency and more maintenance costs for vehicles. Those chemical differences are minor and as more people use biodiesel, the impacts will become less noticeable to the consumer. Finally, biodiesel still depends on fossil fuel energy to refine the product. Even though the efficiency of biodiesel is similar to fossil fuel based diesel, there is still a need for fossil fuel input to refine biodiesel (Sheehan et al., 2000: 13). The required fossil fuel input in the form of electricity for the heating and mixing stages of the biodiesel refining process will still need to come from off of the reservation. Even though biodiesel has some disadvantages, the advantages still make it a viable investment for tribes.

Technical Aspects of Biodiesel Refining

The three main resources that are involved with producing biodiesel are the feedstock, an alcohol and a catalyst, each element affects the energy equation of the biodiesel refining system. The feedstock can significantly alter the energy equation when producing biodiesel. This thesis will focus on utilizing used cooking oil as a feedstock. Each megajoule (MJ) of energy that is in biodiesel, utilizing used cooking oil, requires 0.183 MJ of fossil fuel energy to process the biodiesel, or about 5 MJ of biodiesel out per 1 MJ of energy in (Hill et al., 2006: 11207). This is because waste cooking oil does not need to include the input energy from growing the feedstock because the oil has already been grown and utilized for another purpose. The choice of methanol or ethanol as a chemical reactant will come down to the accessibility of the alcohol and the costs involved with each. From an energy stand point, there is almost no difference between using methanol and ethanol (Janulis, 2004: 866). The final consideration is the type of catalyst used. Sodium or potassium hydroxide are the preferred catalysts because the reaction can occur at lower temperatures, thus keeping the energy added into the system to a minimum (Demirbas, 2009: 29-30). Sodium hydroxide and potassium hydroxide both have a conversion rate of 99%, which is the same as an acid based catalyst and a higher conversion rate than no catalyst being used (95%) (Yusuf et al., 2011: 2744). There is just as efficient catalyst either from a conversion perspective or from an energy perspective than sodium or potassium hydroxide. It is important to note that used cooking oil does contain free fatty acids as well. Yellow grease has less than 15% fatty acids as opposed to brown grease that contains more than 15%. Most waste vegetable oil is a mixture of both, and higher levels of free fatty acids greatly reduce the efficiency of the reaction using sodium or potassium hydroxide (Canakci and Van Gerpen, 2001: 1430). For the purposes of this thesis, biodiesel refining uses used cooking oil, methanol, and sodium hydroxide as resources.

A tribe will have to decide if building a biodiesel refinery is best suited for their reservation. The biodiesel has many uses, for example, powering cars, trucks, and farm equipment, or blended into petroleum diesel. The energy EROI of biodiesel is about 1:5 the amount that is produced by a refinery (Hill et al., 2006: 11207). This is much lower than the EROI of 1:18 that petroleum based diesel uses (Hall et al., 2008: 118). Biodiesel refining on reservation lands is feasible from an energetic point of view. Tribes will need to know if there is enough WVO around their reservation to supply the refineries with enough feedstock to make it feasible to refine biodiesel.

Methodology for Mapping WVO for Reservations (map on page 56)

In order to know if a tribe can use WVO as a feedstock, they need to know how much WVO is close to the reservation. WVO correlates to population as a proxy. The reservation geographic data derived from the *2010 Census Demographic Profile Census Tracts.* Then, *The Indian Lands in America* (National Atlas of the United States, 2005) map, which provided the borders of each reservation, was overlaid. I created a new shapefile using a 50-mile border around each reservation. The buffered shapefile spatially joined to the Census tract map using the summation feature. I figured the sum of all the census tracts within the buffer zone establishes how many people live within fifty miles. The buffer zone joined by the unique attribute federal identifier “FID” so the population data connects to the original reservation shapes. Based on the fact that each person produces about twenty-two pounds of total WVO per year (Wiltsee, 1998: 3), the amount of WVO was established using map algebra (figure 3). This comes to about 3 gallons of WVO per year per person. The data of map is shown in units of gallons of WVO produced per day, and is separated by 20% quartile sections.

$$\overset{\text{1 Person}}{\frac{22\ \cancel{\text{Pounds}}}{1\ \cancel{\text{Year}}}} \times \frac{1\ \cancel{\text{Year}}}{365\ \text{Days}} \times \overset{\text{Specific Gravity}}{\frac{1\ \text{gallon}}{8\ \cancel{\text{Pound}}}} = \frac{0.008\ \text{gallon}}{1\ \text{day}}$$

Figure 3. Amount of WVO produced per day by a person.

In this thesis, the amount of WVO correlates to U.S. census population data, which means that there are inherent flaws in how the data is collected. The first reason being that tribal areas are generally remote and the people are difficult to reach by the mail, phone, or census takers (U.S. Census, 2011: 7-5). This would mean that Native American reservations in rural areas have a higher probability of underrepresentation. Another issue is that Native Americans may not want to respond to government officials trying to count them (U.S. Census, 2011: 7-7). Tribal members may not be interested in speaking up when the government wants to enumerate them. The final issue is that the U.S. Census does not provide their forms in tribal languages, which may cause data to be misunderstood by tribal members (U.S. Census, 2011: 7-8). Even though the majority of Native Americans speak English, some tribal members only speak their native language. Each of these errors reduces the number of people, which reduces the amount of WVO that reflects in this thesis's data .The U.S. Census is the way that most tribes keep track of their on-reservation populations, and so this thesis will rely on the data despite the inherent underrepresentation of the population. Comparing the available WVO to the tribal population mitigates the underrepresentation of the tribal members.

This method does not take the size of the reservation into consideration. For a smaller reservation, it may not matter much, because if a reservation is only 1 mile by 1 mile, then the maximum distance a WVO source would be is still about fifty miles. For larger reservations, like the Navajo reservation, the refinery site chosen may be hundreds of miles away from population centers, but still be represented by the buffer. In addition, this technique does not take into account infrastructure. The site of a biodiesel refinery and a population center may be geographically close, but there may not be roadways between the two. The map created for this thesis compares reservation to reservation and lacks the resolution to choose a specific refinery site on a single reservation. If one were comparing sites, especially within the same reservation requires a customized buffer, with the site in the center and a buffer around major roadways 50 miles in each direction, using restaurants to estimate the amount of WVO.

Chapter 3 Section 2 Solar Energy

This thesis will focus on photovoltaic (PV) panels when referring to solar energy. Solar panels work by using energy from photons to create electricity. The sunlight hits the solar panel and produces electricity that can be either used as DC electricity or run through an AC inverter to be used as alternating current into the electric grid (see figure 4). In comparison to biodiesel, refining, solar energy is a simpler process of creating energy. It is necessary to install solar panels on roofs and on the ground in an open area facing towards the equator. Once installed, the panels need little to no maintenance. Reservations can take advantage of the versatility solar energy offers.

Advantages and Disadvantages of Solar Energy

Solar energy has several advantages that would interest tribes. The first major advantage is that the sun is a truly renewable energy source. The amount of energy that the earth receives from the sun over 40 minutes is equal to the amount of global energy consumption for a year (Zweibel et al., 2008: 65). Another advantage that solar energy offers is that the panels themselves can reduce pollution while producing electricity. In Kansas, each kWh produced by solar energy offsets about 1.39 metric tons of CO_2 (Connors et al., 2005: ES-7). In addition to reducing pollution, solar panels are small, lightweight, and portable forms of electrical production. Solar energy can provide electricity to areas of reservations that are not connected to the electrical grid for their energy needs (Dreveskracht, 2011: 146) Another key advantage is that solar panels also require a small amount of fossil fuel energy to mine the materials, produce the panels and transport them. For 1 MJ of energy used to create the solar panels, the solar panels provide about 6.5 MJ of energy (Lewis, 2007: 799). This makes solar energy a local, renewable energy source that offsets carbon while providing more energy out of the system than into it.

Solar energy has several major drawbacks that might make it not worth the investment by a tribe. The first major drawback is that solar panels are an expensive initial investment. The current price per kWh will need to be \$0.25- \$0.30 in order to recover the initial investment of a solar panel system within a year, which is about three times the current price per kWh (Lewis, 2007: 798). Depending on the type of solar panel the payback time can be between 1.1 years and 13 years (Meier, 2002: 85) The payback time of solar panels depends on the solar density and the price of electricity in an area. Solar panels also take up a lot of space. Depending on the location, the average daily production of solar energy is between 3-10 kWh per square meter. If a person uses about 14 kWh per day, there would be a need for 2-5 square meters per person. Finally, solar panels produce variable amounts of energy. The biggest limitation to Photovoltaic panels being used is that they produce varying amounts of electricity, i.e. they do not work at night and have reduced efficiency when it is cloudy (Zweibel et al., 2008: 66). This thesis will assume that the solar panels will last 30 years, that the average daily solar density is the same throughout the year, and that there is adequate roof space on buildings to accommodate the space that the solar panels will require.

Solar panels are environmentally friendly and are a renewable source of electricity. Solar panels also are expensive and provide a variable amount of energy. Because solar panels are more aligned with Native American cultural values, it has a higher likelihood of being a successful tribal development enterprise (Cornell and Kalt, 2006: 16). A reservation is more likely to embrace solar energy as a technology, even with the drawbacks, because the concept falls in line with Native America ideals (Dreveskracht, 2011: 144). The Mojave Indian Tribe in California has already built a 310 MW solar farm on its reservation (Fontana, 2013). Tribal governments and members may be willing to pay more money for a source of electricity that is not fossil fuel based. This thesis considers solar energy as a viable option for reservations because it is cultural relevant to the tribes and that outweighs the drawbacks.

Technical Aspects of Solar Energy

Solar panels function by using energy from photons to create electricity. The sunlight hits the solar panel and produces electricity that can be either used as direct current electricity or run through an inverter to be used as alternating current (see figure 4). The theoretical limit to the efficiency of photovoltaic panels is about 31% (Lewis, 2007: 798). This is because on average 1 photon out of 3 can be converted into electricity, which means for now there is a theoretical limit to the potential of solar power development. In the future, solar panels will probably become cheaper and less energy intensive to create, even though it is unlikely that their efficiency will increase (MacKay, 2008: 42). Even though PV panels convert a small amount of photons to electricity, tribes can still make use of PV panels. Tribes with access to the electrical grid can sell the excess electricity produced by PV panels to electric companies as well as provide a reliable source of electricity for those areas of a reservation that are not connected to the grid (Dreveskracht, 2011: 146-147). PV panels rely on sunlight to produce electricity, which creates a variable source of electricity. The variable nature of solar energy means that the electricity needs to be stored to be used for later, in batteries or super-capacitors for example (Lewis, 2007: 800). Solar energy provides a local source of electricity that can be under the tribe's control.

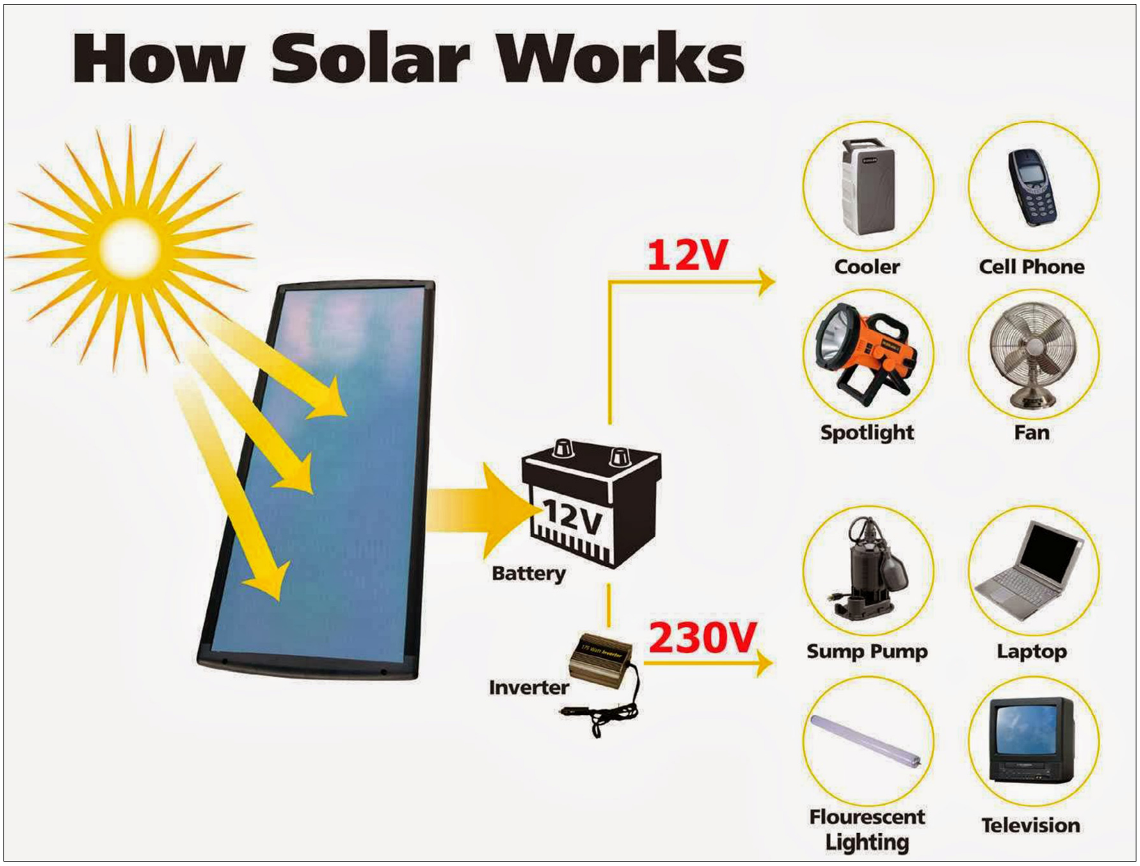


Figure 4. Solar electricity diagram (http://precisiontechelectricnj.com/wp-content/uploads/2012/02/HowSolarWorks.jpeg)

Methodology for Mapping Solar Energy for Reservations (map on page 57)

The Solar resource for each reservation was determined by using National Renewable Energy Labs (NREL) solar maps to estimate the yearly average solar density per day. The process was started using NREL's *Concentrating Solar Resource Direct Normal (2005)* map data. This data assumes that the PV panels are installed tilted from the horizontal at an angle equal to the latitude, and as such does not take topography into account (National Renewable Energy Lab, 2013b). *The Indian Lands in America* (National Atlas of the United States, 2005) map, which provided the borders of each reservation, was overlaid. I spatially joined the two maps using the average function. This averaged the solar density within a reservation. The map's data is in 20% quartiles.

