CELLULOSIC ETHANOL FROM FOREST BIOMASS AND CARBON SEQUESTRATION:

NONINDUSTRIAL PRIVATE FOREST OWNER OPINION AND THE MODELED IMPACT ON CELLULOSIC ETHANOL CARBON EMISSIONS

by
Anna Brunner

A thesis submitted
in partial fulfillment of the requirements
for the degree of
Master of Science
Natural Resources and Environment
University of Michigan
December 2012

Thesis Committee:
Associate Professor William S. Currie, Chair
Assistant Professor Shelie A. Miller

ABSTRACT

Cellulosic ethanol has long been put forward as a more carbon-neutral fuel source than corn ethanol—trees grown for cellulosic ethanol production sequester carbon from the atmosphere and are less intensive to manage. Limits on the forest's rate of growth and the limited distance over which forest biomass can be profitably transported mean that forest owners in the vicinity of a woody-biomass biorefinery must be willing to harvest their timber as feedstock. I conducted a survey of 500 nonindustrial private forest, or NIPF, owners in Michigan to understand their management decision-making. The survey found a significant correlation between owners supporting sales of their timber for cellulosic ethanol production and owners desiring to maintain the same forest for carbon sequestration. However, these two ways of using NIPF land to mitigate net carbon emissions are mutually exclusive. I constructed a new computer model, the Cellulosic Ethanol BioRefinery Accounting Model (CEBRAM), which examines this tradeoff of how best to mitigate net carbon emissions using NIPF land. The model was parameterized for current forest species and growth in Michigan. The overall rate of NIPF biomass harvest and provision by NIPF owners to the biorefinery (referred to as 'participation') indicated by the survey was 47%. At this participation rate the net carbon balance for the biorefinery calculated on an energy basis was 0.03 MgC/ha over the 40 year simulation. Alternatively, when considering both the biorefinery and C storage in non-participating NIPF land within the transport radius, the net carbon was 10.74 MgC/ha over 40 years. If all the NIPF landscape was forested, 20.2 MgC/ha over 40 years would be sequestered, and to compare the presence of the biorefinery with the opportunity cost of this sequestration potential of the land puts the net carbon calculation at -9.46 MgC/ha over 40 years. This negative net carbon value indicates that more net carbon would be emitted with the biorefinery than without it. This analysis indicates that when considering NIPF forest land in Michigan, greater net C sequestration can be achieved through forest growth than through harvest of woody biomass for cellulosic ethanol production.

ACKNOWLEDGEMENTS

I would like to thank the USDA Forest Service McIntire-Stennis program for providing the majority of the funding for this work. Professor Michael R. Moore, and former School of Natural Resources and Environment student Nick Enstice provided helpful feedback on survey protocol and structure. Nicholas Reo pointed me towards the public addresses listed in the Commercial Forest Program, and without these the survey might never have been completed. Bill Currie and Shelie Miller both provided invaluable feedback along the way, and the time and energy they spent working with me is greatly appreciated. John Matters folded and stuffed almost all 1200 surveys into their proper envelopes, and for that, along with his unending support and encouragement, I am grateful.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Global climate change may be the largest problem current and future generations will face. It is a disaster that takes place over decades instead of hours, whose solutions must occur on a global scale instead of only on the household level—these are scales unfamiliar to humanity and make the problem all that more difficult to solve. As characterized by Levin and others, climate change can be thought of as a "super wicked" problem, following a long tradition in social science of characterizing complex, interdisciplinary policy problems as "wicked" (Levin et al 2009, and Lazarus 2010). Super wicked problems are complex, and because of their complexity, their proposed solutions may lead to unintended additional problems. Secondly, a consensus on the best solution to these super wicked problems is often difficult to reach and meanwhile the impact of delayed action in solving the problem is often cumulative, as it is with climate change (Levin et al 2009). Finally, the enormity of the problem leads people to discount the future more than is economically rational, further delaying action. These characteristics describe the challenges we face in dealing with climate change.

ENERGY INDEPENDENCE AND SECURITY ACT

Two basic options exist for dealing with the challenges of climate change—adaptation and mitigation—and both must be aware of the pitfalls of the "super wicked" problem. Adaptation to climate change means that people will work on ways we can respond more effectively to severe weather, rising oceans, and the unpredictability of the climate. Mitigation works to stop climate change from being as severe as it could be, primarily by reducing greenhouse gas emissions or finding new ways to increase the sequestration and removal of those gases from the atmosphere. In the process of mitigation, however, we must be aware of the unintended consequences of policy changes. The Energy Independence and Security Act of 2007, or EISA, was a policy put into place to lessen our reliance on fossil fuels that emit greenhouse gases and to promote the development and use of renewable fuels. EISA mandated that 12.95 billion gallons of renewable fuel be blended with gasoline by 2010 and 36 billion gallons of renewable fuel would be blended into gasoline by 2022. In an attempt to avoid the potentially negative unintended consequences of this policy, it was also mandated that these renewable fuels must emit fewer greenhouse gases than the fossil fuel they were replacing (EPA, accessed November 2012). Which metrics are used to determine the greenhouse gas emissions of various renewable fuels makes a big difference in how successful the EISA is and how effectively these emissions are reduced.

RESEARCH FOCUS

Cellulosic ethanol is fuel source that, if it complied with EISA standards regarding greenhouse gas emissions, could help meet the renewable fuel goals of the Act. The fact that trees and other cellulosic ethanol crops sequester carbon just by growing is one of the things that make this ethanol a renewable energy source with potentially limited carbon emissions. However, setting aside forest to sequester carbon and not using it for any kind of crop production is another way trees could be used in an effort to combat rising carbon emissions. The trade off between growing crops for cellulosic ethanol or, alternatively, using the plants to naturally sequester carbon by allowing them to grow unharvested, has not been explicitly explored in any of the cellulosic ethanol literature to my knowledge. The question most analyses in the current literature address is this: how effective, from a carbon or an economic perspective, is a given alternative fuel or carbon sequestration policy? The question I propose to answer is: how should we use our forest resources in the most effective way if our goal is to reduce net carbon emissions? Additionally, how do the forest owners who would supply these cellulosic ethanol resources feel about using their trees in this way, and how does their level of willingness to provide woody biomass impact the net carbon emissions from a biorefinery and its surrounding landscape?

HOW TO MAKE CELLULOSIC ETHANOL

Cellulosic ethanol, an alternative to corn ethanol and also encouraged under the EISA, is made from the cellulose and hemicellulose material in trees or other woody plants. There are several ways of making ethanol from cellulose, but all involve turning cellulose into sugars and then fermenting those sugars into ethanol. In the first stage of the process the wood must be cleaned and broken down into separate parts, removing the lignin and other materials from the cellulose and hemicellulose. In the second stage, the separated hemicellulose and cellulose are broken down into sugars. Finally, in the third stage, these sugars are fermented into ethanol. The most common process, known as Separate Hydrolysis and Fermentation, or SHF, uses acid hydrolysis in the first two stages and all three stages of the production process must be kept physically separate. Using different enzymes in place of acid hydrolysis, similar results can be achieved by combining stages two and three in a process known as Simultaneous Saccharification and Cofermentation, or SSC. Scientists at the Department of Energy are working on developing new enzymes that would enable the entire three-step process to be accomplished in one location—Consolidated Bioprocessing, or CBP. Developing a standardized and financially viable way of turning cellulose into ethanol is often cited as a barrier to widespread development. Indeed, no commercial scale cellulosic ethanol biorefineries are currently running (Haug et al 2004). In this thesis, the primary source of cellulosic ethanol studied is assumed to be from forest biomass in Michigan.

COUPLED HUMAN AND NATURAL SYSTEMS

A cellulosic ethanol biorefinery's sustainability hinges upon both human and natural factors. A certain threshold of participation from nearby suppliers, such as forest landowners is needed for cellulosic ethanol biorefineries to succeed, economically. Similarly, the participation rate and ecological functions of the forest have an impact on the carbon footprint of the biorefinery, contributing to overall sustainability. Determining the sustainability of this system is not a matter of simply understanding the carbon dynamics of tree growth and the offsetting capabilities of cellulosic ethanol, but is also related to the decisions people make about what kind of alternative energy source to use—if they will even use one—as well as if they want to participate in the bioeconomy and cut down their trees. In the absence of a functioning commercial cellulosic ethanol biorefinery, one way to project what it might look like and how it might impact the landscape is to create a model system and observe what cannot be analyzed in reality. With dynamic systems that could have unintended consequences, a model can be one of the few ways to understand the system more thoroughly. As with most alternative energy systems, cellulosic ethanol is a coupled human and natural system, or CHANS. Indeed there are few systems that are wholly free of the natural world or human presence, and yet we often choose to divide the two. CHANS models must often rely on interdisciplinary collaboration since the scientific methodology for studying and modeling a system is different than the social science methodology of modeling human behavior.

Despite the need for interdisciplinary collaboration, CHANS models often favor one methodology over the other, and so one system is modeled in a much more sophisticated way than the other. Some studies follow a pattern where human preference is informed by economically rational action and the natural world is minimally incorporated (Loibl and Toetzer 2003, Krutilla and Reuveny 2006, Monticino et al 2007, Werner and McNamara 2007). Other studies are characterized by complex natural environments and incorporate people only as factors that force the environment into one state or the other (Akbari et al 1997, Akbari 2002, Pataki et al 2006, Jenerette et al 2007, and Pickett et al 2008). The practicality of simplifying human preference or the dynamics of nature should not be discounted, since it is the role of models to simplify the natural world. However, the goal of CHANS models should be to preserve the complexity of both systems.

FOREST ECOSYSTEM AND BIOFUEL MODELS

CHANS models of forest ecosystems and biofuels can be broken down along similar lines, but the integration of human and natural systems is more thorough in these models, even if some authors rely more on natural science than economics to make their case. There are several papers that are focused on both the dynamics of the biofuel growth and impact on the ecosystem, but also on how economically feasible each type of biofuel might be (Egbendewe-Mondzozo et al 2010, Melillo et al 2009, Searchinger et al 2008, Gan and Smith 2006, Seidl et al 2007). Other papers are focused on the dynamics of nature, but take place in a human-dominated environment, where human decisions are implicitly incorporated (Campbell et al 2008, Farrell et al 2006, Kroetz and Friedland 2008, Fahey et al 2010, Fargione et al 2008, Rhemtulla et al 2009, Caspersen et al 2000). Then there are papers that look at different carbon pricing scenarios and then examine the impact each would have on the environment (Plevin and Mueller 2008, Wise et al 2009, Sohngen and Sedjo 2006, De La Torre Ugarte et al 2000, Froese and Miller 2008). Although these papers used different methods to further understand this coupled human and natural system, the conclusions they drew about cellulosic ethanol production were largely in agreement.

Cellulosic Ethanol Models

The CHANS analysis conducted by Froese and Miller (2008) examined the feasibility of building a mixed coal- and wood residue-fired power plant in Rogers City, Michigan, and comes closest to examining the system I examined in the present study. The study of Froese and Miller (2008) determined that Michigan's waste wood within a 50-mile radius of Rogers City would be sufficient to supply the building. Further, they concluded that harvest on the northern Lower Peninsula of Michigan was currently one-third of the growth rate, therefore an increase in available forest residue was possible. Finally, they concluded that the available loggers and truckers now out of work due to the declining, once substantial paper and pulpwood industry, would help make the new power plant a success. Cellulosic ethanol from either waste residue or plantation biomass could also benefit from this dying industry, although this point was not specifically mentioned by Froese and Miller (2008).