NREL compiled the GIS data in the solar map. The solar energy was determined using the climatological solar radiation (CSR) model. There is an understood degree of error of ±10% for all of the solar density maps using the CSR model (Maxwell, 1998: 505). This means if a reservation has an average solar density of 4.4 kWh per day, it is actually between 4.0-4.8 kWh. Another issue is that the cell size for the NREL maps is 40km x 40km. Solar density varies quite a bit within the cell size, due to terrain, microclimate, cloud cover, ground cover, etc. (George, 1999: 245). The final issue is that a yearly average solar density does not take into account seasonal variability. In the month of December, the days are shorter and there is more cloud cover in most places in the United States than in August (Patel, 2006: 46). NREL is the primary laboratory for the U. S. government for renewable energy, and is tasked with advancing the science to accommodate the energy needs of the United States (National Renewable Energy Lab, 2013a).

This method has one major drawback. This map compares reservations to each other, but cannot show a specific area that is appropriate for building a solar energy collector. For larger reservations, the map averages several 40km^2 date blocks, decreasing the likelihood that a specific site would have the same solar density. In addition, for small reservations, the average may not represent the microclimate of a chosen site. A small reservation could cross several different 40 km^2 cells that could throw off the data as well. Spatial averaging the data is still a sound way to compare reservations. Ground truth measurements are better when considering a specific site than NREL maps. This thesis will use the data that is already out there to compare reservations to each other.

Some tribes have already begun solar energy projects on their reservations. As fossil fuels become scarcer and the technology of PV panels becomes more advanced and cheaper, the feasibility of solar energy projects on reservations will increase. As reservations become more interested in solar as a renewable energy development project, they will need to know if their reservation is well suited for it. The solar map developed for this project is useful for comparing reservations to each other. Direct measurements would be better for site-to-site comparisons. The map designed for this thesis is sufficient to rank which reservations would be better suited for a solar energy project.

Chapter 3 Section 3 Solar Powered Biodiesel

Tribal governments can chose between solar energy and biodiesel refining. There are advantages to combining the technologies. This thesis proposes using solar panels to power a small 50-gallon per day biodiesel refinery. Solar panels could be attached to a building in which biodiesel is refined. Using solar energy will reduce the amount of fossil fuels that are required to produce biodiesel, while keeping the source of the energy on the reservation. The combination of the two renewable energy sources is a creative solution that will help a tribe to develop a sustainable, renewable, local, and decentralized energy project.

Theoretical Model

The first step in proving that biodiesel can be refined with solar power is a mathematical model that shows the amount of electricity that solar panels can generate compared to the amount of electricity that is needed to refine biodiesel. I created a model (figure 5) that assumes a solar insolation of 3.5 kWh/Day/m^2, which means that for every square meter of solar panel 3.5 kWh produces each day. This solar insolation was chosen because it was less than the 4.1 kWh/Day/m^2 approximate average of Kansas (National Renewable Energy Lab, 2005). The mixing of the compounds assumes about 30 minutes of mixing per liter with a .4 kWh blender, or 113 minutes per gallon (Skunpong and Plangklang, 2011: 122). First step is heating the oil to 170^0 F, which takes about .095 kWh, and then the last step is drying the biodiesel at 120^o F, which requires about .053 kWh. The total comes to 0.904 kWh per gallon or 45.2 kWh for 50 gallons. This is fairly close to the 0.989 kWh per gallon (54.4 kWh per 55 gallons) that the Rochester Institute of Technology (2012: 35) found with their biodiesel refining system. The difference is that the Rochester system has pumps instead of being gravity fed. With this information, it would take about 13 m^2 of solar panels to refine 50 gallons of biodiesel. A refinery would need a building the size of 20 m^2 for the equipment and workspace. If the required area of the solar panels is less than 20 $m^{2,}$ the panels the roof is big enough for the panels and there would be no further need to use up more space with solar panels to run the equipment.

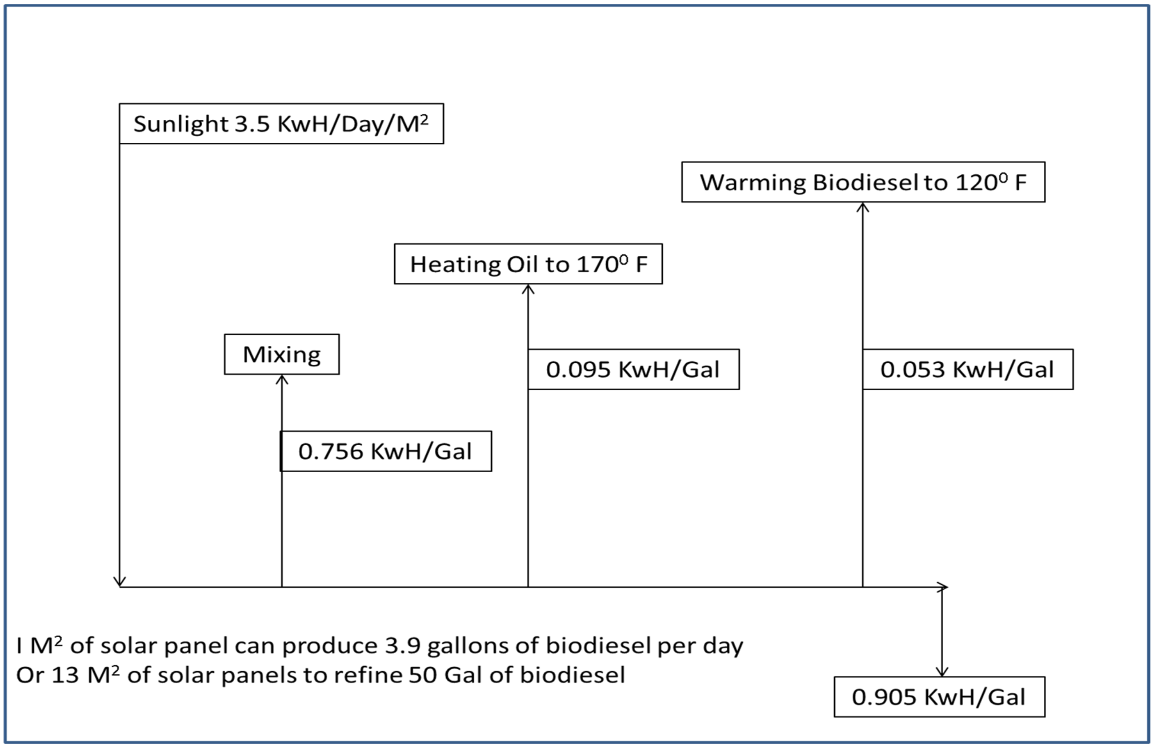


Figure 5. Theoretical Energy Equation for Refining Biodiesel with Solar Energy

Two Proofs of Concept Experiments

The next step is to design experiments based on the theoretical model verifying the theory. In order to provide a “proof of concept,” I conducted two real-world experiments. Appendix 1 explains the experiments in more detail. The first used a tabletop scale model and a DC electrical source plugged into the grid. The second experiments used electricity provided by solar panels (Figure 6). The point of these experiments was to determine whether biodiesel could be refined using solar energy in a real world situation. I compared these experiments’ energy usage to the theoretical energy usage. This is an important step before being able to scale up the project to the 50 gallon per day stage.

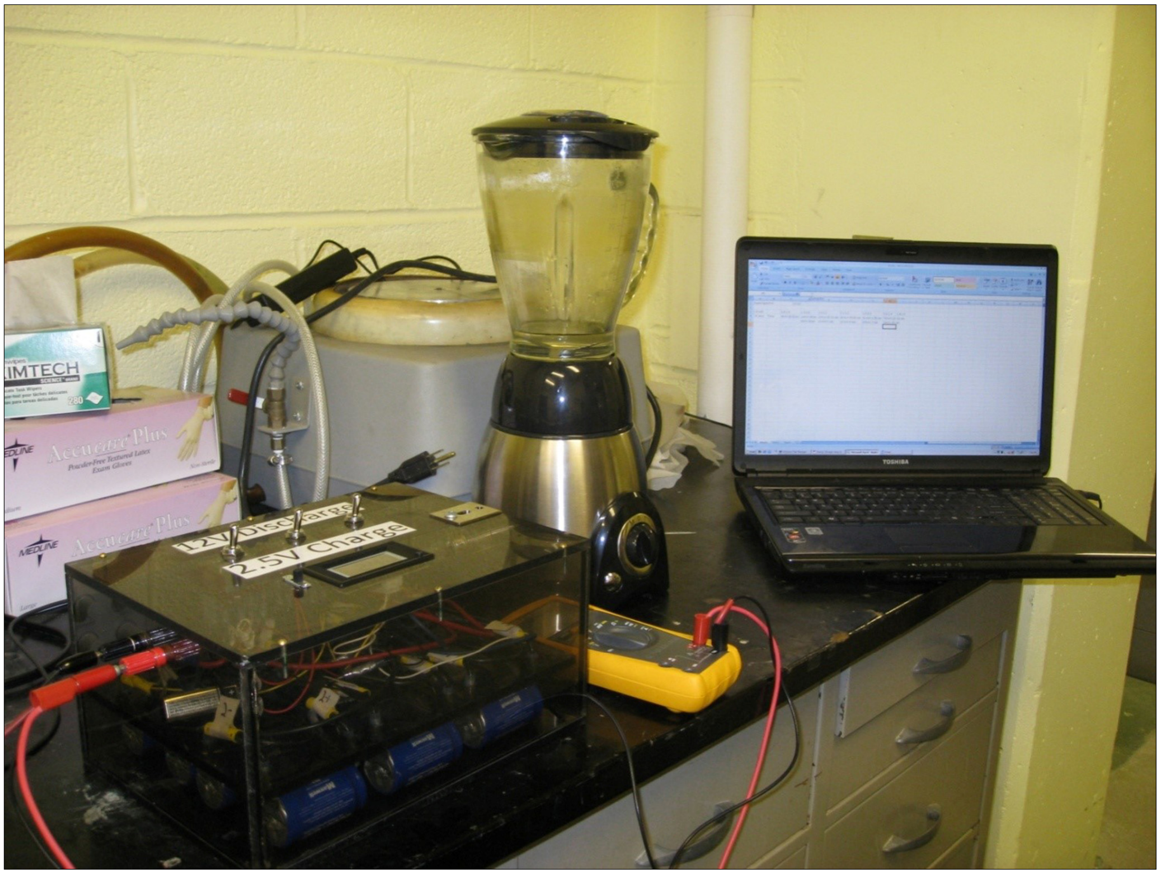


Figure 6. A picture of the equipment used for experiment 1

The first experiment (experiment 1) I conducted using direct current converted from the electrical grid fed into a super-capacitor. The feedstock for this experiment was unused corn oil, or straight vegetable oil (SVO). I chose because SVO created higher quality biodiesel, and if the experiment could not produce biodiesel with SVO, then it would not be able to do so with WVO. The mix times and energy usage is the same for WVO and SVO. A direct current adapter plugged into an alternating current outlet simulated the electricity that would come from a solar panel. The super-capacitor could hold enough charge to run the mixing for five minutes, which is about 0.04 kWh. I reduced the recipe to 200ml feedstock oil to accommodate the fact that the super-capacitor had a limited energy storage capacity. This is equivalent to 1 hour and 34 minutes per gallon of mixing of WVO. Passive solar, which used no electrical energy, heated the oil. Starting with 230ml of oil and methanol produced an average of 20 ml of waste glycerin, which is 9.5% waste glycerin to biodiesel produced. The Rochester system produces about 1 gallon of waste glycerin per 3 gallons of biodiesel, which is about 33% waste glycerin/biodiesel (Rochester Institute of Technology, 2012: 27). The main difference is WVO compared to SVO feedstocks. The average WVO conversion is about 21.74% glycerin/biodiesel, while corn SVO conversion is 10.08%, and the main reason for the increase of waste for WVO is that it has a higher amount of soaps formed from free fatty acids (broken ester chains caused by heating the oil) (Thompson and He, 2006: 262-263). Figure 7 shows that this experiment created biodiesel at the same efficiency as AC systems.

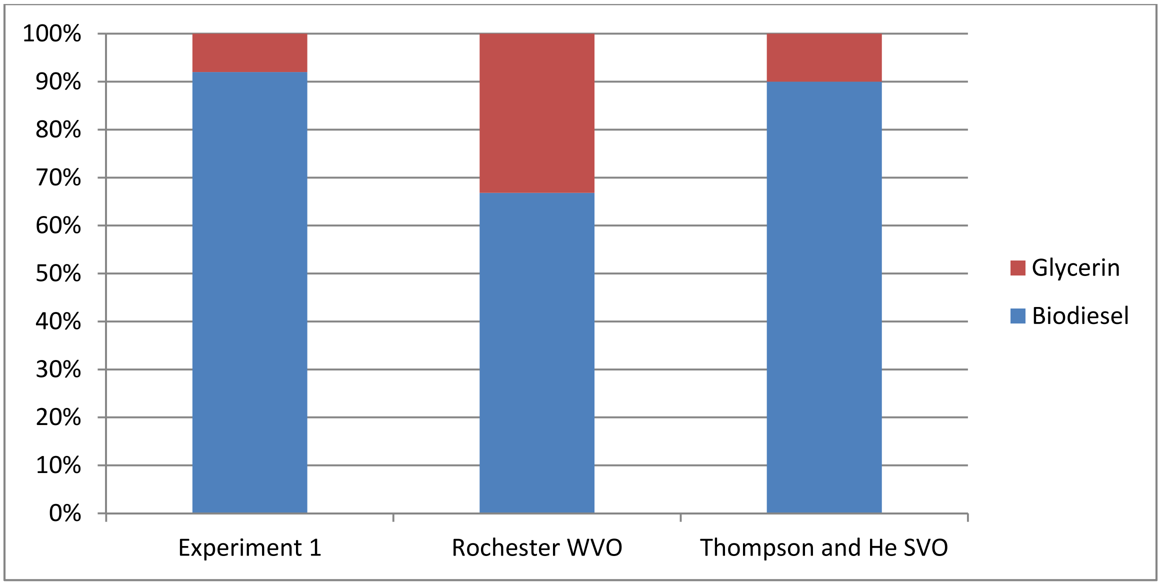


Figure 7. Graph of Experiment 1 vs. Rochester WVO and Thompson and He SVO experiments.

The next real-world experiment (experiment 2) was to try to make biodiesel using a solar powered system. I used the KU Ecohawk's garage for this. They have 6 PV panels (about 1 m^2 per panel) that produce about 1.1 kWh per hour or about 8.8 kWh- 13.2 kWh per day. The solar energy is stored by a battery bank designed to charge electric cars. The electricity was used both for the heating of the oil and the mixing of the ingredients. Passive solar heated the oil, and did not use electricity. I used 500ml of corn SVO and each batch mixed for 3, 6, and 12 minutes. This equates to 23, 45, and 90 minutes per gallon of WVO. In addition to finding out if biodiesel can be made with the same efficiency with solar energy as fossil fuel inputs, the experiment was also designed to see if a reduction in the mix time would affect the production of biodiesel. The 3-minute mixes averaged about 54.67 ml of glycerin with a variance of 6ml, and is about 10.5% ± 0.5% glycerin/biodiesel. The 6-minute mixes averaged about 56.67 ml of glycerin with a variance of 10ml, which is about 10.9% ± 0.9% glycerin/biodiesel. The 12-minute mixes averaged about 55.33 ml with a variance of 4 ml, which is about 10.6% ±0.4% glycerin/biodiesel. Decreasing the mixing time increased the glycerin/biodiesel ratio by about 1% from the Thompson and He (2006: 463) experiments. Figure 8 shows that the mix times can be reduced with little impact to the efficiency of the process.

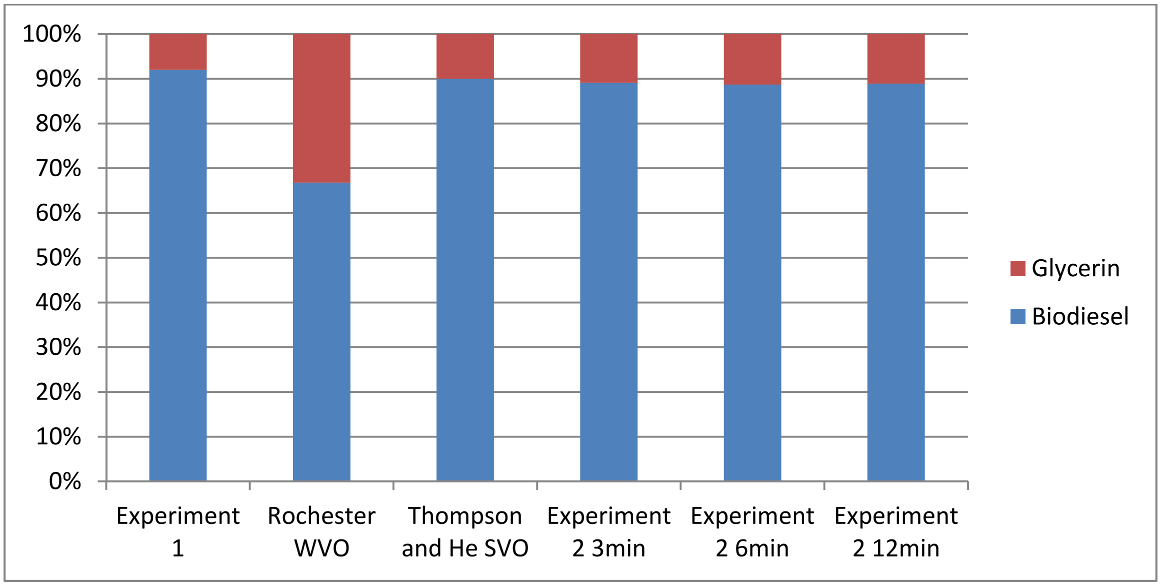


Figure 8. Graph showing the results of experiment 2 compared to other biodiesel refining experiments.

The next step is to compare the theoretical model to the experimental data to make sure that the real world data is comparable to the mathematical model. I acquired the experimental data through the usage of a voltammeter measuring the electrical usage of the system. For the 3 minute mixing, the theoretical electric usage is 0.03 kWh, and the average experimental usage is 0.03 kWh with a variance of 0.01 kWh. The theoretical usage for the 6-minute mix is 0.05 kWh, and the average experimental usage was 0.04 kWh, with a variance of 0.01 kWh. The theoretical energy usage for the 12-minute mixes is 0.09 kWh, and the experimental usage was 0.08 kWh, with a variance of 0.02 kWh. Figure 9 shows that the real world electrical usage is within the standard error of the theoretical data, but the real world usage tended to be less than the theoretical mathematical model. This could be due to the electrical efficiency of the equipment being better than predicted.

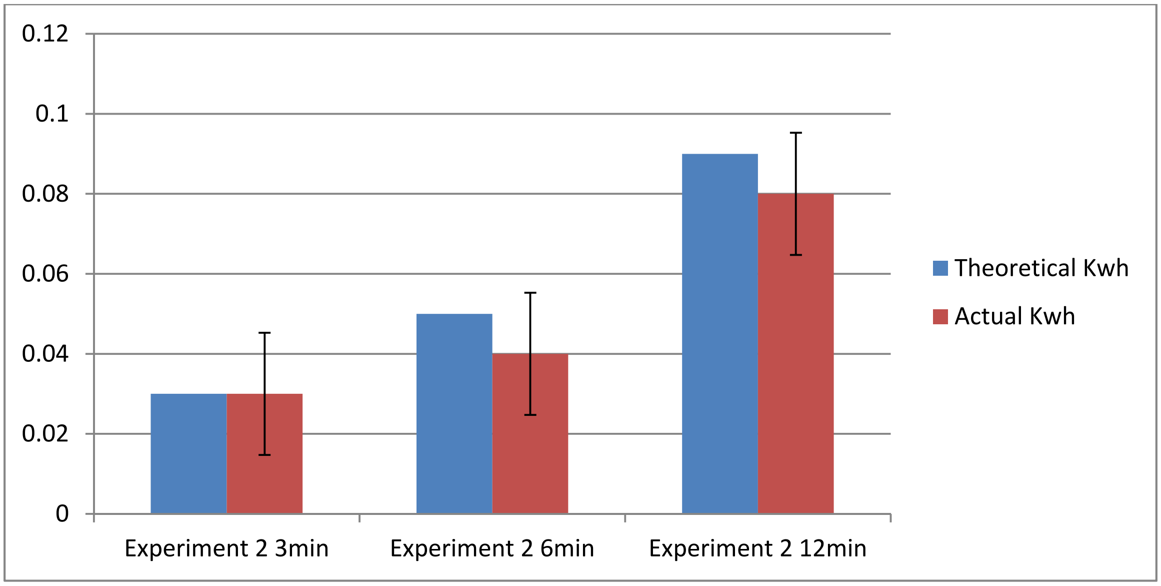


Figure 9. A graph comparing the experimental electrical usage to the theoretical mathematical modeled electrical usage

I extrapolated for larger scale processing, the 3, 6, and 12 minute mixes come to 0.23kWh/Gallon, 0.30 kWh/Gallon, and 0.60 kWh/Gallon, respectively. Thus, the experimental data was very close to the theoretical data, so the increased scale should also be close as long as there is not an increase in electricity usage in the system. The theoretical energy usage is 0.85 kWh/gallon (without the 0.053 kWh/gallon for warming the biodiesel). The experiment showed a reduction of energy used to 0.23kWh/Gallon (or 0.283 kWh/gallon with warming the biodiesel). This is important because the less electricity that a system needs, the fewer solar panels are needed and the lower the start-up costs. In addition to understanding how solar powered biodiesel works, tribes will need to examine how the two technologies interact with each other.

The technologies of solar energy and biodiesel refining have aspects that complement each other. Solar panels are dependent on the sunlight to produce electricity and biodiesel refining requires small amounts of electricity in bursts (Lewis, 2007: 800; Sheehan et al., 2000: 28). This means that the solar energy can be stored until the refinery needs to heat or mix the solution. The only electrical usage for biodiesel refining is the heating and mixing of the chemicals, the settling time and the wash processes do not use electricity (figure 10). Both solar and biodiesel are local energy production sources. Because they are both local, this increases the energy security of a tribe by reducing the dependence on off-reservation energy sources (Demirbas, 2009: 30; Dreveskracht, 2011: 147). The less a reservation is dependent on off-reservation resources, the more independence, and security the tribes have over their own affairs. Also, both solar and biodiesel refining is not dependent on extraction which is more in line with the Indigenous values of sustainability and environmental protection. This is important because as Cornell and Kalt (2006: 16) describe, a tribal sustainable development project has a higher likelihood of success if it is a “cultural match” to the tribe. As a non-extractive renewable project solar powered biodiesel, refining is a cultural match with tribal ideals of sustainability and protecting their lands, while providing economic diversification. Solar powered biodiesel refining has a higher chance of succeeding on reservations than fossil fuel based options because the culturally investment of the people in the development of the project.

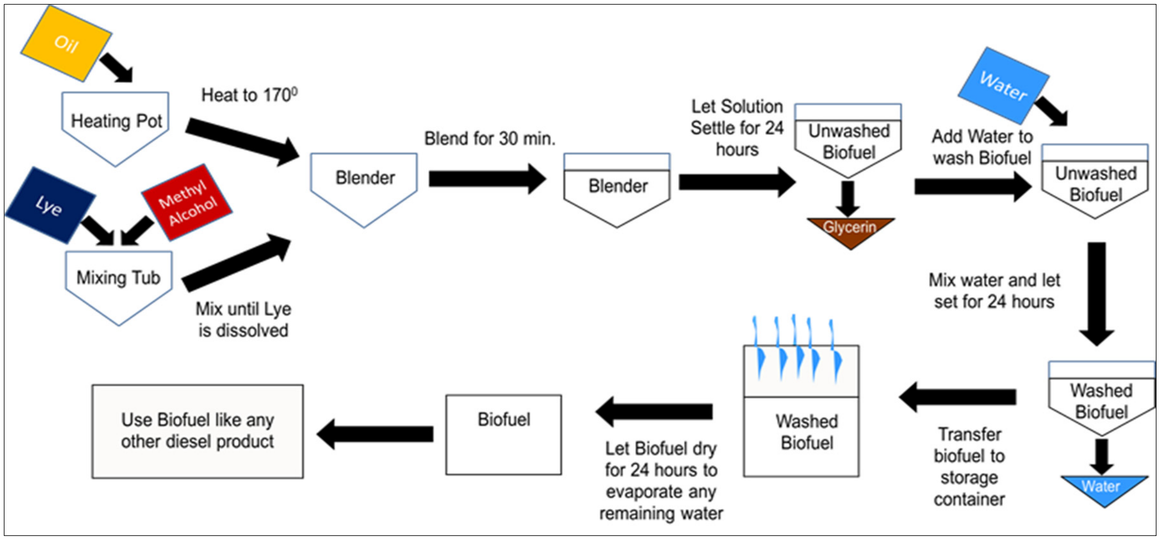


Figure 10. The biodiesel refining process for one liter

Solar powered biodiesel refining also increases the number of factors that a tribal nation would have to consider before construction. The combining of technologies also means combining the initial capital. Solar panels cost about $300 per square meter and a 50-gallon biodiesel refining system can cost $11,000 (Lewis, 2007: 798; Rochester Institute of Technology, 2012: 35). A tribe will need to know how many solar panels will be required to produce 50 gallons of biodiesel each day. Even though one person uses one gallon of gasoline per day, the residential demand for diesel is about 5% of gasoline (U.S. Energy Information Administration, 2013; Cheah et al., 2009: 18).