The success of the partial biomass power plant in Michigan as studied by Froese and Miller (2008) was in part due to the waste wood available within a 50-mile radius of the site. In the analysis by Kroetz and Friedland (2008) that examined wood used for space heating in New England, they also conclude nearby wood sources are critical to the economic feasibility of wood pellet stoves. Their findings suggested that wood pellet space heaters were better for the environment than electricity or natural gas because wood biomass was plentiful nearby, sequestered carbon while growing, and was renewable. Unlike many industries that find savings in expanding processing capacity, those that depend on wood biomass have a negative economy of scale (Hubbard et al 2007, Simpkins et al 2006, Gan and Smith 2006). This negative economy of scale occurs because forests have a maximum tree density and trees only regrow at a specific rate, therefore increasing the scale of the biorefinery will not increase savings for the facility, but will require materials to be transported from increasingly far distances. The density of forest with available wood in Michigan is one of the reasons cellulosic ethanol production might be successful here (Kroetz and Friedland 2008).

The density of forest in Michigan and the rate at which it is available are both key factors in determining a cellulosic ethanol biorefinery's success (Froese and Miller 2008, Kroetz and Friedland 2008). However, it is worth examining how cellulosic ethanol compares to other fuel sources. Farrell et al complied studies of numerous alternative fuel types and compared them, finding each crop measured up differently. They used two metrics to assess how environmentally friendly these fuels were: greenhouse gas emissions per unit energy produced and fossil fuel products used per unit energy produced. Ethanol and cellulosic ethanol, specifically, tended to fare better than gasoline, although one study stood out as contradicting this trend. Cellulosic ethanol was not always better than corn ethanol—in one case corn ethanol used less fossil fuel energy per unit ethanol energy than cellulosic ethanol. The conclusion of this study suggested that cellulosic ethanol may not be the next generation, carbon-neutral biofuel it has been assumed to be (Farrell et al 2006).

Michigan may have the resources to support cellulosic ethanol biorefineries, but whether or not this ethanol is the best way to limit greenhouse gas emissions is unclear (Farrell et al 2006). Egbendewe-Mondzozo and others describe further problems for cellulosic ethanol. They presented a thorough model that captured weather dynamics throughout the year and the impact they had on a variety of biofuel crops. The model then ranked the cost of production for biofuels and concluded that cellulosic ethanol perennials were the most costly to produce, but when compared to the least expensive option, corn stover, these perennial grasses decreased greenhouse gas emissions and improved water quality (Egbendewe-Mondzozo et al 2010). The paper concluded that cost was a challenge for the success of cellulosic ethanol, but environmentally it made sense to work to overcome this challenge. The greenhouse gas emissions as calculated by Egbendewe-Mondzozo differ from the conclusions drawn by Farrell, and further complicate our understanding of cellulosic ethanol as a potentially low-carbon fuel source (Egbendewe-Mondzozo et al 2010 and Farrell et al 2006).

The model constructed by Seidl and others (2007) examined how forest management and end use changes carbon sequestration. The model showed that the management scenario where the forest was left to grow without harvest or intensive management sequestered the most carbon. However, Seidl et al. (2007) concluded that this outcome was not practical, given that people rely on forest resources and some harvest must occur. The model further showed that using wood in long-lasting resources like houses to replace more energy intensive concrete yielded a better carbon outcome than using the biomass for short-lived products like paper. Additionally, they concluded that using the biomass for cellulosic ethanol would permanently offset gasoline carbon emissions and was better for the environment than the temporary carbon sequestration achieved through wood products. So while the forest growing on its own sequestered more carbon, the practical management scenario suggested that the biomass should be used for cellulosic ethanol or in long-lived products such as construction materials (Seidl et al 2007).

Cellulosic ethanol production is shown to remove carbon from the atmosphere by offsetting gasoline emissions, and, though expensive, emits less carbon dioxide per unit energy produced than other ethanol sources (Seidl et al 2007 and Egbendewe-Mondzozo et al 2010). Exactly how carbon emissions are calculated leads to different conclusions about cellulosic ethanol, as shown by Farrell and others comparison of numerous alternative fuel studies. The fossil fuel energy per unit ethanol energy of corn ethanol, in one study, was less than cellulosic ethanol's (Farrell et al 2006). The cellulosic ethanol industry in Michigan is arguably feasible, given the paper industry infrastructure and the density of available tree biomass (Froese and Miller 2008 and Kroetz and Friedland 2008). The barriers to creating this new infrastructure seem to be the price of production and the potential carbon emissions of the process.

TERRESTRIAL CARBON AND LAND USE CHANGE MODELS

The carbon history of a landscape can vary considerably depending on how the land has changed over time, and these changes can influence the overall carbon balance of the cellulosic ethanol system. A study in Wisconsin showed a significant decrease in terrestrial carbon sequestration during the period of agricultural expansion in the state, from 1850-1930 (Rhemtulla et al 2009). Forests were cleared during this time to make way for farms, whose land area peaked during the 1930s. Since then, as agricultural land has turned back into forest, some of the terrestrial carbon sink has also returned. The model in this paper indicated that a complete return to the forest profile from 1850 had not yet occurred, so the state had the potential for more carbon sequestration than was currently happening (Rhemtulla et al 2009). The debate that maintaining some agricultural land in Wisconsin might be necessary or how the carbon profile of the landscape might look with alternative fuel production increasing was outside the bounds of the paper (Rhemtulla et al 2009).

As with the model of Rhemtulla et al. (2009), another CHANS model recognized the powerful role land use change can play when calculating the net carbon emissions of a system. Caspersen and others, in their model, addressed the issue of forest fertilization via elevated CO_2. The increase of carbon dioxide in the atmosphere that contributes to climate change is hypothesized to be able to fertilize trees through photosynthesis—the process that uses carbon dioxide and makes trees grow. In their model, Caspersen et al examined tree growth data over time from a variety of plots throughout the US and concluded that the hypothesized CO_2 fertilization effect was not increasing the growth rate of trees. Any increase to the terrestrial carbon sink could be attributed to land use change, as supported by Rhemtulla et al. (2009). As some agricultural lands reverted to forest, the terrestrial land sink was increasing. No effects from carbon dioxide fertilization were found (Caspersen et al 2000).

The power that reverting agricultural lands back to forest has on the terrestrial carbon sink has implications for the carbon profile of the cellulosic ethanol industry, that would rely on an expansion of managed lands to be successful (Rhemtulla et al 2009 and Caspersen et al 2000). The 2008 paper by Fargione and others gave the land use change caused by biofuels a name: the biofuel carbon debt. In the most extreme case, palm oil grown on what used to be peatland rainforest in Malaysia released 3452 megagrams carbon dioxide per hectare. At the rate that the biofuel was able to offset carbon, it would have taken 423 years of biofuel production to offset the initial carbon debt from the land use change. The model also calculated the carbon debt of cellulosic ethanol from prairie grass grown on marginal cropland in the US and concluded there was no carbon debt associated with this biofuel. Land use change emissions caused by converting land to biofuel production have a wide range and cannot always be said to negatively impact the carbon profile of the biofuel (Fargione et al 2008).

Melillo and others, like Fargione, examined the impact of global land use change and assumed that biofuels would continue to be promoted as the best replacement for fossil fuel used in vehicles. Their model predicted that as biofuels are encouraged, more forest would be cut down and the land would be changed over to grow biofuels, some of which, like corn stover, are more energy-intensive than others. The paper concluded that the biggest problem with cellulosic ethanol was the unintended consequence of land use change that would end up emitting carbon on a large scale. If these emissions occurred, cellulosic ethanol could not be relied upon to be a carbon-neutral transitional energy source, but in the long term after paying off the carbon debt, using marginal lands to grow biofuel crops, it could be thought of as a renewable energy source (Melillo et al 2009).

Similarly, the Campbell et al paper on the global potential for ethanol recognized that how the biofuel was grown and any land use change associated with the production of the biofuel would impact the carbon profile of the fuel (Fargione et al 2008, Melillo et al 2009). The paper opens with the statement that if biofuels were grown on previously forested land due to competition with agricultural land, carbon emissions would increase due to land use change. And if biofuels like corn were continually relied upon, they would compete directly with food corn and the price of food would increase. The solution to this problem proposed and investigated in the paper, was to grow cellulosic ethanol crops on marginal land. The model was focused on determining how much marginal cropland exists where cellulosic crops could be produced. The paper concluded that the potential of marginal lands, globally, would be capable of supplying less than 8% of current primary energy needs. Marginal croplands cannot be the only way biofuels are grown if they are expected to supply all our alternative fuel demand (Campbell et al 2008).

Like the papers by Campbell, Fargione, and Melillo, the analysis by Searchinger et al. (2008) on the global potential for ethanol recognized the potential pitfalls of unintended or indirect land use change (Campbell et al 2008, Fargione et al 2008, Melillo et al 2009, Searchinger et al 2008). Searchinger's paper used a global agricultural model to project the impact that an increase in corn ethanol production would have on food prices and carbon emissions. The paper concluded that as demand for corn ethanol increased, global land use change to meet demand would release large amounts of carbon, while the price of food crops would increase. The price for corn would increase by 40%, and due to a smaller portion of crop production set aside for soybeans and wheat prices for these commodities would rise as well, by about 20%. Using marginal lands to grow cellulosic ethanol was determined to not impact food prices as much, but the feasibility of implementing the necessary laws to restrict its growth to marginal land was questioned. The paper concludes with a warning that expansion of ethanol crops could cause food prices and carbon emissions alike to rise, and the practicality of ensuring low carbon emissions from cellulosic ethanol is unlikely (Searchinger et al 2008).

An analysis conducted by De La Torre Ugarte and others for the US Department of

Energy concluded that carbon pricing policies that encouraged cellulosic ethanol would likely cause land use change, but that the negative impacts from carbon emissions could be controlled. The Department of Energy paper concluded that the market pressure to grow biofuels would lead to abandoned marginal lands being used again to grow crops, while farmers would maintain their current crop lands for biofuel production. The land use change papers by Fargione, Melillo, Campbell, and Searchinger all concluded the same shift to marginal land would take place, but they concluded this was a problem and that the marginal land should be used for biofuels, not food crops (Fargione et al 2008, Melillo et al 2009, Campbell et al 2008, Searchinger et al 2008). Additionally, the shift to marginal land, unless regulated, could spill over into forested area being cut down. The conclusion from De La Torre Ugarte that marginal land would now come back into rotation was presented as a good thing, with only a brief mention that food prices would likely rise, and with no mention that forest ecosystems might also be targeted by biofuel crop expansion. The model used by De La Torre Ugarte was a modified agricultural yield model, so including the potential for deforestation would have been difficult (De La Torre Ugarte et al 2000).

Utilizing marginal land to grow biofuel crops, or using it to grow displaced food crops, has been presented as a way to limit land use change carbon emissions (Fargione et al 2008, Melillo et al 2009, Campbell et al 2008, Searchinger et al 2008, De La Torre Ugarte et al 2000). Gan and Smith's 2006 paper looks at avoiding the need to grow biofuel crops at all, and just rely on waste biomass, such as logging residue, to power biorefineries or power plants. This residue is already discarded by the logging and wood products industry, although it normally remains on the land and contributes to the carbon cycle of the forest. Not all of the available residue would be economical to have removed from the harvest site and to have transported to a main location for processing, so a 70% residue recovery rate was assumed. Even with this decrease the model calculated that 13.9 million dry tons of biomass would be available each year to offset fossil fuel energy emissions. When residues and wood waste from other sources were combined, the potential energy created would displace about 3% of US electricity sector's total carbon emissions, circa 1997. This paper concluded that the waste biomass currently discarded could be turned into energy to a degree that would put a dent in carbon emissions (Gan and Smith 2006).