Besides startup costs, a tribe will need to consider the amount of energy invested compared to the amount of energy produced. The solar energy will reduce the electrical input for biodiesel refining by 0.141 MJ per 1 MJ (Hill et al., 2006: 11207). The solar panels will increase the efficiency of the biodiesel refining process to using only 0.042 MJ of energy to produce 1 MJ of biodiesel. Simply put, 1 MJ of energy in equals 24 MJ of biodiesel out. Fossil fuel-based diesel has uses 1 MJ of energy in to produce 12-18 MJ of diesel out (Murphy and Hall, 2010: 109). The biodiesel is comparable or better from an energy standpoint than fossil fuel-based diesel.

Biodiesel is an advanced biofuel according to the Section 211(o) (1) of the Clean Air Act (42 USC 7545(o)). Advanced biofuels need have 50% less life cycle greenhouse gas emissions than the baseline emissions for 2005 of 91 grams of carbon dioxide per mega-joule (gCO_2/MJ) (Lattanzio, 2013: 9). A 50% level of life cycle emissions would have to be less than 45.5 CO2/MJ. Biodiesel has a life cycle emission direct rate of 76.6 gCO_2/MJ. This is offset by 72.6 gCO_2/MJ due to using biomass carbon, which means the net carbon is about 4gCO_2/MJ (Thamsiriroj and Murphy, 2011: 60). Biodiesel on its own is considered an advanced biofuel, but by using solar energy, the life cycle direct emission rate drops to 65.2 gCO_2/MJ and a net emission of about 3.5 gCO_2/MJ. Solar powered biodiesel is 96% less net CO_2/MJ than the baseline exceeding the required 50% for the definition of an advanced biofuel. Therefore, a tribe would be providing its people with energy while helping the United States achieve its renewable energy goals.

I have placed a few limitations on analysis in this thesis. The first of which is that diesel engines make up a small percentage of all vehicles. This assessment will assume that each reservation will have 100% diesel vehicles, which will represent the demand for a liquid fuel source. Another limitation with this thesis is the accessibility of methanol and potassium hydroxide, which should be easily accessible, but probably not within the boundaries of the reservation. This thesis will assume that these will both be completely accessible and tribes can purchase them. The next limitation will be that this thesis will assume that the solar systems to the main power grid and are used to offset energy usage. The final assumption is that tribes will use PV panels instead of other solar options.

The combining of solar energy and biodiesel refining provides tribes with a unique opportunity to accommodate their energy needs. A solar powered biodiesel system can provide a liquid fuel while reducing a tribe's carbon footprint. The two technologies also balance some of the drawbacks that they would have individually. It would be more expensive than using electricity from the power grid and tribes would need to know about the availability of both solar and used cooking oil resources. There are aspects to the technology that are too complex to address in this thesis, as well as unknown factors of an untested technology. This will be resolved with the continuation of the research into real world testing and a dissertation. There is enough information in the case studies for tribes to begin examining solar powered biodiesel as a sustainable source of renewable energy.

Methodology for Mapping Solar Powered Biodiesel Potential on Reservations

GIS is a powerful tool for spatial analysis, but it is only as accurate as the data utilized. Map 3 uses data that I interpreted from maps 1 (on page 56) and map 2 (on page 57), and as such has the same issues described in the previous sections. I figured the solar powered biodiesel index by dividing the available WVO (data from Map 1 dataset on page 56) by the number of panels per refinery (data from map 2 dataset on page 57) and shown in map 3 (on page 58). I based this formula on the fact that the more WVO that is available, the more likely that a reservation will have access to enough to accommodate their liquid fuel needs. In addition, the fewer PV panels that a refinery requires equates to lower initial investment. The reservations with a higher index value have a higher likelihood to take advantage of solar powered biodiesel.

Since this map uses both NREL and TIGER data, the spatial and temporal resolution only allows a comparison between reservations. A singular site location would require a map with greater resolution. I based the solar/biodiesel index on the usage of all available WVO and optimal solar conditions. Some places may not want to provide their WVO, and solar conditions are highly variable. Tribes can quickly examine the feasibility of using solar energy to refine biodiesel. A tribe will need to assess their own fuel and electricity needs to see if solar powered biodiesel refining will be able to provide for their energy needs.

By creating the solar powered biodiesel maps, tribes can determine to what extent their renewable resources compare to other reservations. Solar panels can provide enough energy to refine biodiesel, but the area of PV panels needed varies based on the geography of each tribe. The two real world experiments proved that biodiesel could be refined using solar energy. The solar powered biodiesel map showed which reservations had the best availability of solar and biodiesel resources. If this research were to continue, the next step would be to build a refinery on a reservation and test the system's ability to refine biodiesel. The data from the solar powered biodiesel map will help determine which reservations would be best suited for testing a 50-gallon per day refinery.

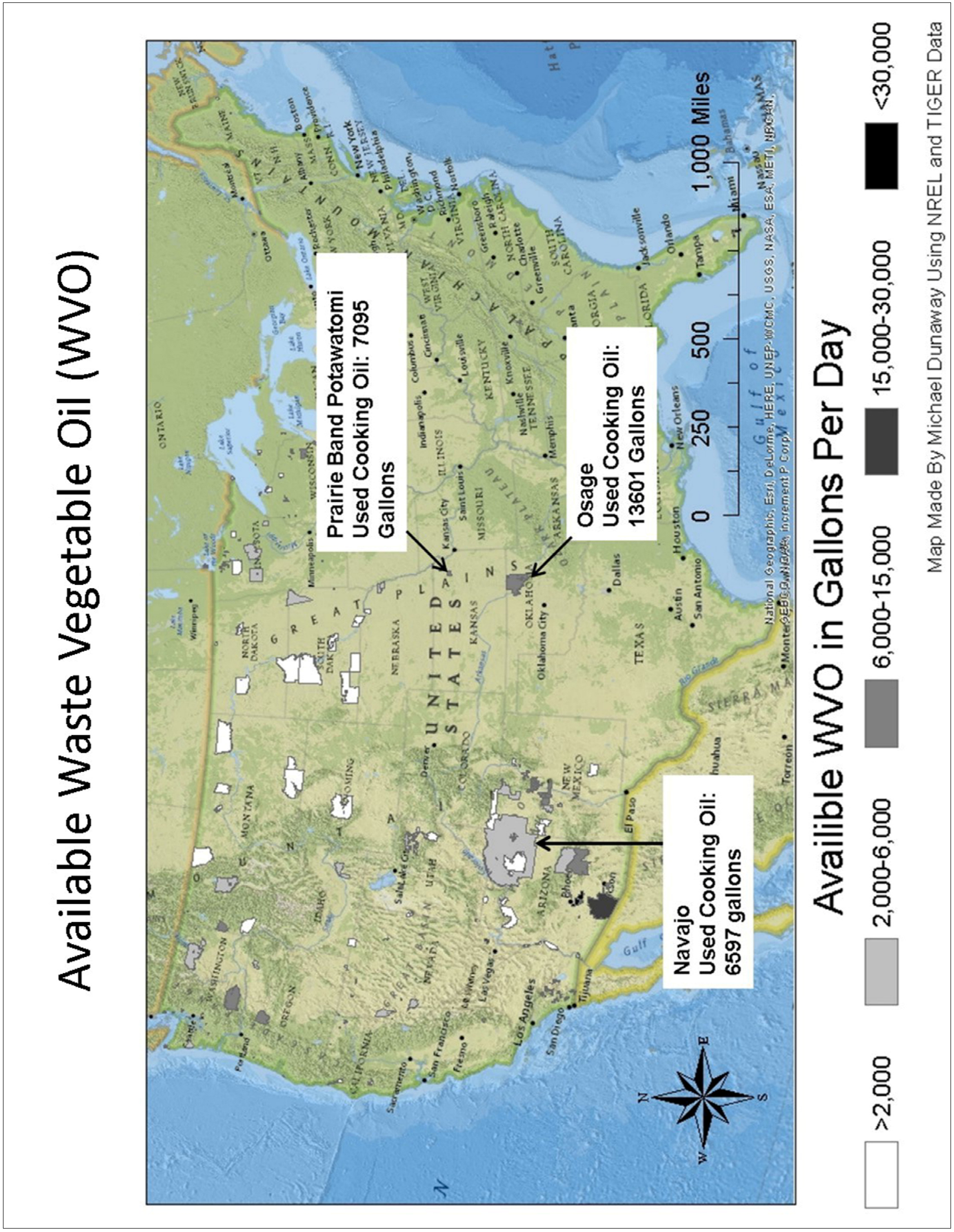
Chapter 3 Conclusion

By combining solar power and biodiesel refining, the technologies mitigate the disadvantages of each of each other, and there is the added advantage of being more energy efficient to produce than petroleum based diesel. The mathematical model shows that in theory the two technologies can work together. The real world experiments proved that this technology is possible. Solar powered biodiesel refining can allow tribes to provide their own fuel while using renewable resources that align with their own interests. Tribes also need to know which reservations would be best suited for each of the technologies. To this end, this thesis created the solar, biodiesel, and solar powered biodiesel maps. Tribes can use these maps to make their own decisions about renewable energy projects. Thusly, these maps strengthen tribal sovereignty by giving tribes more choices of where their energy comes from and informing tribes about possible renewable energy projects in which they can invest.

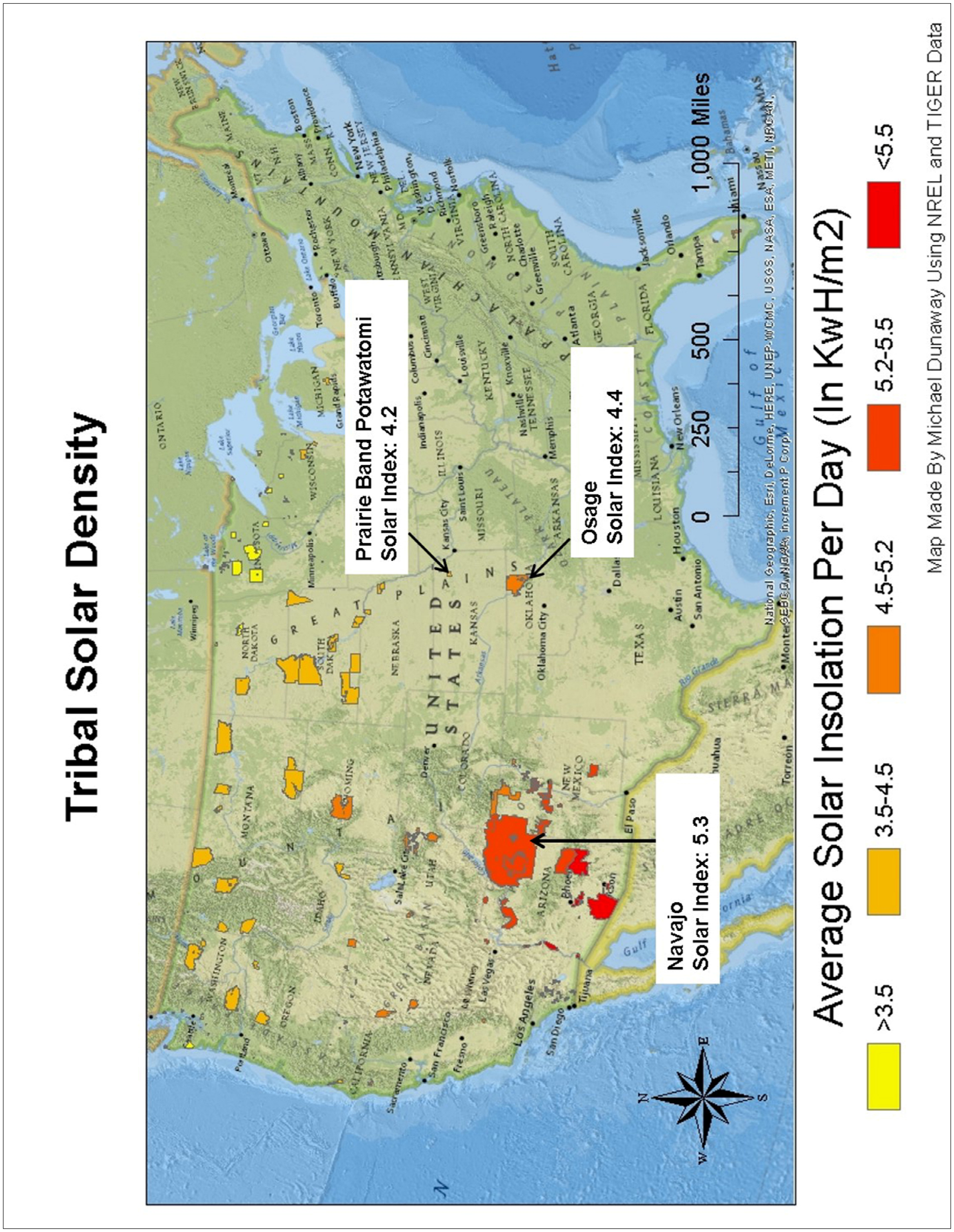
Based on the experiments I conducted, a 50-gallon per day refining facility is the largest scale that a refinery. A larger facility increases the amount of mechanization that a refinery would need. An increase in machinery means an increase to the electricity per gallon required to refine the biodiesel. A refinery of this size is large enough for a single person to operate. This is not large enough though for commercial application. These small-scale refineries can accommodate the needs of a small reservation. The Rochester experiments used a refining 55-gallon a day refining system (Figure 11). This refining system is small enough to fit in the corner of a two-car garage.