Land use change, either direct or indirectly caused by the expansion of biofuel production, limits the carbon sequestration of the terrestrial carbon sink and adds a significant amount of carbon debt to cellulosic ethanol, making it unlikely that this ethanol is a low carbon emissions fuels that could help meet the renewable fuel standard set up by EISA (EPA accessed November 2012). However, if cellulosic ethanol crops are grown on marginal land, or use waste resources like logging residue in place of a dedicated crop, the land use change carbon emissions of cellulosic ethanol drop considerably. The largest challenge to cellulosic ethanol's success as a low carbon fuel would appear to be the unintended consequence of biofuel crop expansion—land use change carbon emissions. Limiting biofuel crop expansion and discouraging competition with food may be partially achieved through different carbon pricing policies, but even these policies may have unintended and harmful consequences.

CARBON PRICE MODELS

Plevin and Mueller examined three kinds of carbon regulation policies and used their model to conclude which one would favor which energy industry. The first carbon policy would regulate carbon emissions throughout the lifecycle of fuel production, from cradle to gate. This policy would be most costly of all for energy producers. The second carbon policy would price carbon only at the factory or refinery level, and this policy was less expensive for all than the first. The final policy would institute a low carbon fuel standard that all fuels would have to adhere to, by making whatever changes they could to achieve low carbon emissions from vehicles. Under this policy, corn ethanol would actually receive a subsidy, due to the carbon being offset by its use. Depending on what stage of the industrial process the government policy influenced carbon emissions, each of these different policies would be effective. The conclusion drawn by this study was that ethanol has carbon emissions throughout its life cycle, but when it is compared with direct emissions from cars using other fuels, it is carbon neutral (Plevin and Mueller 2008).

The policies examined by Plevin and Mueller could lead to unintended and negative consequences, according to the article by Wise (Wise et al 2009, and Plevin and Mueller 2008). Wise et al advocated for a carbon tax that was not just focused on some stage of industry, but on all carbon emissions—a proposal that would be closest to the first policy examined by Plevin and Mueller to price emissions along the lifecycle of the fuel's production, but which would exceed even these wide boundaries. Under a carbon tax on all carbon emissions, corn ethanol would compete with food corn on a more equal basis. Forest growth would be encouraged, but certain farming activities would be discouraged, like livestock production, due to its carbon intensity. The paper concluded that taxing all carbon emissions solved problems that industry-specific carbon pricing could not, but that other issues, such as discouraging livestock production, might arise (Wise et al 2009).

The issue of how to tax carbon emissions is related to the market to price carbon.

Putting a price on carbon would benefit forest landowners who could then be compensated for the carbon their trees sequester, as opposed to a tax on carbon that would punish forest landowners who cut down their trees to grow corn. The model by Sohngen and Sedjo examined the price of carbon, not how to tax carbon emissions, and found that the initial market price and the subsequent rate of increase or decrease in price would have an impact on how much forest carbon was sequestered. The best way to encourage forest carbon sequestration was to set the initial price of carbon high and have it decrease over time. This trajectory would incentivize landowners to commit to sequester carbon early, as opposed to starting with a lower carbon price and having it increase, which would likely see landowners delay in agreeing to sequester carbon while they waited for the market to reach a higher price before committing to a program. This model suggested that rewarding those who sequestered carbon was a better way to influence people than taxing carbon emissions, but that ultimately the market forces should be well understood before a policy was implemented (Sohngen and Sedjo 2006).

A part of effective carbon regulation through pricing is the ability to measure carbon emissions or sequestration effectively. The CHANS model by Fahey and others (2010) examined the carbon profile of different forest ecosystems given carbon sequestration regulation. If forest carbon could be accurately profiled and accounted for, then countries would be much closer to being compensated for the carbon their forests sequester and individuals could start being paid to manage their forests for carbon storage as well. Fahey's research determined that there were accurate forest models out there for the US that drew upon long-term data collected by the Forest Service Forest Inventory Analysis program. Models for other forest types in other regions of the world present a challenge, but with a model template that worked well for the US it is possible to imagine similar models for other countries. The paper concluded, however, that there were more issues with accurate carbon sequestration accounting than there were with biofuel production accounting, and this difference made investment in biofuel production as a way to decrease carbon emissions more reliable than forest carbon sequestration. The paper acknowledged issues of unintended land use change, but still considered biofuel carbon accounting to be more accurate and effective (Fahey et al 2010).

CELLULOSIC ETHANOL IN THE FUTURE

From all of the CHANS models addressed here that deal with some aspect of cellulosic ethanol or carbon sequestration, several things become clear. Cellulosic ethanol faces barriers to becoming the alternative fuel that replaces traditional gasoline in cars, and these barriers are primarily economic (Egbendewe-Mondzozo et al 2010). If the economic barriers fall, perhaps due to carbon pricing, cellulosic ethanol could either be environmentally beneficial or harmful, depending on how it is implemented. The various options on carbon pricing could hurt the ethanol industry or could give it a subsidy (Wise et al 2009, Plevin and Mueller 2008). The rate at which carbon prices rise or fall could encourage forests to be used for carbon sequestration or make forest owners hesitant to commit to such a program (Sohngen and Sedjo 2006). The value attached to cellulosic ethanol production could even sway enough farmers to expand into producing ethanol that unintended and harmful land use change occurs, with forests being cut down to make way for biofuels and in the process emitting more carbon than the biofuels will offset (Campbell et al 2008, Searchinger et al 2008, Melillo et al 2009, Fargione et al 2008). The size and importance of the terrestrial carbon sink helps slow the onset of climate change by absorbing carbon dioxide from the atmosphere, but what policy will best ensure its expansion or stability in the face of expanded cellulosic ethanol production is unclear (Rhemtulla et al 2009, Caspersen et al 2000). Therefore, from these studies, it remains to be seen if cellulosic ethanol is capable of being a clean, low-carbon fuel—some other form of ethanol may be cleaner (Farrell et al 2006).

Positive conclusions supporting cellulosic ethanol can also be drawn from these CHANS models. Using marginal or abandoned cropland to grow cellulosic ethanol reduces the carbon emitted when the land enters cellulosic ethanol production (Melillo et al 2009, De La Torre Ugarte et al 2000, Campbell et al 2008, Searchinger et al 2008, Fargione et al 2008). Additionally, relying on forestry residue or other waste products that are currently discarded would limit the need to use new crop land to grow biofuels, again limiting the carbon emissions from land use change (Gan and Smith 2006, Froese and Miller 2008). In heavily forested areas, the proximity of the biomass would make cellulosic ethanol refineries more profitable by minimizing transport costs, and a declining forestry sector would likely have useful infrastructure that could be drawn upon (Kroetz and Friedland 2008, Froese and Miller 2008). Changing the end-use of forest biomass from pulp and paper to cellulosic ethanol would not significantly change how the land is used or managed, but would offset carbon in a more permanent way by replacing gasoline consumption, something Michigan is in a position to take advantage of (Froese and Miller 2008, Seidl et al 2007). Carbon accounting for cellulosic ethanol is more accurate than the current carbon accounting practices used for carbon sequestration credits, and this precision would make it easier to effectively track carbon emissions over time (Fahey et al 2010). It remains unclear how forest landowners feel about carbon sequestration or using their biomass for cellulosic ethanol since the CHANS studies discussed did not cover landowner preference. There are few papers that examine the preferences of nonindustrial private forest owners, but these individuals would be critical to the success of a biorefinery in Michigan due to the negative economy of scale biorefineries must overcome (Hubbard et al 2007, Simpkins et al 2006, Gan and Smith 2006).

NONINDUSTRIAL PRIVATE FOREST OWNER SURVEYS

The Committee of the Natural Research Council prepared a thorough report on the biofuel industry, including its history, barriers to implementation, and public understanding of the fuels (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). Similar to the CHANS models discussed previously, the report concluded there were serious problems with land use change emissions from biofuel expansion and that until these problems are addressed, ethanol cannot meet the standards for carbon emissions reduction as set under EISA (EPA accessed November 2012 and Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). Using biomass from wood products to make cellulosic ethanol could cause an increase in the price of wood products, but where timber harvest for wood products is decreasing, the potential exists for expansion into ethanol production with a minimal carbon debt.

An additional barrier to the success of the cellulosic ethanol industry was determined to be the forest landowners who would supply the biomass. Studies of nonindustrial private forest, or NIPF, owners in Kentucky and Iowa concluded these forest owners were enthusiastic about cellulosic ethanol, but unsure of the economic success the industry would have, and therefore hesitant to become involved in timber sales to the industry. Over the last

50 years, the majority of yearly timber harvest has come from NIPF land, it is likely that these landowners will supply the bulk of forest biomass for cellulosic ethanol as well, and so their views of the industry are important for its success (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). The supply of timber from NIPF lands comes overwhelmingly from those who own large parcels of land and have an active management plan. Most NIPF owners use their land primarily for aesthetic enjoyment and do not have a management plan. A study of NIPF owners in Arkansas, Florida, and Virginia found that those with small-tracts of land that do harvest tend to use the biomass for personal, non-commercial purposes (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011).

The most comprehensive study of NIPF owners, the National Woodland Owner Survey, or NWOS, has been carried out by the Forest Service annually since 2002, with results of the national survey posted online (Butler et al 2012). I used the online survey data to extract information about Michigan NIPF owners, specifically, and I will report this information here. Michigan NIPF owners most commonly own between 1 and 9 acres of forested land, and aesthetic enjoyment of the land is the most common reason for ownership, similar to landownership reasons given in other studies of small NIPF owners (Butler et al 2012 and Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). Most of these NIPF owners do not actively manage their land, with 95% reporting they have no management plan. The reasons given for wood harvest tend not to be for commercial gain, with 22% saying they harvested wood to improve the remaining tree quality, 17% to remove natural damage, 16% because trees were mature, and 14% because wood was needed for personal use (Butler et al 2012). These findings are again similar to those described in the National Research Council report (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011).

Smith also uses data from the NWOS, along with other sources, to report on the state of the nations forest resources (Smith et al 2007). In 2007, 56% of the nation's forests were under private management by individuals, tribes, corporate entities, or associations. The dominant reason for ownership, nationally, was for aesthetic reasons, although 58% of NIPF owners in the survey had at one time or another commercially harvested their forest. Since the findings from Smith et al come from the same source as Butler et al 2012, there is not much difference in the data, although the Smith report looks at national trends, while the numbers I describe above were focused on Michigan, specifically. NIPF make up the majority of land ownership and have a mixed view on timber harvest, with smaller-tract owners less likely to cut down their biomass than NIPF owners with large tracts of forest.

Data from the NWOS were used in a study focused on the role inheritance plays on forest land management. (Majumdar et al 2009). There is a history of intergenerational land transfer of human capital in agriculture that Majumdar posits also exists in NIPF land. Using the NWOS data, the study shows that individuals who inherited their forest are more likely to harvest their land and feel that forest harvest is a reason for ownership than NIPF owners that purchased their land. As discussed in Smith and Butler, most NIPF owners report that the top reason for ownership is aesthetic (Smith et al 2007 and Butler et al 2012). Majumdar's paper finds that first-generational forest owners are more likely to value their land for its non-market values than those landowners who inherited their property. Nationally, 28% of NIPF owners inherited their land and the majority of them intend to pass along their land to their children, indicating the possibility of long-term support for the timber industry on these inherited NIPF lands (Majumdar et al 2009).