Figure 11. A picture of the Rochester refining system.

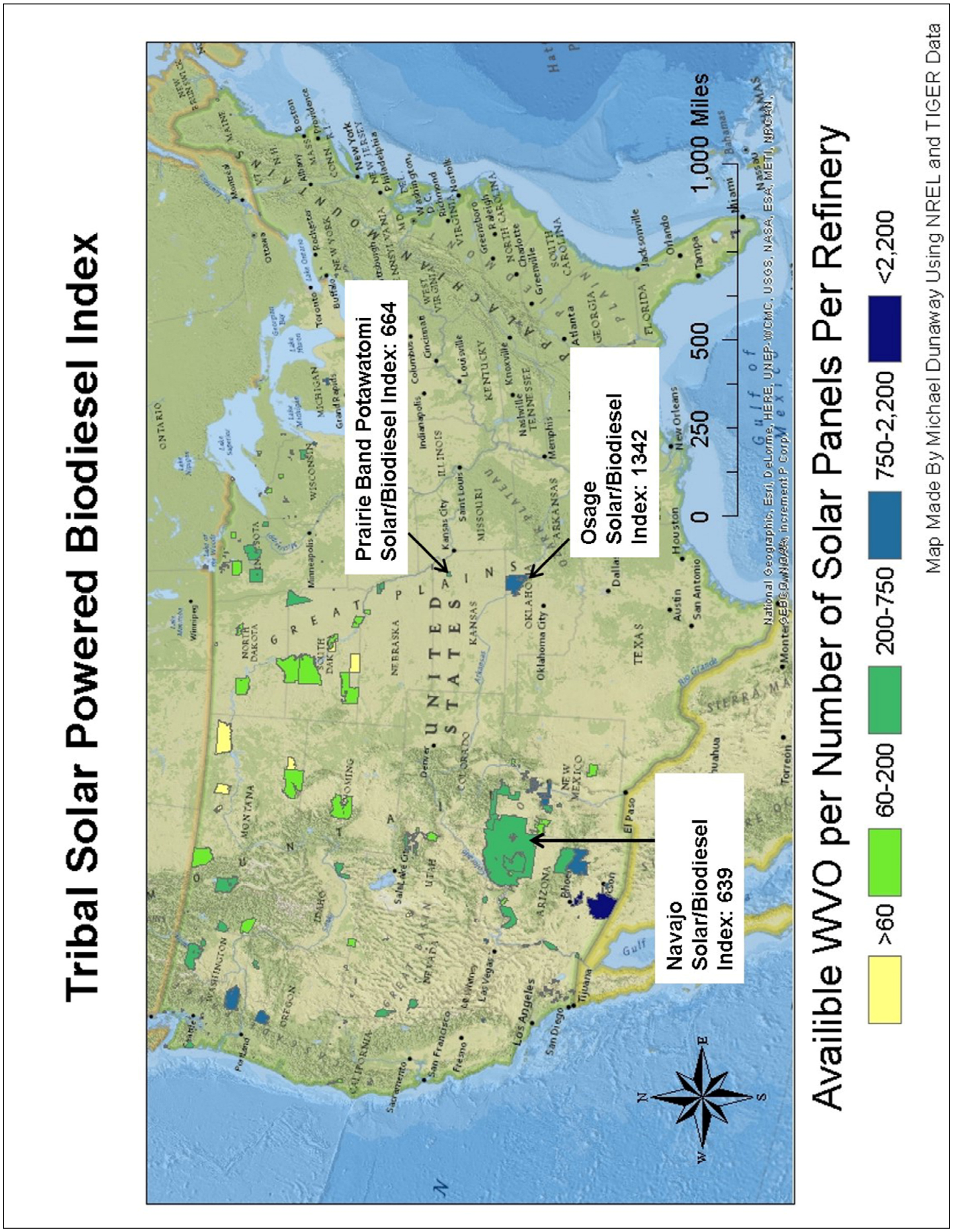
Tribes can use GIS to determine if there is enough available renewable resources to invest in a solar-powered biodiesel refinery. Each reservation will need to look at the economic and social factors that could influence a tribe to choose one of the technologies over the others. Mapping the renewable resources only tells part of the story. Each reservation is unique and requires an extensive ground-truthing before choosing a site to continue this research.



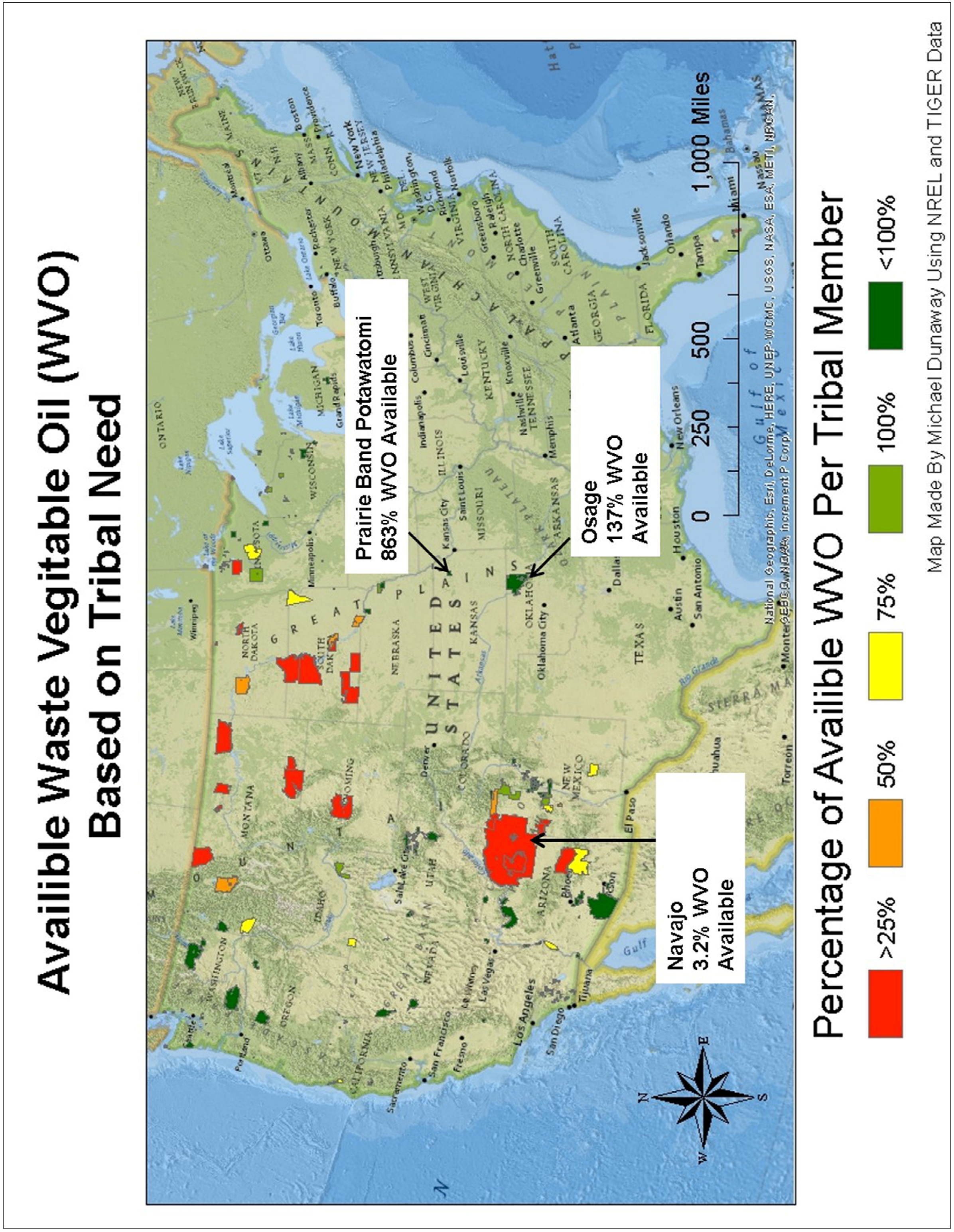
Map 1. Availability of Used Cooking Oil for Reservations



Map 2. Availability of Solar Energy for Reservations



Map 3. Number of Potential Solar Powered Biodiesel Refineries on Reservations.



Availible Waste Vegitable Oil (WVO) Based on Tribal Need

Prairie Band Potawatomi 863% WVO Available

Osage 137% WVO Available

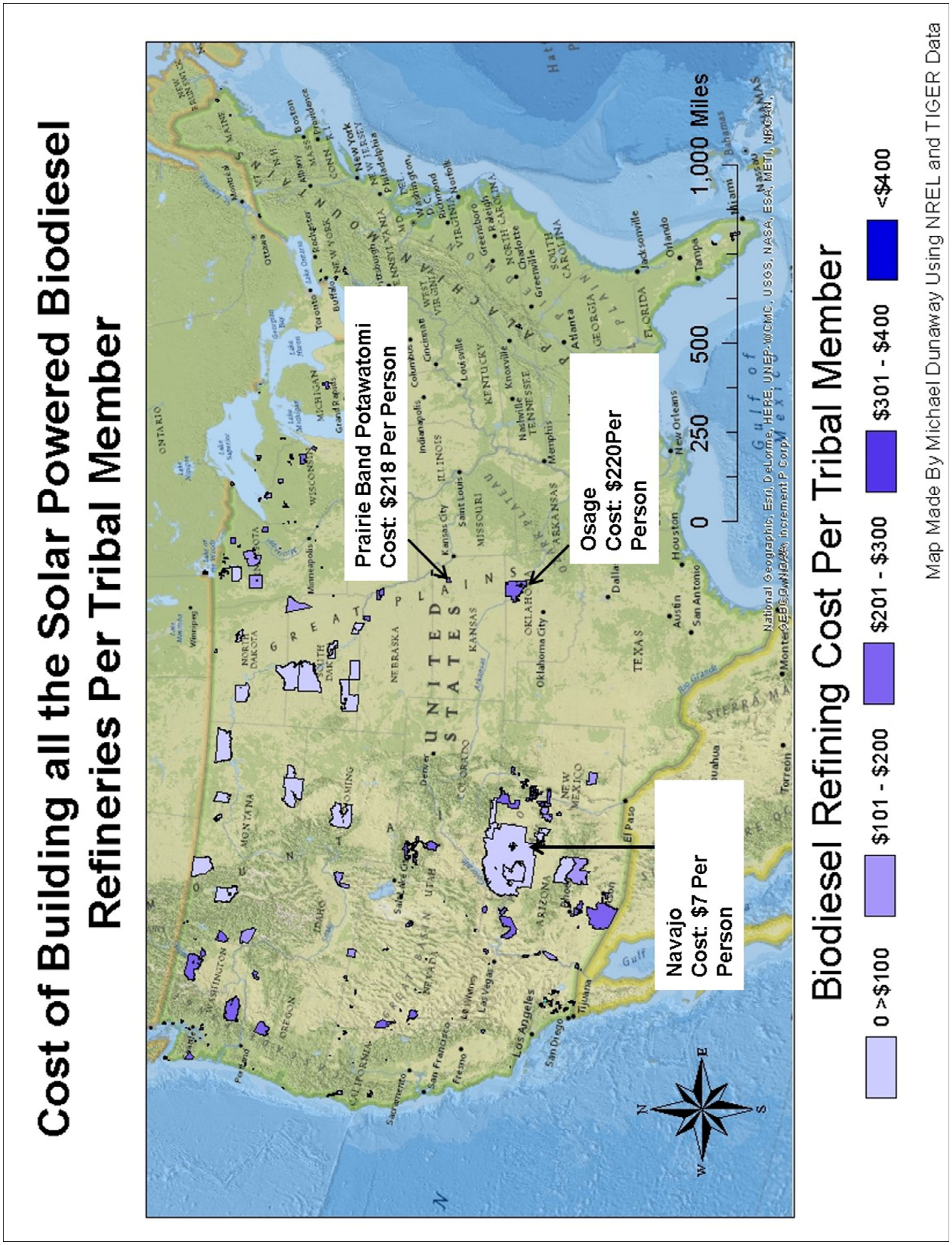
Navajo 3.2% WVO Available

Percentage of Availible WVO Per Tribal Member

Map Made By Michael Dunaway Using NREL and TIGER Data

National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Map 4. Percentage of Available WVO Based on Tribal Population



Map 5. Cost of Building the Maximum Amount of Solar-Powered Biodiesel Refineries per Tribal Member

Chapter 4 Case Studies

Chapter 4 Introduction

Every Native American reservation is unique; but there are generalities that span across the majority of reservations. Most reservations are in the Western portion of the United States, west of the Mississippi River mainly due to the Indian Removal Act of 1830. On average, Native American reservations have the highest poverty rates of any racial or ethnic class. 27% of Native Americans live below the poverty line, while 11.6% of whites live below the poverty line. (U.S. Census, 2013: 3). The high rates of poverty also lead a lower standard of living on reservations. The physical, economic and social isolation lead residents of reservations to “underclass behaviors” which include high rates of crime, drug abuse and alcoholism as well as low rates of income, high school graduation and stable family units (Sandefur, 1989: 41). Renewable energy options should take into account the lower standard of living and education. Solar-power and biodiesel are best suited for this thesis because they are technologies that need very little training to operate. Reservations have a number of elements that can lead to successful economic development projects: 1) resources that can be turned into economic activities, 2) a built-in source of human resources, 3) governments that can set policies that encourage economic growth through policy and 4) a culture that promotes the generation of communal well-being rather than personal wealth (Cornell et al., 1992: 8). A renewable energy project will increase the chance that it will be successful if it takes advantage of these elements on a reservation.