Even though most NIPF owners state the primary reason for ownership has to do with the non-market value of their forest and are not interested in timber harvest, they also do not appear interested in enrolling their forest in land conservation programs. Current participation in forest management and conservation programs runs from 2-18% (Le Vert et al 2009). A survey of Virginian NIPF owners found that 77% would not consider participating in a conservation easement program. Similar to the findings of the NWOS, this study by Le Vert found that recreation in the forest was the most important reason for ownership, with timber harvest being one of the least important reasons. Despite a strong interest in using the land for its non-market goods, few NIPF owners were willing to commit to enroll their land in some kind of conservation easement. Among those that were willing, cooperation with neighbors and an environmental ethic were characteristics of these NIPF owners that set them apart from those unwilling to participate in conservation programs (Le Vert et al 2009).

The forest stewardship program run by the State of Minnesota had a similar issue with low enrollment, with only 2% of eligible land enrolled in the Sustainable Forest Incentives Act, or SFIA (Kilgore et al 2008). A study of NIPF owners in the state found that there were several significant factors that were associated with a participation in SFIA. If the landowner had heard of the program before they were twice as likely to agree to participate as those who had not heard of it before. The land covenant required for enrollment was highly unpopular with NIPF owners, along with the low compensation price, and these two pieces were cited as barriers to higher enrollment. Like other studies of NIPF owners, Kilgore et al found most reported aesthetics, recreation, and supporting wildlife habitat as reasons for ownership (Kilgore et al 2008, Butler et al 2012, Smith et al 2007, Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). Although many surveyed NIPF owners felt the compensation rate for enrollment was too low, some forest owners felt the program aligned with their reasons for ownership so well that they would actually pay to participate in SFIA (Kilgore et al 2008).

Plantinga looked willingness to enroll NIPF land in carbon sequestration programs and concluded that forest owners do not have enough information to decide at what carbon price they should enroll their land in a carbon sequestration compensation program. Plantinga asked what value forest owners would need to be compensated at in order to enroll in such a program and found a bias towards acceptance when carbon prices were higher than those suggested by traditional economic valuation. The paper concluded that this discrepancy could be due to landowners lacking information they need to make an informed choice, or that perhaps the value landowners placed on their land was not fully captured by traditional economic metrics. Similar to the NIPF owners who would be willing to pay to enroll in Minnesota's SFIA program, there may be a non-market value these forest owners are adding to the carbon price they demand (Kilgore et al 2008 and Plantinga 1997).

Nonindustrial private forest owners make up the majority of forest owner types within the United States (Smith et al 2007). Those that own large tracts of land are more likely to support timber harvest, as are landowners who inherited their forest land (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Majumdar et al 2009). Most NIPF owners are against commercial timber harvest, but do support using the land for wildlife habitat, or for purely aesthetic reasons (Smith et al 2007, Kilgore et al 2008, Le Vert et al 2009). Despite valuing the land for non-market purposes, enrollment in conservation easement programs remains quite low, around 2% (Le Vert et al 2009 and Kilgore et al 2008). Some landowners appear to value how their land is used outside of a purely monetary framework, expressing willingness to pay to enroll in conservation programs, or demanding more compensation for carbon sequestration than the land is economically worth (Kilgore et al 2008, Plantinga 1997). The Committee of the National Research Council report found enthusiasm for harvest for cellulosic ethanol was widespread, but committing to concrete action in support of the industry was minimal (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). NIPF owners may view biomass harvest for use in a biorefinery differently than they view traditional timber harvest, since it would actively offset gasoline emissions and benefit the environment more than timber harvest. The currently available studies on NIPF owner land use would suggest little actual support for cellulosic ethanol and a hesitancy towards enrollment in programs that place use restrictions on the land, as carbon sequestration programs would (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Kilgore et al 2008, Le Vert et al 2009). In Michigan, with the State's history of forestry, will NIPF owners feel differently (Froese and Miller 2008)?

CELLULOSIC ETHANOL, LAND USE CHANGE, AND HUMAN DECISIONS

Cellulosic ethanol grown from trees comes from a renewable energy source, since trees can be replanted, and some species can regrow quite quickly. As they grow, trees sequester carbon in their leaves, branches, trunks, and roots, and eventually in the soil around them (Plantinga and Birdsey 1993). Because of this ability to sequester carbon, some carbon balance models of cellulosic ethanol assume the carbon released when trees are burned is equal to the carbon sequestered when the trees are replanted and regrown, and therefore ignore a more careful study of the carbon flow (Bowyer et al 2005, Hattori and Morita 2010). The carbon sequestration process is more complicated than this, with young forests sequestering carbon faster than older forest ecosystems.

Although the isolated process of growing trees for cellulosic ethanol production may sequester carbon, the land use change implications of encouraging widespread biofuel crop production can make ethanol carry a heavy carbon debt (Melillo et al 2009, De La Torre Ugarte et al 2000, Campbell et al 2008, Searchinger et al 2008, Fargione et al 2008). All biofuels must confront the tradeoff between using the land to sequester carbon or using it to grow and harvest biofuel crops. Carbon sequestration policies may have unintended consequences as well, raising the price of livestock production or inaccurately crediting forests for carbon they have not sequestered (Wise et al 2009, Fahey et al 2010). The carbon emissions from a given facility are impacted by the boundaries set under a policy, like the EISA, or in the model used to capture predicted dynamics (EPA accessed November 2012).

How individuals react to the restrictions set down by a given policy will ultimately determine its success or failure. In the case of a cellulosic ethanol biorefinery supplied by NIPF owners in the Northern part of Michigan, we have too little information to know how NIPF owners would respond. Existing research on NIPF owners suggests that a majority of them would be against harvesting their biomass, although perhaps would express interest in the cellulosic ethanol program (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Smith et al 2007, Kilgore et al 2008, Le Vert et al 2009). The majority of NIPF owners also seem opposed to entering into programs that would restrict their land use, and so support for carbon sequestration programs may also be limited

(Kilgore et al 2008 and Le Vert 2009). Will NIPF owners in Michigan agree to sell their biomass to a cellulosic ethanol biorefinery in the State? Given this support, what will carbon emissions from the biorefinery look like? If the rate of support changed, how would the carbon emissions from the biorefinery change?

RESEARCH OVERVIEW

Michigan, specifically, the Upper Peninsula and northern portions of the Lower Peninsula, was chosen as the location of the study due to the presence of an experimental cellulosic ethanol biorefinery in the area, as well as the ease of access to data (Simpkins et al 2006 and Lindauer-Thompson 2008). I focus here on nonindustrial private forest, or NIPF, owners in order to represent forest owners in general because they make up 40% of the forest landowners in Michigan, and as such they will have a major impact on the success or failure of any biorefinery in the State (FIA, accessed April 2012). The unknown opinions of this diverse group of people regarding cellulosic ethanol relative to their potential impact on the budding industry made them an ideal group to study. I researched NIPF owner opinions and decision-making factors by designing a survey instrument, mailing it to NIPF owners, and analyzing the results. This information was integrated into a new carbon accounting model that calculated the carbon footprint of a biorefinery with the participation rate indicated by the survey, as well as the carbon impact over the range of participation rates to see how changing the rate might change calculations of net carbon emissions. The output of the model attempts to describe the dynamics of NIPF owner participation on the carbon balance of cellulosic ethanol processing.

The new model developed and applied here, CEBRAM, which stands for Cellulosic

Ethanol BioRefinery Accounting Model, incorporates the most likely participation rate of nonindustrial private forest owners selling biomass to a biorefinery as indicated by the survey results of these landowners throughout the state of Michigan. Research into contingent valuation surveys and other forms evaluating how humans value non-market goods and services informed the survey. The survey asked a variety of questions, with both multiple choice and fill-in-the-blank response options, but which all focused on how NIPF owners use and value their land. The survey was mailed to addressees listed as participants in the Commercial Forest Program on the Michigan Department of Natural Resources' website (Michigan DNR accessed June 2010). The survey results add to the limited understanding we have about NIPF owner characteristics, land use, and decision-making. The survey interacted with the model only to indicate the most likely rate of NIPF owners selling biomass to be used for cellulosic ethanol production. Other results from the survey could be used to inform more complex models that use demographic information and NIPF owner decision-making as part of their analysis.

The model, CEBRAM, also drew upon a preexisting model by Lindauer-Thompson that detailed tree growth and harvest with carbon levels for a typical northern hardwoods dominated forest in Michigan (Lindauer-Thompson 2008). The Lindauer-Thompson model output was used to provide forest carbon data for the overall analysis of a cellulosic ethanol biorefinery's footprint. The accounting model of the biorefinery was constructed in Excel. CEBRAM calculated the carbon footprint of a commercial scale biorefinery under the level of participation in selling wood to the refinery indicated by survey results and then shows how changing the level of participation impacts the fossil fuel energy used or offset by the biorefinery. CEBRAM uses carbon numbers from Lindauer-Thompson and survey data results along with other inputs to show the change in carbon offset by cellulosic ethanol.

METHODS

SURVEY METHODS

Coupled human and natural system, or CHANS models have the challenge of bringing together disparate types of data. Where natural systems data are found in largely quantitative terms, the human data are often purely qualitative. Human preference and decision-making are also often not well understood in the context of natural systems, and so gathering this qualitative information is the first step towards understanding how these two categorically separate spheres interact on a regular basis. CHANS modelers often rely on survey instruments to gather information about human decision-making prior to constructing their models (Jeon and Herriges 2010, Scarpa 2009, Shaikh et al 2007, Bergmann et al 2008, Brey et al 2007, Kilgore et al 2008, Garcia de la Fuente et al 2010). This thesis is focused on one such CHANS—how the decisions and preferences of nonindustrial private forest, NIPF, owners impact the carbon profile of a cellulosic ethanol plant in Michigan. While Michigan has a great deal of forest resources that could be converted to cellulosic ethanol, the private landowners must agree to use their biomass for this purpose before a biorefinery could be successful. Additionally, NIPF owners are in an inherently powerful position when it comes to how their tree carbon impacts the carbon balance in Michigan because a growing forest sequesters carbon naturally. Understanding how NIPF owners use and value their forest resources in Michigan directly informed the model characterizing the carbon profile of this CHANS.

POPULATION AND SAMPLE

The State of Michigan is ranked fifth in the country in terms of timberland acres, with 18.6 million. A majority of these acres belong to nonindustrial private forest owners (Centrec Consulting 2006). In a study of Michigan's potential bioeconomy, nonindustrial private forest landowners expressed negative opinions towards harvesting their trees, an opinion that conflicts with data collected nation-wide where a majority of NIPF owners indicated they had participated in commercial harvest (Centrec Consulting 2006 and Smith et al 2007). Across the United States in 2007, 38% of the forest land was categorized as privately owned by noncorporate entities. The National Woodland Owner Survey, conducted each year by the Forest Service, provides some information about these nonindustrial private forest owners, going back to 2002. Their survey results suggest that 58 percent of these owners participate in commercial harvest, but the majority own their land for reasons other than as a source of income. Aesthetics, family legacy, and privacy are the top reported reasons for landownership. Additionally, the national average age of the forest owner is 75 or older and many plan to sell or transfer their land in the coming years, indicating land use or reasons for ownership may soon change (Smith et al 2007). Yet the median age for the Michigan family forest owner is between 55 and 64, and the majority of these landowners, as well as the majority of impacted acres, plan on leaving the forest land as it is or with minimal change (Butler et al 2012). The Michigan NIPF owner may differ from the national NIPF owner in ways that could impact the success of the local cellulosic ethanol economy.

As the Renewable Fuel Standard report from 2011 states the NIPF community will likely supply most of the biomass used for cellulosic ethanol because the majority of timber harvested over the last 50 years has come from this community (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). Knowing more about these nonindustrial private forest owners, especially in Michigan with its strong history of forestry, will be useful in understanding how much support there is in the NIPF owner community for cellulosic ethanol. Since information on Michigan NIPF owners' opinions about forest use and cellulosic ethanol is largely unstudied, I constructed a survey that asked about current land use, the interest in cellulosic ethanol, and interest in compensation for keeping their forests growing in order to sequester carbon. Additionally, the survey asked questions about how NIPF owners used their forest land and how they made decisions about how their forest land was used. Demographic information was also collected.

The survey, a mix of multiple choice and open-ended response, was mailed to nonindustrial private forest owners in Michigan enrolled in the Commercial Forest program run by the Michigan Department of Natural Resources. The choice of mailing survey was made because the other options for a survey instrument were less feasible or less desirable. Given the size of the population, one person conducting in-person interviews throughout Michigan would have taken an impractical amount of time. Research by Groves 1990 also suggests that in-person interviews can change the survey results. Survey participants tend to feel social pressure when answering questions during in-person interviews and give responses that they feel are more socially acceptable than they might give otherwise (Groves 1990). Additionally, the presence of an interviewer in your house is far more disruptive than a phone call or a self-administered survey over the Internet or via the mail. Phone interviews, like in-person interviews would have taken a great deal of time and also exert social pressure on respondents, although less so than in-person interviews. So that multiple surveys may be cross evaluated both phone and in-person interviews require that the interviewee stick to a set script. The required consistency in the questions asked and the tone and context in which they are asked is more easily achieved via self-administered written surveys (Groves 1990). Phone and Internet access across the United States is not uniform, and some potential members of the population could be excluded from the sample because they lack telephone or Internet service (Groves 1990). Self-administered Internet surveys require a set of contact information that can be difficult to access and may not include members of the population who do have an email address, but who are not in the email database.

The population for this survey was all NIPF owners in Michigan, but the sample came from respondent NIPF owners who were enrolled in the state of Michigan's Commercial Forest Program, or CFP, whose addresses were posted for public access online in 2010. The sample may be different from the population, largely because most NIPF owners are against timber harvest, but these CFP enrollees have agreed to it as a condition of their enrollment (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Smith et al 2007, Le Vert et al 2009, Kilgore et al 2008). Few NIPF owners are comfortable with land use restrictions that enrollment in programs like the CFP demands, with between 2- 18% participating in forest management programs (Le Vert et al 2009). The sample was chosen based on the accessibility of the mailing list and the short time frame in which the surveys needed to be mailed out. Given the differences between the sample and the population, it is possible that the survey results would only apply to a small proportion of the NIPF owner population. The surveys were mailed on February 25, 2011 with a deadline for return set for March 31, 2011. Late survey responses were included in the results up to June 1, 2011.

DESIGN

The survey was kept short at four pages in length and was prefaced by a letter that explained the purpose of the survey (Appendix A). While the main goal of the survey was to determine the NIPF owner attitude towards cellulosic ethanol and compensation for sequestering carbon by growing trees and how owner attitudes were reflected in their willingness to provide woody biomass as feedstock to biorefineries, the reported goal in the introductory letter was less specific. It read, “This study is hoping to clarify how private forested landowners use their land and view their land use options” (Appendix A). A more detailed description of the survey's focus was not revealed in the letter so as not to bias respondents in their answers. In the introductory letter the link between the survey and the University of Michigan was invoked several times to convey the authority behind the survey, something recommended to increase the response rate (Houston and Nevin 1977). The first questions posed in the survey were simple ones about the respondent and as the survey progressed the answers became more complicated and tried to assess the respondent’s preferences or behavior. University of Michigan School of Natural Resources and the Environment professor Michael R. Moore in personal communication suggested this design. At the end of the survey, space was provided for comments or questions and these were recorded in the survey results. To view the survey design in full, please see Appendix A.

Questions one and two, asked for the location of the forested land by township and total acreage, respectively, and were designed to check respondent answers against the information provided in the Commercial Forest Program (CFP) database. In order to match respondent’s answers with the county and acreage enrolled in the CFP each survey was given a number. The number was associated with county and acreage information, but never the name or address of the enrollee. The anonymity of the responses given is often cited as key to receiving honest answers to survey questions (Groves 1990). Questions one and two specified that the survey was in regard to forested land, but did not inform respondents that their addresses were obtained from the CFP and therefore the responses given cannot be assumed to only apply to land enrolled under the CFP. In question two, a few respondents supplied county locations rather than township and several misspelled their township name beyond easy recognition. Therefore, these responses were not included in the land distribution result data. The answers supplied in question two regarding township were assumed to be township names, even if counties of the same name also exist in Michigan. When multiple townships were identified and no division of land was given, it was assumed that the land was equally divided between the townships.

Questions three and four asked respondents if they had inherited their forested land and if the majority of their income came from the forested land, respectively. Both questions were designed to get at the idea of how owners value their land, whether from an emotional baseline, presumed more likely if the land was inherited, or from a monetary baseline, presumed more likely if the forest was the primary source of income. Land use valuation, primarily from the contingent valuation method practiced in economics, is complicated to calculate since forest land use is not necessarily a part of a market with traditional pricing. Questions regarding the relationship between landowner income and the landowner-assessed value of the land are valid, but not at issue in this survey since neither the income of the landowner nor the monetary value of the land were ever determined. This survey was more interested in whether or not NIPF owners make decisions with money as the primary driver or as some secondary force—not the precise dollar value of their forest use decisions.

Question five asked how respondents used their land, and question six asked how long, in years, each activity had been engaged in. Question seven asked if there was an alternative area nearby where the activities practiced in question five could be pursued. Question five attempted to set up how forest resources are used, specifically if they are used in ways that would preclude the trees being harvested for cellulosic ethanol. The longer the forest activities have been practiced, are respondents less likely, more likely, or neutral in regards to giving them up? However, if there is a viable nearby resource that can replace the forest experience for the forest owner, as question seven attempted to determine, then the impact of cutting down trees might be lessened (Hanley et al 1998).

Question eight asked if a certified forester prepared a forest management plan (FMP) for the land. This question is a check against CFP enrolled land, which must have a FMP. Additionally, NIPF owners with FMPs or who actively manage the forest themselves, may have a healthier forest ecosystem than NIPF owners who do not manage their forest actively. Because this sample group's CFP enrolled land was required to have an FMP they were likely to have a higher rate of some type of forest management than the population of NIPF owners in Michigan.

Questions nine, ten, and eleven focused on the tradeoff addressed in the CEBRAM model. Since trees can offset carbon through being used for an alternative fuel or sequester carbon by growing, there is a tradeoff in terms of carbon storage that should be addressed when choosing between these two options. Question nine asked if forest owners would consider selling some or all of their trees for use in cellulosic ethanol, while question eleven asked if forest owners would consider being compensated for keeping their forests intact with the purpose of sequestering carbon. Question ten asked how people felt about global climate change as the Intergovernmental Panel on Climate Change presents it: occurring and with human activities as the primary driver (Pachauri and Reisinger 2007). While fuel independence might be a reason to support selling your biomass to be used for cellulosic ethanol, the main logic behind supporting compensation for natural forest growth is to sequester carbon and therefore is directly related to climate change. Some NIPF owners might agree to sequester carbon just for the sake of appropriate monetary compensation, even if they do not believe in climate change, just as some NIPF owners might agree to sell their biomass for cellulosic ethanol because of compensation. If the goal is to minimize carbon emissions into the atmosphere, we need to determine what process—carbon offset through cellulosic ethanol production or carbon sequestration through forest growth—emits the least carbon and then understand what might motivate or prevent NIPF owners from agreeing to this process.

Question twelve tried to determine how NIPF owners make decisions about their land use, whether they only take money into account, or if its a mix of money, personal opinion, or how the land is currently used. Specifically, question twelve asked the respondents to consider what factors they would take into account if they had to choose between using their forest for cellulosic ethanol, keeping the forest growing to sequester carbon, or deciding to manage in some other way. This question could help determine what motivates people to make the land use decisions they do and how future surveys may want to focus their questions (Dietz et al 2009).

Question thirteen asked for the age of the respondent, and was the final question in the survey. The final question did not require a lot of introspection and therefore should have been easy to answer, and if the question was off-putting to some people it would not have negatively impacted any further questions due to its location in the survey.

ANALYSIS AND APPLICATION

Most of the analysis of survey results was conducted using simple statistical tools. However, questions nine, ten, and eleven were in turn compared for correlation using chi-squared contingency tables, which are a more complex form of statistical analysis. Three contingency tables were created comparing question nine with question ten, question ten with question eleven, and question nine with question eleven. The basic idea behind a contingency table is to determine how close the expected distribution of answers to two questions comes to the observed distribution. The one set of response options is given as row variable, while the other set is the column variable. The contingency table creates a matrix of question-specific answer pairings, each row and column of which is totaled and used to calculate the expected spread of responses assuming the response options are independent of one another. For this test, significance indicates that the row and column variables have a relationship that cannot be explained through chance alone. If there is a significant relationship between two questions, the standardized residuals for each of the row and column response option pairings is calculated. Any value above 1 indicates an unusual relationship that cannot be explained only by chance.

For data to be analyzed using the chi-squared contingency table it must meet the assumptions of independence between the measurements, of coming from a random sample, and of having a large enough sample size. This assumption of independence both between responses and between the two questions, led to certain response options being excluded from the contingency table. Similarly, people who only answered one of the questions and not both, or who answered with multiple responses, were not included in the contingency table. The survey data did come from a random sample of the population and was large enough to use the chi-squared test on. For question nine the response options excluded from the contingency analysis were “I am not sure what I would do, or it would depend on additional factors” and “I prefer not to respond.” These two options are not expressing an action that the landowner would take and therefore are not answering the question directly enough to convey the landowner's opinion. For a similar reason the options “I have not formed a view one way or the other” and “I prefer not to respond” were excluded from the analysis of question ten. For question eleven the options excluded were “I would consider maintaining my forest stand to sequester carbon for appropriate compensation,” “I need more time to consider my options and gain more information,” and “I prefer not to respond.” Again, each of these response options does not indicate direct commitment to action by the landowners and was not included in the contingency table for this reason. If the phrase “...consider maintaining my forest stand...” had been replaced with something more concrete, such as “...maintain some of my forest stand...” a more direction action would have been implied and this option would have been included. As written, it was not kept in the analysis.

The Private Landowner Forest Decisions Survey 2011 was designed to elicit how NIPF owners currently use their land, whether they would be interested in selling their forest biomass for cellulosic ethanol production, if they would consider letting their forest grow and be compensated for the sequestered carbon, and what factors they take into account when making land use decisions. Data from this survey was used in conjunction with the model described below to gain further understanding of the challenges to and benefits from cellulosic ethanol as an alternative fuel produced in the State of Michigan.

MODEL METHODS

The goal of the model developed and used here, CEBRAM, which stands for Cellulosic Ethanol BioRefinery Accounting Model, was to reasonably describe the carbon impact of a cellulosic ethanol biorefinery from cradle to gate—the point of initial tree growth through ethanol production, but not downstream delivery (Gonzáles-García et al 2011). CEBRAM calculated the net carbon emissions of a cellulosic ethanol biorefinery at the level of participation indicated by the survey, and also calculated the impact that a changing NIPF owner participation rate would have on the net carbon balance.