This thesis evaluates three reservations for their renewable energy resource potential to become a viable source of economic development. The reservations are the Prairie Band Potawatomi, the Osage, and the Navajo. I choose the Prairie Band Potawatomi reservation because of its proximity to the University of Kansas, which allowed greater familiarity with the environment. I choose the Osage reservation because I lived on that reservation for several years and I know the area quite well. Finally, I decided to evaluate the Navajo based on three facts: 1) geographically largest reservation, 2) highest Native American population living on a reservation 3) and I wanted one reservation in which I did not have a personal connection. The reservations are in the Great Plains and Southwestern portions of the United States, which excludes areas in the Northern Plains or the Pacific Northwest. Tribes in these areas can apply this methodology to their reservations as well.

Even through reservations do differ in geography, culture, and, histories this thesis will only focus on the economic affects solar-powered biodiesel refining on the reservations. A cost-benefit analysis evaluates the time that it would take a reservation to recover the cost of investing in the technology, how much profit the technology would generate per year based on income, and how much money each technology saves. Finally, I will show different plans that each reservation can re-invest the profits from investing in solar-powered biodiesel refining to further strengthen their energy sovereignty.

Chapter 4 Section 1 Tribal Culture and History

It is important to take into account a tribe’s history and culture before beginning any project on their lands and this especially important when starting an economic development project. The project needs to be a “cultural match” with the tribe in order for it to be successful (Cornell and Kalt, 2006: 16). This section of the chapter will explore each of the test case tribes’ history, culture, and government structure. Tribal history can give researchers insight into the tribe’s connection to the land. Tribal culture demonstrates the values and ideals of a tribe. The tribal government structure helps researchers to understand the treaty partnership the tribe has with the United States government. Understanding these elements will help to provide researchers with the tools to empower tribes through economic development projects using renewable energy.

The Prairie Band Potawatomi Nation

Understanding the history of a tribe is important for researchers to be able to work with tribes to develop energy projects. First contact with the Potawatomi occurred in 1634 when fur traders encountered the tribe near Lake Michigan, and soon after the tribe became heavily involved with the fur trade (Low, 2011: 11). The Potawatomi language is Central Algonquian, indicating that the tribe is related to several other tribes such as the Cree, Kickapoo, Menominee, Odawa, and Ojibwa (Wetzel, 2006: 63). The tribe originally resided on about 782,000 acres spanning across Indiana, Illinois and Michigan which was mostly covered by forests (Edmunds, 1972: 243). The Prairie Band Potawatomi reservation was formed by the Treaty with the Potawatomi Nation (1846) in which Article 4 allotted 576,000 acres or 36 square miles. The treaty reduced their lands by about 200,000 acres and relocated them from their homes near the forests of the Great Lakes to live in the tall grass prairies of Kansas. Articles 5 and 6 of the treaty that formed the reservation also gave the tribe money to relocate from Illinois and per capita payments for the tribal members for the first 30 years after their relocation (1846). The United States wanted these payments to help the tribal members to establish themselves in the plains and become self-sufficient.

The Prairie Band Potawatomi Nation is now located in Jackson County in the Northeast corner of the state of Kansas. It consists of mostly mixed grass prairie, with riparian forest areas and is just northeast of the Flint Hills region. It encompasses 77,400 acres and currently consists of ~800 tribal members residing on the reservation (Prairie Band Potawatomi Nation, 2011). This is much smaller than the original allotted lands described in the 1846 treaty. Today, the poverty rate of the Prairie Band Potawatomi is 23.5%, which is based on the federal poverty rate for a family of four people with a household income of less than $23,492 (U.S. Census, 2013: 15). Based on this fact, there is a need for the tribe to diversify their economy, and a renewable energy project could be beneficial to tribal members by both creating jobs and reducing energy costs. The tribe does have a casino that employs about 150 tribal members or roughly 20% of the tribal members (Prairie Band Potawatomi Nation, 2013). This makes the Prairie Band Casino the largest source of income for tribal members. The Prairie Band Potawatomi Nation is governed by a tribal council that manages all of the governing responsibilities for the tribe (Prairie Band Potawatomi Nation, 2007). This means that if a researcher would like to work with the tribe to develop a renewable energy project that they would have to go through the tribal council.

The Osage Nation

Even though the Osage reservation is also in the Plains, they have a completely different culture and history than the Prairie Band Potawatomi. Marquette and Joliet made the first documented contact with the Osage in 1673 and their territory spanned across Kansas, Oklahoma, Missouri and Arkansas (Burns, 2004: 46). The Osage language is in the Siouan linguistic group and they are related to other tribes' in this language family, such as the Lakota, Dakota, Crow, Hidatsa and Mandan, but their linguistic subgroup makes their language more closely related to the Ponca, Omaha, Kansa and Quapaw languages (Rankin et al., 2002: 180). The Osage lived in the area that of their reservation since before contact.

The Osage Reservation is located in the Northeast area of the state of Oklahoma and is completely comprised of Osage county. The Drum Creek Treaty established the Osage reservation (1870). Currently approximately 10,000 tribal members reside on the reservation, however, there are about 40,000 non-Native Americans residing on the reservation as well (U.S. Census, 2012: 14). Like the Prairie Band Potawatomi, the Osage reservation is also mostly mixed grass prairie with riparian forest areas, but is located at the southern tip of the Flint Hills region. The Osage reservation has the highest non-Native American population of all Reservations. Today, the Osage have a poverty rate of 21.7%, which means that about one fifth of the Osage population are living in poverty (U.S. Census, 2013: 15).

Several aspects of the Osage reservation make it different from other reservations. One of the unusual aspects of the Osage reservation is that the Osage people actually purchased their reservation and voluntarily relocated themselves to the reservation (Miller, 2013: 52). This leads to a unique relationship with the United States Government. There are several examples of this, the Osage were immune from the Dawes Act, and in the 1907 Oklahoma Enabling Act, the Osage lands were specifically treated differently than the rest of the Oklahoma Territory (Moschovidis, 2011: 192). In 1906, The United States Congress passed an act that divided the Osage lands into individual allotments and gave ownership of those allotments to tribal members, and these tribal members are known as “headright” holders (Zomer, 2007: 257). The 1906 Act also established tribal membership based on the tribal roll of the time, however, in 2007 new members could be added to the membership based on their relationship to a member on the roll (Osage Nation Congress, 2007: 4). Additionally, in 2007 the Osage changed their government structure that was similar to the Prairie Band Potawatomi system and created a three-branch system similar to the U.S. government system. These differences in Osage history have impacts that can affect working with the Osage Nation today.

The two major sources of income for the tribe are rich oil and natural gas reserves, and several casinos. In 2007, the Osage mineral estate paid $56.3 million in headright payments to Osage tribal members (Taylor and Sarasota: 4). It is important to note that not all Osages are headright holders, and this causes a significant economic disparity between both parties. The Osage also own six casinos that employ roughly 1,000 people and accounts for about $140 million in tribal revenue (Taylor and Sarasota: 15-16). The casinos have helped to rebalance the economic disparity between headright holders and non-headright holders and fund the majority of the Osage government. The Osage have a GNP $172 million a year which puts the Osage in a stronger economic position compared to other reservations (Taylor and Sarasota: 4). This means that the Osage are in a strong position to diversify their economic portfolio.

The Navajo Nation

Spanish Conquistadors first encountered the Navajo in 1583 by Antonio de Espejo near the San Juan River in modern day New Mexico (Maryboy and Begay, 2000: 275). The Navajo language group is Nadene which makes the Navajo linguistically linked to the Tlingit, Haida, Beaver and Athabasca peoples located around British Columbia and Alaska (Carmean, 2002: 2). The prevailing theory is that the Navajo broke off from the Athabasca people before contact with Europeans and settled in the American Southwest. The Navajo traditional lands are bounded by four sacred mountains: Hesperus Mountain in Colorado (north), Huerfano Mountain in New Mexico (East), Mount Taylor in New Mexico (south) and San Francisco Peaks (west) (Blake, 2010: 34). The Navajo Reservation is mostly in the Northeast corner of the state of Arizona, but includes small areas in New Mexico and Utah as well and is within the boundaries of the four sacred mountains. The Treaty of 1868 established the reservation, and signing the treaty was a condition for the release of the Navajo imprisonment at Bosque Redondo near Fort Sumner (Csordas, 2000: 463). The Navajo where forced to live at Bosque Redondo after their surrender at the end of the Navajo War in a series of forced marches that became known as the Long Walk (Kessell, 1981: 254). The Navajo have a strong tie to their lands because they are living in the same area that they were before contact.

Most of the reservation is desert, but there are arid steppe lands in the highland areas and the tops of the plateaus. The Navajo reservation comprises 27,000 square miles (which is larger than many states in the United States) and currently is home to over 250,000 tribal members (Navajo Nation, 2011). The population number the tribe reports is higher than the census data that puts the Navajo tribal members living on the reservation at about 174,000 (U.S. Census, 2012: 14). Today, the poverty rate of the Navajo is 33.1%, which means for a family of four people the household income is less than $23,492 (U.S. Census, 2013: 15). The tribe operates four casinos, however the casinos are new and have yet to impact the poverty level of the reservation (Lee, 2013: 128-129). This means that even though the tribe has casinos, there has been little impact to the economy of the Navajo.

The Navajo have a three branch governing system similar to the United States. The Navajo governing system has an executive branch that includes a President and Vice-President as well as several departments, a legislative branch that includes an 88 member tribal council and 110 local chapter governments and a judicial branch with a supreme court, several district courts and a family court (Wilkins, 2002: 112). Another unique aspect of the Navajo governing system is the establishment of the Peacemaker Court. The Peacemaker court is an option for Navajo tribal members to resolve disputes outside of a western court system and is similar to mediation or arbitration where a non-biased third party hears all of the sides of an issue and makes a decision on how to resolve the issues (Joh, 2000: 124). The Peacemaker court has its foundations in Navajo history and culture. The Navajo have access to several different energy resources that they could access. The Bureau of Indian Affairs (BIA) arranges leases for corporations to extract the resources and pay royalties to the tribe, in the case of the Peabody Coal Mine, the royalty is 12.5% (Adamson, 2003: 5). Therefore, it is difficult for the Navajo to use their energy resources to assert their sovereignty; however, by investing in non-extractive renewable energy they would be able to exercise their energy sovereignty without taking resources from their lands and sending them off the reservation.

Each tribe has a different history, culture and government structure. This means that each tribe will have its own unique issues when it comes to developing renewable energy projects as a means to create economic growth. A researcher will need to be flexible with their solutions and work closely with tribal members to come up with creative solutions. There will be no one size fits all solutions that will work for every tribe. The key element is working with tribes to empower their ability to exercise their sovereignty and create a new source of economic investment that will benefit the tribe without sacrificing their identity.

Chapter 4 Section 2 Economic Impacts

Each tribe needs to understand the fundamental initial costs for solar-powered biodiesel refining. The initial cost for a single 50 gallon per day system is $11,000 for the biodiesel refining system (Rochester Institute of Technology, 2012: 35). The cost of PV panels is between $250 and $350 per square meter (Smestad, 2008). This thesis will assume an average cost of $300 per square meter. Each reservation will need a different number of solar panels that affects the initial investment.

There will also be variable costs per gallon of biodiesel refined with solar energy. The variable costs for materials, such as methanol, sodium hydroxide, electricity, etc., are $1.04 per gallon (Rochester Institute of Technology, 2012: 35). High quality waste vegetable oil can sell for about 40 cents per pound (which comes to $3 per gallon) on the open market, due to the increase demand for biodiesel production (Curwin, 2012). There are ways that tribes still can get WVO at little to no cost, for example, education of how the oil will be used, a tribal run waste oil disposal business, or by creating soap using the waste glycerin that they could trade for the WVO. Due to the variable cost of WVO, either people pay for WVO disposal, or up to $3 per gallon purchased from a WVO dealer, this thesis will assume a $1 per gallon cost of the WVO. The price of WVO can increase the production cost to $2.04 per gallon. Finally, the labor commitment for one person is about 2.75 hours to produce a 50 gallon batch (Rochester Institute of Technology, 2012: 35). Assuming paying a person $10 an hour, the labor cost is $0.55 per gallon. This brings the total cost of biodiesel production to $2.59 per gallon. This thesis will assume $2.59 as the basis for the variable cost when figuring the economic analysis of solar-powered biodiesel refining.