To accomplish this goal, CEBRAM interacted with an already constructed model, MITRIX (Lindauer-Thompson 2008), which modeled forest growth dynamics and harvest, and monitored the carbon in the ecosystem. CEBRAM used these carbon numbers for the tree input at the forest stand scale and then modeled harvest conditions, transport to the biorefinery, and biorefinery energy use to come up with the carbon impact of a commercial scale cellulosic ethanol biorefinery on a landscape scale. The biorefinery was assumed to be located in the landscape of Michigan's Upper Peninsula and the northern Lower Peninsula.

Private landowners hold 67% of timberland acres in Michigan, most of which are between 10 and 25 acres in size. (Smith et al 2007 and Michigan Department of Natural Resources 2008). Biorefineries are constrained by the growth rate of the biomass they rely on, and also the distance that must be traveled in order to reach mature stock. Therefore it makes the most sense to locate a biorefinery in the middle of small patches of forest that can be traveled to in the short period of time (Froese and Miller 2008 and IEA Bioenergy 2002). Nonindustrial private forest owners, or NIPF owners, are the ideal partners for cellulosic ethanol biorefineries because they can provide a vast number of forest lands that are often near one another, but that are at different stages of growth. A biorefinery's success depends in large part on the willingness of NIPF owners to sell their trees to the biorefinery, and not to some other group or to be used for some other purpose. How many NIPF owners participate with a biorefinery will also impact the carbon balance of the facility because less participation will require further travel away from the refinery to find wood. Additionally, since tree growth naturally sequesters carbon, there is an inherent trade-off between letting trees grow or cutting them down for a fuel that offsets gasoline consumption. CEBRAM calculated the carbon sequestered by unharvested trees and compared this value to the carbon offset by using ethanol instead of gasoline.

KEY ASSUMPTIONS

The model in this thesis, CEBRAM, used the percent participation rate of NIPF landowners as reported in the survey to determine the net carbon of a cellulosic ethanol biorefinery. Additionally, the model examined the net carbon emissions of the biorefinery under a range of NIPF owner participation rates, to show how a departure from the value found in the survey would impact carbon emissions.

In setting out to model the carbon balance of a cellulosic ethanol biorefinery, there are some basic assumptions about the system that were made. First, the timestep of the model was one year and each year was assumed to be identical, so that they could be extrapolated over the length of the simulation. The length of the simulation was chosen because critical technological developments that could change biorefinery standards or alternative fuel options could happen within this time frame (Searchinger et al 2008, Righelato and Spracklen 2007, De La Torre Ugarte et al 2000). The maximum area covered was known as the scenario area, and was dependent on the percentage of NIPF owners that participate in selling their biomass to the biorefinery, the percentage of NIPF relative to the rest of the landscape, the demands of the biorefinery on a yearly basis, and the rotation period that defined at what age a forest was mature and ready for harvest. A key assumption that helped define the extent of the scenario area was that the biorefinery would harvest mature biomass as close to the biorefinery as possible, before moving on to harvest mature biomass further away (Agriculture, Forestry, and Waste Management Technical Work Group 2008, IEA Bioenergy 2002). Additionally, the scenario area did contain land not classified as NIPF, but this land had no bearing on the model, other than to force a greater driving radius for harvested biomass transport. The decision to exclude the carbon balance of land other than NIPF was made to keep the assumptions about owner decision-making to a minimum, to focus on the landowner group holding the majority of forest resource, and to investigate the trade-off between using biomass to offset carbon by producing a fuel that replaces gasoline and growing that biomass to sequester carbon in the ecosystem (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011 and Michigan Department of Natural Resources 2008). The biorefinery was assumed to be located in the Upper Peninsula and northern Lower Peninsula of Michigan, in the United States.

The land use history of the NIPFs was assumed to have been one of regular harvest with a rotation period of 30 years, although the prior use of the biomass in the land use history has no bearing on the model. This assumption was based, in part, on the land use history of the Upper Peninsula and northern Lower Peninsula of Michigan having been harvested regularly in its past, and in part because an assumption that forest stands were already on the same rotation period as the one used in the model made the analysis easier (Gough et al 2007 and Michigan Department of Natural Resources 2008). A 30 year rotation period was assumed both due to precedent for other modeled cellulosic ethanol plantations (Seely, Welham, and Kimmins 2002 and IEA Bioenergy 2002) and because it eliminated the need for fertilizer use, which I assumed was not used by NIPF owners (Froese and Miller 2008). The landscape was isotropic, because we assumed even distribution of NIPF owner land over the scenario area, even distribution of NIPF owners participating in selling biomass to the biorefinery, even distribution of NIPF owners not participating, even distribution of the age of the forest, regardless of NIPF owner participation, and that the age of all NIPF owner forests' ranged from 1 to 30.

NIPF owners were considered participants if they harvested their biomass for sale to the biorefinery and were considered non-participants if they kept their biomass growing and did not harvest it. All NIPFs are assumed to be managed for aspen dominance, although other species of tree also grew in the forest, and new seedlings did sprout throughout the rotation period. NIPF owners were assumed to have only two ways of using their land—either to participate in selling their forest biomass to the biorefinery, or to not participate and keep their forest growing with no harvest. While non-participating NIPF owners may have many reasons to keep their forest growing, such as for recreational hunting or camping, the ultimate and perhaps unintended result of these growing forests is carbon sequestration. Once a NIPF owner used their land in one way, they did not switch mid-simulation to use their land in the other way. The decision to limit the NIPF owners to only two management styles was made to highlight the carbon sequestering tradeoff between producing a renewable fuel that displaces gasoline and allowing the trees to sequester carbon through growth (Gonzáles-García et al 2011b). Understanding NIPF owner preferences may have a big impact on the carbon profile of a cellulosic ethanol biorefinery, especially if the carbon profile of participating NIPF owners looks significantly different from that of non-participants (Centrec Consulting Group 2006).

The biorefinery was assumed to only get biomass from NIPFs, the maximum processing capacity in terms of biomass was always met, and the biomass only came from the merchantable biomass in mature stands that were 30 years of age. The carbon profile of the growing biomass when viewed from a stand perspective changed as the forest stand aged, and changed drastically if the biomass was harvested. At the landscape scale—which considered multiple stands of all ages, assumed to be between 1 and 30, assumed to be evenly distributed across the landscape, and assumed to be even in quantity and quality—the carbon in the harvested landscape did not change over the length of the simulation due to the assumption of an isotropic area. Because the harvested land carbon was viewed at the landscape scale, the carbon profile for harvested land did not change over the length of the simulation (Lindauer-Thompson 2008).

The equipment used to harvest mature biomass was assumed to be a feller and a forwarder (Hubbard et al 2007 and Gonzáles-García et al 2009b). The first step in the process was to cut down the trees using a feller, and then to use the forwarder to move the trees in a given location to a centralized loading point where unmerchantable biomass could be removed and the remaining biomass could be placed onto a truck for transport to the biorefinery (Gonzáles-García et al 2009b). Unmerchantable biomass was defined by Haugen and Weatherspoon (2002), and so sawtimber, poletimber, dead and cull trees, sapling, and limbwood were all items used by the biorefinery. The fate of the unmerchantable biomass was outside the scope of this study. After transport to the biorefinery the wet biomass, at an assumed 40% moisture, was assumed to air dry down to about 7% moisture (Gonzáles-

García et al 2011b and Gonzáles-García et al 2009). All references to dry biomass and wet biomass refer to these percent moisture levels and any corresponding calculation from another cited source aligns with these moisture levels within at least 4 percentage points. The method of transporting wet biomass prior to chipping led to a more efficient biomass transport system than other options and allowing wet biomass to dry prior to chipping led to a more stable drying environment than other options (Hubbard et al 2007). Chipping the biomass at the harvest site is also a common practice, although it requires that these chips be used within six weeks to minimize decay. Although the time lapse between harvest, drying, and use of biomass was not accounted for in the model, understanding that harvest would not be practical year-round in the Michigan environment led to the assumption that a more stable form of biomass for onsite storage at the biorefinery would be preferred (Hubbard et al 2007).

The biorefinery was located at the center of the scenario area, which was conceived as a circle so that the maximum distance traveled from the biorefinery to retrieve biomass was equal in all directions. The biorefinery was assumed to be located somewhere in the Upper Peninsula or the northern Lower Peninsula of Michigan. The biorefinery used the dilute sulfuric acid/saccharification and simultaneous cofermentation, or DA/SSC, process to produce ethanol and used the waste lignin to power the plant (MacLean and Spatari 2009 and EBAMM 1.1). Choosing the technology for the biorefinery to be modeled was restricted by the available literature covering carbon emissions from a cellulosic ethanol biorefinery. While there are a fair number of life cycle analyses of biorefineries, there are few that isolate the biorefinery carbon emissions from other aspects of the ethanol production chain in the way needed for use in CEBRAM. There are even fewer life cycle analysis with the right breakdown of carbon emissions reported that also model a cellulosic ethanol biorefinery using wood as an energy source (EBAMM 1.1 and MacLean and Spatari 2009). Therefore, the assumptions applied by the authors of the EBAMM 1.1 model and the NRCan GHGenis 3.9 models inform the assumptions CEBRAM must follow (MacLean and Spatari 2009). The biorefinery, unlike other carbon inputs in CEBRAM that used only CO_2 figures, reported emissions in terms of carbon dioxide equivalents, which will raise the overall value of reported carbon emissions due to the inclusion of greenhouse gasses other than carbon or carbon dioxide.

Although vehicles using ethanol in place of gasoline were not specifically modeled in CEBRAM, the assumption was made that ethanol would offset gasoline use in a relationship based purely on the energy contained in each fuel (Schafer et al 2009, Kalogo et al 2007, and De La Torre Ugarte et al 2000). Within this assumption was the further assumption that 100% of the ethanol produced would be used to offset gasoline. Also, it was assumed that consumer driving habits did not change as a result of ethanol availability, with the exception that consumers would use all available ethanol before gasoline. The assumption regarding human behavior was made to make the model more simplistic.

CEBRAM relied upon the above assumptions to model the landscape level activities that contribute to the carbon balance of cellulosic ethanol from the forest harvest through ethanol output, but relied upon the ecosystem level processes of forest growth and carbon to come from a model developed by Lindauer-Thompson 2008. MITRIX, which stands for MIchigan MaTRIX, used MatLab to model a forest ecosystem typical of the northern Lower Peninsula of Michigan. The model can be set with historical values for stems per hectare by diameter class, or your own initial stand state values can be input. The model contained preset management plans that determined harvest effects and the one used by CEBRAM promoted an aspen dominated forest ecosystem. To do this, the model removed all the trees, excepting those in the smallest size class, from each species besides aspen during a harvest. Aspen trees were removed if they were above 20 centimeters in diameter at breast height. While MITRIX showed individual stands to have oscillating carbon profiles that spike just before harvest and drop precipitously post harvest, at the landscape level, given the assumed isotropic character of the landscape, the carbon profile for the harvested land can be assumed to remain unchanged over the length of the simulation. This logical conclusion of unchanging carbon in harvested lands was supported by the output of MITRIX forest stands that showed after a few full rotation periods of harvest and regrowth, the carbon in the stand stabilized so that the first year post harvest had the same carbon profile as any future first year post harvest (Figure 1).

Unharvested forest land does have a changing carbon profile at the stand level, and CEBRAM relied upon MITRIX output to model these changes. The land use history for input into MITRIX was user defined as having been a 30 year old, aspen dominated forest. The user defined input actually came from MITRIX output when it was run on a 30 year rotation period for 200 years, using a preloaded stems per hectare profile from MITRIX titled UMBS Wells 1974 and managing for aspen dominance. The user defined MITRIX scenario informed values that CEBRAM used to approximate land productivity, in units of wet biomass per hectare, as well as the change in megagrams carbon per hectare over the length of the simulation (Lindauer-Thompson 2008).

Most of these assumptions were put in place in order to make the model feasible. Some, however, were put in place to highlight the trade-off between sequestering carbon via tree growth and using tree biomass to make ethanol that offsets gasoline consumption, while others were required because of limitations of available literature. In the symbols used to describe the model process, capital letters indicate a state variable applied over the length of the simulation, while Greek letters indicate a parameter that was either drawn from literature, or user defined. All other state variables were calculated based on their relationships to one another. The model was outlined in the rough order in which processes take place, setting up the landscape profile first, then harvest, distance driven to transport biomass to the biorefinery, and preparing the biomass to be turned into ethanol. These steps were followed by an analysis of the biorefinery itself, the gasoline it offset, and concluded with the unharvested forest carbon and totals of carbon dynamics over the length of the scenario.

BIOMASS DEMAND

Given the assumption that the biorefinery always has enough biomass to run at maximum capacity, it followed that the biomass used in the simulation is known. The biomass used in the biorefinery was assumed to be at 7% moisture, but in other stages of the biorefinery production chain the wood was green, at an assumed 40% moisture (Gonzales-Garcia et al 2011b). Once the wet wood weight was known the area needed to sustain that amount of biomass could be calculated. Given that only merchantable biomass was used in the biorefinery, that not all NIPF owners were participating in selling their wood to the biorefinery, and that the landscape was made up of other land use types besides NIPF, the calculation of the area needed to sustain yearly biomass must account for each of these. The weight of the biomass needed and the corresponding area it covered can be calculated and other sections of the biorefinery chain—some of which were dependent on wet or dry weight biomass and others on the corresponding area—could be focused on.

With the biorefinery demand, β, the wet weight of biomass could be determined using a converter, η (Mattingly, Robb, and Wong 2008, Boundy et al 2010, Humbird et al 2011). The converter assumed that the percent lost in weight was equal to the percent loss of moisture as the biomass dried (Gonzáles-García et al 2011b and Gonzáles-García et al 2009).

$$b = \frac{\beta}{\eta} \qquad (1)$$

where b (wet tonnes biomass per year), β (dry tonnes biomass per year), and η (dry tonnes biomass per wet tonne biomass).

With b it was then possible to calculate how much area it took to grow this biomass, so that the value of A, the scenario area, could be determined. The conversion value from wet weight biomass to area used to grow the biomass, ζ, came from Lindauer-Thompson (2008). The harvestable biomass in a given area of the forest used to calculate ζ assumed a 30 year rotation period that was managed for aspen dominance in the stand. The harvested biomass was calculated by finding the difference between the biomass during the harvest year and biomass left post-harvest, excluding any growth that may have taken place during that timestep (Lindauer-Thompson 2008). Wet biomass grown over a set area was calculated at the stand level and then scaled up to apply to every harvested ecosystem over the entire landscape. ζ assumed biomass to be made up of leaves, branches, and stems, not all of which were actually used by the biorefinery in making ethanol (Lindauer-Thompson 2008). It was assumed that only merchantable biomass, as defined by Haugen and Weatherspoon (2002), was used by the biorefinery. The percent of total harvest biomass that was made up of merchantable biomass, μ, and ζ, could be used to calculate the area needed to supply the biorefinery with biomass for one year, a_b.

$$a_b = \frac{b}{\zeta \cdot \mu} \qquad (2)$$

where a_b (hectares per year), b (wet tonnes biomass per year), ζ (wet tonnes biomass per hectare), and μ (percent). This, a_b, was the area needed to maintain the biorefinery, without accounting for the impact that the relative presence of NIPF owners—participating and not—would have on the scenario area as a whole. Finally, the biorefinery was assumed to require the same amount of biomass each year and in order to maintain constantly operating throughout the length of the simulation the supply of biomass and area covered accounted for the rotation period required for the trees to mature.

To calculate the area needed over the length of the scenario and not just one year, the yearly area was multiplied by the length of the rotation period, assuming that trees harvested once would be harvested again if they reached maturity before the simulation ended. To calculate the scenario area over the length of the simulation, it was assumed that an equal amount of area was used per year for the length of the rotation period—that is, until the forest regrew and that biomass could be harvested once more. Up until this point all values had been calculated on an annual basis; the scenario area was the first instance of a value calculated over the length of the simulation. Taking into account the percent NIPF owner participation, φ, the rotation period in years, ρ, and the percent NIPF relative to the landscape as a whole, κ, yielded the scenario area in hectares, A (equation (5)) (Forest Inventory Analysis website FIDO program, and Froese and Miller 2008). Along the way, the total NIPF owner hectares, participating or not, per year, a_φ, (equation (3) and the NIPF owner hectares, participating or not, over the length of the simulation, A_φ (equation (4) was calculated. The percent NIPF owner participating changed from scenario to scenario, and therefore was set by the author. The rotation period was also chosen by the author, but corresponded to rotation periods used in other studies (IEA Bioenergy 2002 and Seely, Welham, and Kimmins 2002).

$$a_{\varphi} = \frac{b}{\zeta \cdot \mu \cdot \varphi} \qquad (3)$$

$$A_{\varphi} = a_{\varphi} \cdot \rho \qquad (4)$$

$$A = \frac{A_{\varphi}}{\kappa} \qquad (5)$$

where a_{φ} (hectares per year), b (wet tonnes biomass per year), ζ (wet tonnes biomass per hectare), μ (percent), φ (percent), A_{φ} (hectares), ρ (years), A (hectares), and κ (percent). Both A_{φ} and A were measured over the length of each 40 year simulation.

BIOMASS HARVEST

Now that the biomass demand from the biorefinery has been determined in units of both wet weight and dry weight, and the extent of the scenario area has been calculated, the energy used to cut down and remove unwanted parts of the biomass harvested each year can be ascertained. The harvest process involved using two machines, a feller and a forwarder, to first cut down the trees and then move them to a centralized location before they were loaded onto a truck. Any unmerchantable biomass was thinned out prior to transport. The thinning, felling, and forwarding harvest process is common to smaller-scale forest harvest operations, and since NIPF owners tend to have small plots of land, this harvest system is appropriate (Smith et al 2007 and Hubbard et al 2007). The disposal of this biomass was outside the scope of this study, and it was not accounted for in the stand level carbon cycling used to calculate change in ecosystem carbon (Lindauer-Thompson 2008). The biomass during harvest was assumed to be wet weight, since it was just cut down. (Gonzáles-García et al 2009b). θ calculates the diesel energy used per unit biomass, including thinning, felling, forwarding, and transportation of workers who operated the harvest machinery (Gonzáles-García et al 2009b). Using ω_{dmj}, the CO_2 emissions from harvest, the CO_2 emissions from the harvesting process on a yearly basis, c_h (Schafer et al 2009) could be determined.

$$c_h = (b \cdot \theta) \cdot \omega_{dmj} \qquad (6)$$

where c_h (megagrams carbon dioxide per year), b (wet tonnes biomass per year), θ (megajoules diesel per wet tonne biomass), and ω_{dmj} (megagrams carbon dioxide per megajoule diesel).

AVERAGE DISTANCE DRIVEN

This section calculated the average distance driven and energy used by trucks transporting the harvested merchantable biomass to the biorefinery, as well as the energy used to drive the empty truck from the biorefinery to the harvest site. The average distance driven one way was calculated as the length of the radius, in kilometers, of a circle half the area of the scenario area circle, ξ, and then adjusted for the curvature of the road, ς. This calculation was based on the assumption of an isotropic scenario area, in that an equal amount of mature biomass would be at the edge of the scenario area circle as was immediately adjacent to the biorefinery, and at all points in between. It is of note that the average distance driven from year to year throughout the scenario will not change. Each year, the average distance driven one-way would approximately be at a halfway point—not based upon the radius of the scenario circle, but the area of the circle (National Research Council 2011). The value for ς came from Baraga and Marquette counties in the Upper Peninsula of Michigan, and it was assumed that the average road tortuosity from this area represented the general road tortuosity covered (Google Earth 6.1). The tortuosity was calculated using 20 roads of varying lengths and finding their deviation from a straight-line distance. The average difference between these 20 samples was taken, and the tortuosity factor of 1.27 was calculated.

Once the average distance driven per truck trip both to and from the harvest site, *d*, was known, then the average distance driven round-trip per year, d_k, could be calculated given that the biomass each truck can carry, δ, would yield how many trucks are used per year, d_t (Gonzáles-García et al 2009b). A fraction of a truck was assumed to not be possible, and so the value for d_t was rounded up to the nearest integer. Each truck was assumed to carry the maximum amount of biomass possible during each trip and each truck ran on diesel fuel (Gonzáles-García et al 2009b).

$$\xi = \sqrt{\frac{A}{2\pi \cdot 100}} \tag{7}$$

$$d = \left(\sqrt{\frac{A}{2\pi \cdot 100}}\right) \cdot 2\varsigma \tag{8}$$

$$d_t = b \cdot \delta \tag{9}$$

$$d_k = \left(\sqrt{\frac{A}{2\pi \cdot 100}}\right) 2\varsigma \cdot d_t \tag{10}$$

where ξ (kilometers per truck trip), *A* (hectares), *d* (kilometers per truck trip), ς (unitless), d_t (truck trips per year), *b* (wet tonnes biomass per year), δ (wet tonnes biomass per truck trip), and d_k (kilometers per year). In equation (7) *A* was divided by 2 because the radius calculated was half the area of the scenario area, and *A* was divided by 100 in order to convert hectares into square kilometers. Equation (8) was multiplied by 2 and the road tortuosity to convert equation (7) from one-way average truck travel to the average truck travel in both directions.

To calculate the CO_2 emissions from the average distance driven round-trip in one year, d_k, the fuel economy of the trucks both while empty, α_e, and while full, α_f, was needed. An equal distance was assumed to be covered while the trucks were full as when they were empty, and each truck was assumed to have uniform fuel economy (Gonzáles-García et al 2009b). Knowing α_e and α_f combined with d_k would yield diesel used per year, and knowing the CO_2 emissions from diesel combustion, ω_{dl}, allowed for the calculation of the CO_2 emitted from picking up and delivering biomass to the biorefinery during one year, c_d (Schafer et al 2009).

$$c_d = \left[\left(\frac{\alpha_e \cdot d_k}{2}\right) + \left(\frac{\alpha_f \cdot d_k}{2}\right)\right] \cdot \omega_{dl} \qquad (11)$$

where c_d (megagrams carbon dioxide per year), α_e (liters diesel per kilometer), α_f (liters diesel per kilometer), d_k (kilometers per year), and ω_{dl} (megagrams carbon dioxide per liter diesel).

BIOMASS PROCESSING

The trucks carrying the biomass needed to be able to load and unload the biomass they were carrying, and this exerted energy separate from driving the biomass to the biorefinery. The trucks were assumed to have separate loading devices that were also diesel powered (Gonzáles-García et al 2009b). Once at the biorefinery, the biomass was air dried and then chipped into uniform pieces 1.60 millimeters in size using a knife mill (Sun and Cheng 2002). Once the biomass arrived at the biorefinery, dried, and was processed into chips, it was then ready to be turned into ethanol. The drying time of biomass, decay rate of the biomass, and any time lapse between harvest, chipping, and ethanol production was not accounted for as it was outside the scope of this analysis.