Prairie Band Potawatomi

One 50 gallon per day refining system would to accommodate 1/16 of their residential fuel needs. Based on the population data, there is 7095 gallons of WVO produced per day within 50 miles of the Prairie Band Potawatomi Reservation (map 1 on page 56). Dividing the available 7098 gallons of WVO in the area by 50 gallons needed per refinery, the Prairie Band Potawatomi could build about 142 refineries to maximize the usage of all of the WVO in the area. This is roughly eight times the current needs of the Prairie Band Potawatomi (see Map 4 on page 59).

Therefore, there is more than enough accessible WVO for the Prairie Band Potawatomi Nation to be able to utilize used cooking oil as a feedstock.

A solar-powered biodiesel refinery will require about 11 square meters of photovoltaic panels per refinery (see map 3 on page 58). The PV panels will be able to provide the 42.5 KwH to refine 50 gallons per day. The biodiesel refinery alone will cost about $11,000 to construct and will also require solar panels that cost about $300 per square meter (Rochester Institute of Technology, 2012: 35; Lewis, 2007: 798) . Each refinery needs 11 square meters of solar panels (see Map 3 on page 58) which means that the initial investment for the solar panels will be $3,300. The total startup cost per refinery will be $14,300. The cost for the 16 solar-powered biodiesel refineries that the tribe needs to cover its liquid fuel needs is $286,000. The payback time will be the same as a single refinery. The total investment also comes to a cost of $218 per tribal member on the reservation (map 5 on page 60).

The payback time for each refinery is on the amount of profit per day that a refinery generates. The cost per gallon of materials is $2.59 based on the previously discussed factors. If the biodiesel displaces $1.31 of buying fossil fuel based diesel that is sold at about $3.90, the refinery would pay for itself in 175 days (Energy Information Administration, 2013b). The tribe's gas station could sell the biodiesel, but the biodiesel would be subject to state and federal taxes. The Kansas state diesel tax is $0.26 and the Federal diesel tax is $0.24, which brings the total taxes on the fuel to $0.504 (Energy Information Administration, 2012). This brings the cost of the fuel to about $3.09 per gallon and the profit per gallon down to $0.81 per gallon and the payback time to 353 days. The annual profit from selling the diesel per refinery comes to $14,782.50.

Osage

The Osage Nation needs about 10,000 gallons of fuel per day to accommodate the fuel needs for the Osage tribal members if one tribal member uses 1 gallon of diesel per day. With this in mind, the Osage will need to build between 180-200 refineries. GIS and spatial analysis can determine how much used cooking oil is near the Osage reservation and if there is enough to accommodate the reservation's fuel needs. According to TIGER data (see map 1 on page 56), there are 1,700,000 people within a 50 miles of the Osage Nation. Based on the population data, there is 13,601 gallons of used cooking oil within 50 miles of the Osage. If the Osage Nation can refine all of the available WVO into biodiesel, there is enough available WVO for 272 refineries, see Map 4 on page 59).

The solar density determines the number of solar panels per biodiesel refinery on the Osage reservation. Each refinery needs 10 square meters of solar panels (see Map 3 on page 58) which will increase the startup cost by $3,000. This will provide the .85 KwH per gallon required to refine biodiesel. The total startup cost per refinery will be $14,000 (including the $11,000 biodiesel refining equipment cost). If the Osage wanted to invest in 200 solar-powered biodiesel refineries the initial investment would be $2,800,000. The initial investment comes to about $220 per tribal member on the reservation (Map 5 on page 60). Nevertheless, the payback time will be the same if the tribe invests in 1 refinery or all 200 solar-powered biodiesel refineries.

The payback time for the Osage is determined by taking the sales price subtract the variable cost per day and dividing that into the initial costs. The variable costs are $2.56 per gallon (based on the costs figured above), and the average sales price of diesel in Oklahoma is $3.90 (Energy Information Administration, 2013b). The tribe would offset $1.36 per gallon if they used the biodiesel instead of buying diesel for tribal government purposes. If the tribe sold the biodiesel at their gas station, state and federal taxes would apply. The Oklahoma diesel tax is $0.14 and the federal diesel tax is $0.24 bringing the total diesel tax to $0.38 per gallon (Energy Information Administration, 2012). This reduces the tribal profit to $0.98 per gallon and the payback time to 286 days. The annual profit from selling the biodiesel on the open market is $17,885.

Navajo

If one tribal member uses one gallon of diesel per day, the Navajo Nation needs about 200,000 gallons of fuel per day to accommodate the fuel needs for tribal members. With this in mind, the Navajo will need to build about 4,000 refineries. Based on the population data, there is 6,957 gallons of WVO produced per day within 50 miles of the Navajo Reservation (map 1 on page 56). By dividing the available 6,957 gallons of WVO in the area by 50 gallons needed per refinery, the Navajo could build 140 refineries to maximize the usage of all of the WVO in the area. This is roughly 3% of the required fuel needs of the Navajo (Map 4 on page 59 also demonstrates this). There is not enough WVO for the Navajo to use as a feedstock for biodiesel. This means that they would have to use the biodiesel to cover a small part of their need and diversify their energy portfolio or find another feedstock that would work for the geography of the reservation.

The initial investment per refinery will depend on the solar density of the reservation. The concentration of solar energy determines the number of solar panels on each Navajo refinery. A solar-powered biodiesel refinery will require about 8.5 square meters of photovoltaic panels per refinery (see map 3 on page 58). This means that there would not need to be additional fossil fuel based electricity to refine the biodiesel. The PV panels will be able to provide the 42.5 KwH to refine 50 gallons per day. The total startup cost per refinery will be $13,550 (including the $2,550 for the solar panels and $11,000 biodiesel refining equipment cost). The Navajo will be able to build solar-power biodiesel refineries at the least amount of initial investment of the case studies in this thesis (about $7 per person according to Map 5 on page 60).

The payback time for each refinery is important because the Navajo do not have enough WVO in comparison to their population. The $2.56 per gallon is the variable cost figured above. The average sales price of diesel in Arizona is $4.09 (Energy Information Administration, 2013b). The tribe could use the biodiesel for their tribal vehicles or for back-up generators and offset the cost of buying diesel by $1.53 and would be able to pay for itself in 178 days. The Navajo may want to sell the biodiesel on the open market. The Arizona diesel tax is $0.18 and the federal diesel tax is $0.24 bringing the total diesel tax to $0.42 per gallon (Energy Information Administration, 2012). This reduces the tribal profit to $1.09 per gallon and the payback time to 247 days. The annual profit from selling the biodiesel on the open market is $19,892.50.

For each reservation, the payback time is less than one year. The cost offset for tribal government usage of biodiesel ranges between $1.31 and $1.53 that a tribe could save instead of buying biodiesel on the open market. If one of these tribes decides to sell their biodiesel on the open market, the average annual profit for each refinery is $17,520. The Prairie Band Potawatomi and the Osage have plenty of WVO when compared to their population, but the Navajo do not have as high of a concentration of WVO compared to their tribal population. Based on this; the profile of a reservation, a small tribal population near large urban centers, that is best suited for refining biodiesel using solar energy is in the southwestern part of the United States. These case studies have also shown that the Navajo that do not have as much WVO compared to their tribal population can create profits for the tribe.

Chapter 4 Section 3 Investment Options

If investing in solar-powered biodiesel refining is profitable, the question then becomes how can a tribe reinvest the profits to continue strengthen their energy sovereignty. The first step is to keep investing in solar-powered biodiesel refineries until the tribe is able to use all of the WVO that they can access. The smaller scale decentralized nature of the refineries will allow tribes to invest in one small-scale refinery at a time and will reduce the chances that they will over-extend their resources past their ability to acquire WVO. Once the tribe is able to use solar energy to refine all the WVO that they have access to, they will need to invest in another renewable energy resource that is a local source of energy. Finally, the tribe will want to look at federal and state incentives to further increase their profits from their renewable energy projects.

The Potawatomi Plan

The Prairie Band Potawatomi have the most available WVO compared to their population compared to the other reservations. They have the lowest tribal population, which means they have more options regarding their solar-powered biodiesel refining profits. I would recommend that the tribe start with one test project and use the biodiesel for tribal government uses (i.e. tribal vehicles and back-up generators). Then, use the money saved by the test project to invest into more small scale refining systems, until they have maximized how much WVO they can access around the reservation. The biodiesel that they do not use for government purposes can be sold at market value at their gas station. Once the tribe maximizes the refining of the biodiesel, the next investment would be to provide solar energy to all tribal homes.

The Prairie Band Pottawatomi will need to know how much it will cost to invest in solar energy systems for tribal homes. The tribe requires about 11200 KwH per day to accommodate the tribe's electrical needs. On the reservation, solar panels could produce about 4.2 KwH per square meter per day (see map 2 on page 57). If each person requires about 14 KwH per day, each person needs 3.3 square meters of solar panels. This comes to roughly 2,640 square meters of solar paneling required to fulfill the electric needs of the entire reservation, and the investment would be about $786,000 (Lewis, 2007: 798). The tribe can have enough money to pay for the solar panels 3.3 years after the tribe develops 16 solar-powered biodiesel refineries.

In addition to helping tribal members with increasing energy costs, investing in solar-powered biodiesel refineries and solar energy projects for tribal members has other financial benefits. In Kansas, each KwH produced by solar energy offsets about 1.39 metric tons of CO_2 per year. (Connors et al., 2005: ES-7). The tribal solar energy project would still offset about 15,797.76 metric tons of CO_2 per year. The carbon offset for biodiesel is 11.7 kg CO_2/gallon (Rochester Institute of Technology, 2012: 32). Solar-powered biodiesel produces 87.5% of the emissions that biodiesel using fossil fuel based electricity (Hill et al., 2006: 11207). This means that each gallon of solar-powered biodiesel offsets 11.8 kilograms of CO_2 per gallon. Each solar-powered biodiesel refinery would produce 215.35 metric tons of CO_2 per year less than their fossil fuel based counter parts. Assuming that the tribe builds 16 solar-powered biodiesel refineries, the annual carbon offset for the solar-powered biodiesel refineries is 3445.6 metric tons of CO_2. Bringing the total CO_2 offset to 17,024.76 metric tons. Carbon credits can be sold through emission trading organizations like the European Union Emissions Trading Scheme that prices Carbon credits at between $12 and $19 per metric ton of carbon offset (Kossoy and Guigon, 2012). This can mean an increased income from both systems between $200,000 and $325,000 from carbon credits.

The Osage Plan

The Osage have enough WVO to build over 250 refineries.They may not be able to access all of the available WVO because using WVO to refine biodiesel has become a booming business. The Osage should start small with a single test facility. Like with the Prairie Band Potawatomi plan, the tribe should begin by using the biodiesel for tribal government business and re-investing in more biodiesel refineries. The Osage have “tribal enterprises,” Osage owned businesses that partner with the tribe to allow the businesses to have the sovereign protections of the tribe. A tribal enterprise established to build biodiesel refineries and sell the biodiesel on the open market. The tribal enterprise could contract with local ranchers and oil drilling companies, instead of selling the biodiesel at their gas station. The ranches and oil companies are the largest sources of non-tribal businesses on the reservation and both are heavily dependent on diesel usage. The flexibility of using smaller scale decentralized refineries will allow the Osage to build up their refineries one at a time while making sure that they do not over extend their access to WVO in the area. Once the Osage area able to access all of the available WVO in the area, they will want to reinvest in solar energy systems for tribal member homes. They can also use the profits to create a tribal program that will help tribal members to pay their energy bills. Diversifying the social programs, will help more people deal with the increasing cost of energy.

The next step would be to start using solar energy to help offset the rising cost of electricity. The Osage Nation requires about 18,000 KwH per day to accommodate the tribe’s electrical needs (Energy Information Administration, 2013a). The Osage Nation can use solar panels to produce about 4.4 KwH per square meter per day (see map 2 on page 57). If each person requires about 18 KwH per day, each person needs 4.1 square meters of solar panels. This comes to roughly 41,000 square meters of solar paneling is required to fulfill the electric needs of the reservation. At a cost of about $300 dollars per square meter, for 41,000 square meters, that the Osage require, the investment would be about $12,300,000 (Lewis, 2007: 798). If the Osage build 100 refineries, then they would be able to invest in solar energy for about 350 homes per year (or enough electricity for 1,200 tribal members per year). It would take roughly 7 years of reinvesting the profits from 100 solar-powered biodiesel refineries to provide enough solar panels for every Osage home.

Once the Osage provide enough solar panels for every Osage home, they would reduce the majority of the tribe's carbon footprint. In Oklahoma, each KwH produced by solar energy offsets about 1.05 metric tons of CO_2 per year. (Connors et al., 2005: ES-7). The Osage could offset about 189,420 metric tons of CO_2 per year by investing in a PV system that meets their energy needs. The 100 solar-powered biodiesel refineries would offset 10,767.5 metric tons of CO_2 each year, bringing the total carbon offset to about 200,000 metric tons of Carbon offset per year. On the carbon credit market the offset would be worth between $2.4 million and $3.6 million per year (Kossoy and Guigon, 2012). In the end, investing in solar-powered biodiesel refining, the tribe could diversify their economy, profit from their investment and reduce their carbon emissions.

The Navajo Plan

The Navajo do not have enough WVO to meet the fuel needs of the tribal members if each member uses 1 gallon of biodiesel per day. They are only able to build about 170 refineries based on the amount of available WVO. In addition, they will not be able to access all of the available WVO. The Navajo reservation is isolated, so the initial solar-powered biodiesel refinery should be near a main highway near a large urban area. The Navajo may only be able to provide enough biodiesel for tribal government purposes. If they would like to sell the biodiesel on the open market, the best way to do that would be to contract with a mining operation off-reservation. Mines use heavy equipment and portable generators that require diesel, but an added benefit of using biodiesel with the mining generators is that there are less particulates emitted during combustion (Howell and Weber, 1997: 4). This would require the refineries built in clusters so that it would be easier for the mining operation to access the biodiesel easily.

The next investment that the tribe should make is in solar energy for their tribal members. The tribe requires about 2.5 million KwH per day to accommodate the tribe's electrical needs. On the reservation, solar panels to produce about 5.3 KwH per square meter per day (see map 2 on page 57). If each person requires about 12.5 KwH per day, each person needs 2.4 square meters of solar panels. This comes to roughly 471,698 square meters of solar paneling is required to fulfill the electric needs of the reservation. The total investment for all of to meet the electrical needs for the tribe would be about $141 million (Lewis, 2007: 798). If the tribe is able to build 100 solar-powered biodiesel refineries and sell the biodiesel on the open market, they could provide solar paneling for about 650 Navajo homes per year. It would take more than 70 years to use the profits from 100 solar-powered biodiesel refineries to be able to pay for all of the solar panels that the tribe would need to meet its electrical need.

After ten years of investing in solar energy for the tribe, 6,500 homes or 26,000 tribal members will have their energy needs met. In Arizona, each KwH produced by PV panels offsets about 1.39 metric tons of CO_2 per year. (Connors et al., 2005: ES-7). The 6,500 solar-powered homes will offset 325,000 KwH of electricity or 451,750 metric tons of CO_2. The amount of carbon offset by 100 solar-powered biodiesel refineries will be 10,767 metric tons of CO_2, bringing the total carbon offset to 462,517 metric tons. The carbon credit would be worth about $6.9 million per year (Kossoy and Guigon, 2012). These profits reinvested into providing solar panels for tribal homes and increase both tribal energy security and profits from selling carbon credits.

Chapter 4 Conclusion

In order for tribes to empower their energy sovereignty by investing in solar-powered biodiesel refining, they need to have a firm understanding of their history, know the initial investment costs and payback time, and have goals for re-investing the profits to continue to empower themselves. Each case study demonstrates how other tribes would be able to approach investing in renewable energy projects. Tribes can use tools like GIS to conduct economic analysis as well as quickly determining available renewable resources for the tribe.

Using TIGER and NREL data, a tribe can determine how much the total investment in solar-powered biodiesel refining will cost the tribe per person. The formula used to assess cost per tribal member is based on the number of refineries on a reservation (limited by either available WVO or 1 gallon per tribal member) divided by the number of tribal members. Based on this data, the Navajo have the lowest cost per tribal member at about $7 per tribal member (map 4 on page 59). This is mainly due to the high tribal population and low availability of

WVO Using GIS to compare the number of refineries that a tribe can build to their tribal population. The Navajo have the lowest available WVO per tribal member of all of the reservations (Map 5 on page 60). This makes the Navajo the least expensive, but the worst option for investing in solar-powered biodiesel refining. This analysis shows the Navajo can still diversify their economic development with solar-powered biodiesel refineries and strengthen their energy sovereignty.

The Navajo are not alone, about 100 reservations do not have enough WVO to produce 1 gallon of biodiesel per day for each of their tribal members. If the Navajo are in the worst position to make use of the technology, but can still profit from investing in it, then the other reservations that have low WVO availability can also use biodiesel refining with solar energy to strengthen their sovereignty. In addition, using the profits to reinvest in renewable energy there is an added synergistic value for the biodiesel refining. Over time, the tribes will be able to increase their energy security, while encouraging economic growth. These case studies provide a window to the bigger picture of how tribes can start with small investments in renewable energy that can have big payoffs in the end. The investment of renewable energy projects on reservations will become more viable as technology becomes cheaper and federal/state incentives become more available.

Chapter 5 Conclusion of the Thesis

Native American tribes face many socio-economic problems. I get overwhelmed when I try to look at all of them at once. How are Native Americans going to be able to survive economically in the face of rising energy costs? The research I have conducted indicates that solar-powered biodiesel refining can be a part of that solution.

I chose to examine solar-powered biodiesel refining though the lens of Indigenous geography because Indigenous identity is an important aspect of sovereignty. In order to exercise their sovereignty more effectively, an Indigenous community needs to be able to decide who is a part of it. Sovereignty is important to resource management, because tribes need the authority to manage the resources within their territory. Maps like those made with GIS are one of the best ways to protect Indigenous resources and territory. Resources and territory are important to identity, because Indigenous culture is a product of the natural world. Solar-powered biodiesel refining will depend on several factors to be successful. It will need to use the renewable feedstock of WVO sustainably. The renewable energy resource maps need to give knowledge to tribes, not take it. In addition, the biodiesel profits should benefit the tribal community. The refining system proposed in this thesis would fail to empower the tribe, and most likely fail completely without the tools of Indigenous geography.

I choose solar-powered biodiesel refining over solar panels or biodiesel separately because it synergized the benefits of both while lessening the negative aspects of both technologies. Solar energy is expensive, takes up a lot of space, and does not produce that much energy. Biodiesel refining is heavily dependent on fossil fuel energy, and has a low energy return on investment. Combining the two technologies, allows the high profit of the biodiesel to pay for the solar. In addition, after building a biodiesel refinery, it requires a low amount of electricity to operate, which means that solar energy can power it lowering the amount of fossil fuels used. Finally, the EROI of solar and biodiesel refining is far lower than fossil fuels, however the energy return has a multiplicative effect which means that solar-powered biodiesel refining has a better EROI than diesel refined from fossil fuels.

The case studies highlight the process undertaken before a researcher proposes solar-powered biodiesel refining to a tribe. Understanding the tribal culture and history helps the researcher to insure a high “cultural match” between the technology and the tribe. The cost benefit analysis shows how much money a refining system will cost and the recovery time of the investment. GIS is a tool that can help tribes to discern if there is enough WVO in their area to invest in a solar-powered biodiesel refinery. The plans shown in this thesis are just examples of how different tribes can re-invest their profits back into renewable energy development projects. Researchers and tribes need to work together to create a plan better tailored to their needs.

The logical next step for this research is to build a demonstration project that uses solar energy to refine biodiesel. My work will continue with my Ph.D. dissertation focusing on the construction of a 50-gallon per day system built on the Osage reservation. A real world test will show tribes that they can use this technology. Building a refining system on the reservation would be an opportunity for tribal members to be educated about renewable energy and to show that investing in renewable energy means that they are in control of the resource. A demonstration project would not yield a lot of profit, but it would be enough to sustain the system for several years and pay the labor costs to run the system, which would mean several years of data to analyze. In addition, a demonstration project could serve as a biodiesel research facility, where different feedstocks could be tested and refined. Furthermore, there could be a chance to expand the facility for ethanol production on-site, as well as a soap-making facility to put the biodiesel waste product to use.

I will also be able to explore the social and political issues that can arise when I build a solar-powered biodiesel refinery on a reservation. I would like to collaborate with the tribe through their tribal government, but this may not be possible due to tribal politics. In that case, I have already established connection with a small group of tribal members that are willing to work with me. We have a site picked out, and the group includes an engineer, a machinist, the landowner who is willing to run the refinery, and a CDL short haul truck driver. In addition to my expertise, there is enough human resources to build and run a solar-powered biodiesel refining system. Another issue is finding the initial investment for the refining system. I will only need about $20,000 for start-up capital, so I will apply for grants to cover this. There are several tribal and rural energy grants, as well as private grants. I have already begun working with the Climate Institute in Washington D.C. The Climate Institute is a private organization that is working on finding funding through donations for this project. The Climate Institute has also provided me with a small research team that will assist with technical, legal, and logistical issues.

I have two long-term goals for this project. First, I hope that this project and projects like this will get tribes talking about where their energy comes from. Second, I wanted to provide something for engineers to tinker with and make more efficient. The first computer was the size of a room, and now we carry them in our pockets. How far can this technology for using solar energy to refine biodiesel go in a few decades? Who knows? Nevertheless, I do not like the prospects for the future if no one is working on creative practical solutions. I would like to see renewable energy projects like solar-powered biodiesel refineries begin to crop up all over Native American reservations.

Appendix 1: Solar Powered Biodiesel Refining Experiments

Experiment 1

The first experiment used a super-capacitor charged by a direct current power source that I plugged into the electric grid. The direct current power source created the same type of electrical output as a photovoltaic cell. I connected the super-capacitor to a blender to mix the chemicals to refine biodiesel. The super-capacitor had a limited storage capacity and could only run a blender for about seven minutes. The super-capacitor did not hold a constant charge, which caused the blender to slow down as the electricity drained. I created four test batches of biodiesel from 200 ml of vegetable oil, 30 ml of Methanol and .7g of potassium hydroxide. The formula based on the process described in figure 1.For this experiment, I was unable to heat the oil to 170^0 F and the formula I reduced to accommodate the seven-minute limit blending time. The experimental data is in figure 2. The closer the amount of glycerin is to the 30 ml of methanol, the better the reaction efficiency is. I measured the amount of glycerin using a graduated cylinder. The test batches are all within the degree of error.

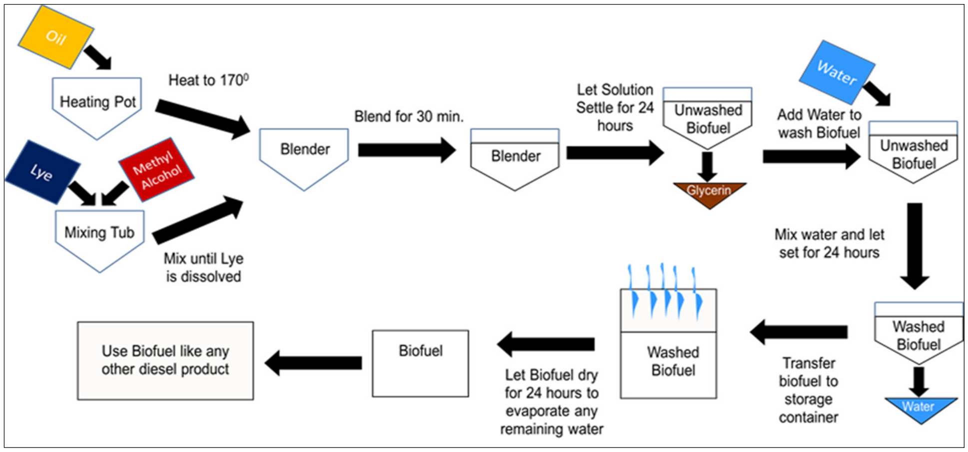


Figure 1. The biodiesel refining process for 1 liter of feedstock oil

Test		Glycerin (ml)		Biodiesel (ml)
1		20		210 ml
2		22		208 ml
3		18		212 ml
4		20		210 ml

Figure 2. Experiment 1 results

Experiment 2

I based the second experiment on the formula in Figure 1.The batch size was 500 ml of oil with 75 ml of methanol and 1.75 g of potassium hydroxide. The power source was from solar cells charging a battery bank. I heated the solution to 170^0 F using a hot plate and mixed it with a blender. I was able to take measurements of the electric usage with a voltammeter. I used three different mix times to see if I could reduce the energy input into the system without sacrificing the quality of the reaction. The mix times where 12 minutes, six minutes, and three minutes. The results are in figure 3. The closer the amount of glycerin is to the 75 ml of methanol used in the experiment, the better quality the chemical reaction. I measured the amount of glycerin with a graduated cylinder. The amounts of glycerin produced where within the degree of error and similar to other experiments conducted with grid based electricity as seen in Chapter 2.

batch 1	kwh	Glycerin (ml)	Mix Time		**batch 2**	kwh	Glycerin (ml)	Mix Time
1	0.09	57	12 min		1	0.07	53	12min
2	0.05	63	6 min		2	0.04	54	6min
3	0.04	58	3 min		3	0.03	56	3min

batch 3	kwh	Glycerin (ml)	Mix Time
1	0.07	56	12min
2	0.04	53	6 min
3	0.03	52	3min

Figure 3. The results of experiment 2

Conclusions

Solar powered biodiesel refining does not reduce the overall quality of refining biodiesel. Heating the biodiesel does seem to have a small impact on the quality of the biodiesel. The average glycerin production for experiment 1 was about 9% and experiment 2 was about 10% of the total fluid. The mix time reduction in experiment 2 yielded an average of 11% glycerin for 12 minutes, an average 11% glycerin for 6 minutes and an average of 11% glycerin for 3 minutes, which means that the lower mix times did not affect the quality of the reaction. Biodiesel can be refined on a small scale using solar energy. Increasing the scale to the point that more machines will be required will increase the amount of electricity used and are beyond the scope of these experimental models. I estimate the maximum scale that these tests model is about 50 gallons per batch.

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