The values for loading and unloading energy per truck trip, λ_l and λ_u, respectively, along with the CO_2 emissions per energy in diesel, ω_{dmj}, allowed the CO_2 emitted each year during this process to be calculated, c_l (Gonzáles-García et al 2009b).

$$c_l = [(\lambda_l \cdot d_t) + (\lambda_u \cdot d_t)] \cdot \omega_{dmj} \qquad (12)$$

where c_l (megagrams carbon dioxide per year), λ_l (megajoules diesel per truck trip), d_t (truck trips per year), λ_u (megajoules diesel per truck trip), and ω_{dmj} (megagrams carbon dioxide per megajoule diesel). Similarly, once the energy used to run the chipping machine per dry tonne biomass, ι, was known the CO_2 emitted per year when processing the biomass before turning it into ethanol, c_i could be determined (Sun and Cheng 2002). Since the chipper used dry biomass, β was used, along with the conversion value ω_{dmj}.

$$c_i = (\beta \cdot \iota) \cdot \omega_{dmj} \qquad (13)$$

where c_i (megagrams carbon dioxide per year), β (dry tonnes biomass per year), ι (megajoules diesel per dry tonne biomass), and ω_{dmj} (megagrams carbon dioxide per megajoule diesel).

BIOREFINERY

The ethanol produced at the biorefinery, which used a dilute sulfuric acid/simultaneous saccharification and cofermentation process could then be calculated. The type of biorefinery was chosen based on the need to find carbon emissions data, ω_{el}, for this step in the system. The ω_{el} value used comes from well cited, but imperfect data, as detailed in the discussion section (Farrell et al 2006, Schmer et al 2008, EBAMM 1.1, Pimentel and Patzek 2005, and Wang 2001). The simulation's parameters used in CEBRAM took into account the energy from running the plant with diesel, capital equipment, processing water, and effluent discharge. Values for the emissions from producing the enzymes and other materials used in the DA/SSC process came from MacLean and Sapatari (2009). ω_{el} was in units of CO_2 equivalent, unlike other conversion factors used, which only focus on CO_2 emissions. The value of ω_{el} may have been slightly larger than if only CO_2 emissions were calculated, but this discrepancy in units was tolerated due to limited alternative emissions values and so the CO_2 equivalent numbers are included.

With the rate of ethanol production, ε, per dry tonne biomass (MacLean and Sapatari 2009), the liters of ethanol produced per year, could be ascertained. With these values and the CO_2 equivalent emitted per liter ethanol ω_{el}, the CO_2 equivalent emitted per year attributable to turning biomass into ethanol, c_e could be determined (EBAMM 1.1, Schmer et al 2008, Farrell et al 2006, and MacLean and Sapatari 2009).

$$c_e = (\beta \cdot \varepsilon) \cdot \omega_{el} \qquad (14)$$

where c_e (megagrams carbon dioxide equivalent per year), β (dry tonnes biomass per year), ε (liters ethanol per dry tonne biomass), and ω_{el} (megagrams carbon dioxide equivalent per liter ethanol).

GASOLINE OFFSET

Ethanol was assumed to offset carbon emissions by replacing gasoline in vehicles. This equation assumed that all ethanol produced went towards replacing gasoline on an energy equivalent basis. The CO_2 emissions from gasoline were limited to those created when gasoline was fully burned under stoichiometric conditions, and therefore did not include upstream production factors (Schafer et al 2009). Consumer preference was assumed to always buy ethanol before gasoline, but to otherwise not change driving characteristics.

Given the ethanol produced per year and the energy in ethanol relative to gasoline, γ, the gasoline not used in a given year due to ethanol use could be discovered (Schafer et al 2009). Further, knowing the CO_2 emitted per liter gasoline, ω_{gl}, allowed calculation of the CO_2 emissions that were prevented from forming because ethanol replaced gasoline, per year, c_g.

$$c_g = (\beta \cdot \varepsilon \cdot \gamma) \cdot \omega_{gl} \qquad (15)$$

where c_g (megagrams carbon dioxide per year), β (dry tonnes biomass per year), ε (liters ethanol per dry tonne biomass), γ (liters gasoline per liters ethanol), and ω_{gl} (megagrams carbon dioxide per liter gasoline).

FOREST CARBON

Using output from MITRIX (Lindauer-Thompson 2008) the carbon profile of an unharvested forest could be calculated. Since the unharvested landscape starts out identical to the landscape that was eventually harvested, there would be some forest areas that had just been harvested and start out at age 1, all the way up to forest areas that were just ready to harvest at age 30. Unlike the carbon profile of the harvested landscape, which was in equilibrium from a landscape perspective due to harvest on a regular rotation, the unharvested landscape would keep growing and sequestering carbon over time (Figure 2). The amount of carbon sequestered was dependent on the age of the forest when the simulation began, and so the concept of a starting age class needed to be introduced. The goal was to determine the change in carbon for each different starting age class, over the length of the simulation, and then to determine the average change in carbon per hectare. Where x was the current age class, n was the total number of age classes, τ was the number of years per simulation, Δf was the change in carbon per area over the length of the simulation, and f was the average change in carbon per area over the length of the simulation.

$$f = \frac{\sum_{x=1}^{n} \Delta f(x,\tau)}{n} \qquad (16)$$

where x (age class), n (age class), τ (years per simulation), and Δf (change in megagrams carbon per hectare over simulation length). Knowing f and the unharvested area over the length of the simulation, A_u, allowed us to calculate F, the change in carbon over the length of the simulation and total unharvested hectares affected.

$$A_u = A_\varphi - (a_b \cdot \rho) \qquad (17)$$

$$F = \left[\frac{\sum_{x=1}^{n} \Delta f(x,\tau)}{n}\right] \cdot A_u \qquad (18)$$

where x (age class), n (age class), τ (years per simulation), Δf (change in megagrams carbon per hectare over simulation length), A_u (hectares), A_φ (hectares), a_b (hectares per year), ρ (years), and F (megagrams carbon over simulation length).

SIMULATION CONCLUSIONS

To obtain the carbon balance of the simulation, which required adding the sequestered carbon and the emitted carbon and finding the difference between the two, the units were standardized to megagrams carbon per simulation length. As many units were in carbon dioxide, υ, the carbon dioxide to carbon converter was introduced (Boundy et al 2010). Additionally, τ, the simulation length in units of years per simulation, was used to calculate the megagram carbon numbers over the length of the simulation, T. The value of T only included the carbon emitted or sequestered from a strict energy balance view. The gasoline offset by the ethanol production, T_g, was the only source of offset carbon. The other carbon sources, from harvest (T_h), from the distance traveled transporting the biomass (T_d), from the loading and unloading process (T_l), from running the chipper (T_i), and from the process of making the ethanol (T_e), were all sources of emissions. T_b included the same carbon offset and emissions sources as T, but also included the carbon sequestered by the non-participating NIPF trees, F. Finally, the opportunity cost of operating the ethanol refinery with respect to the foregone carbon sequestration of all NIPF land was determined, T_o. T_o cast the widest net, and encompassed not only foregone carbon sequestration, but also the tree carbon sequestered on non-participating NIPF land.

$$T = \left(c_g \cdot \upsilon \cdot \tau\right) - [\upsilon \cdot \tau \cdot (c_h + c_d + c_l + c_i + c_e)] \tag{19}$$

$$T_b = \left[F + \left(c_g \cdot \upsilon \cdot \tau\right)\right] - [\upsilon \cdot \tau \cdot (c_h + c_d + c_l + c_i + c_e)] \tag{20}$$

$$T_o = T_b - \left(A_\varphi \cdot f\right) \tag{21}$$

RESULTS

SURVEY RESULTS

The Private Landowner Forest Decisions Survey 2011 was mailed to 1203 addresses supplied by the Michigan Department of Natural Resources' Commercial Forest Program, or CFP, in their online database (Michigan DNR accessed June 2010). The full text of the survey can be found in Appendix A. There were 106 bounced letters and 505 responses, yielding an effective response rate of 46%. There were 110 surveys returned that were not fully complete, but their responses were included, where given. In most cases in this study, questions were evaluated individually, allowing for the inclusion of partially completed surveys. Where correlation values were assessed, improperly completed surveys were excluded from the analysis. Six surveys were returned completely blank, but most noted in the comments section that the land had either been sold or the intended recipient of the survey was deceased. One survey was filled out completely with the choice “I prefer not to respond” marked for each question. In the case where individuals would answer a question with multiple preferences where only a single choice was required, the data was not included. The exception to this rule was for question three, which asked whether or not land was inherited. For the 25 respondents who answered with both yes and no, all 25 were counted in the affirmative. The question was intended to determine if inheritance might factor into the management of the land, and so the yes and no responses were counted as yes.

QUESTION RESPONSE RATE

The response rate for each question fluctuated, with slightly fewer responses for the latter survey questions. The average response rate dropped by 7% from page one to page two, and by 9% from page one to page four (Table 1).

In question two, respondents were asked to report the township that their land was within and there were 458 usable responses. The townships most frequently represented by survey respondents were located in the western Upper Peninsula of Michigan, with several townships reaching a rate as high as 15 respondents. The southeast Lower Peninsula was the least represented and had almost no township represented (Figure 3). Similarly, the distribution of land represented by survey responses and broken down by township was most heavily concentrated in the western Upper Peninsula, while the southeast Lower Peninsula has almost no acreage represented in the survey (Figure 4).

The mean parcel size held by respondents was 238 acres, and the mode was 40 acres. There were 148 respondents who reported having fewer acres than those recorded as enrolled in the CFP, while 225 respondents reported having more acres than the CFP had listed as enrolled. The number of respondents who reported having acreage equal to that held under the CFP was the lowest, at 113. The range of reported acres ran from 5,000 down to 8. The median acreage was 120 (Figure 5).

OWNERSHIP AND LAND USE

Question three asked if forest land had been inherited. The clear majority of respondents did not inherit their land, with 76% marking “no” to question three. Only 23% of respondents inherited some or all of their land (Figure 6). Most people enrolled in the CFP program purchased their land, or came by it in a way other than inheritance.

About one fifth of respondents fell into the age ranges of 50-57, 58-65, and 66-73. No respondent was younger than 25 and only three were older than 91 (Figure 7).

To determine the role income might play in decision-making about land, question four asked if the majority of the respondents' income came from the forested land. In the overwhelming number of cases, it did not—97% of respondents did not rely on their land as their primary source of income, while 2% did (Figure 8).

Questions five and six are related, the first asked for activities carried out on the forested land, and the second asked how long these activities had been practiced. Multiple answers could be given for these two questions. NIPF owners most common land use activity was “hunting/fishing/trapping,” at 82% of question respondents marking it (Table 2). The longest practiced activity for NIPF owners was “just being around nature” with a mode of 50 years (Figure 9). There were three outliers, one each for “Timber or firewood harvest,” “ATV,” and “Conservation purposes, such as wildlife habitat.” The outlier for timber harvest was the most extreme, at 140 years (Figure 9).

Question seven was related to the previous two questions, but a more complex analysis was needed to identify what activities could continue nearby if necessary—as would be the case for some activities if the owner's trees were cut down to use for ethanol. Most respondents could practice all their current activities on nearby land (Figure 10).

The majority of NIPF owners, 82%, were in compliance with the CFP requirement that all enrolled land have a current, certified forest management plan, or FMP. Question eight did not give the respondents an options to answer that only some forest land was under an FMP, which could have been the situation for respondents who held some land under the CFP and other land outside of the CFP restrictions. Few respondents, at 12%, did not have certified FMP, but actively managed the land themselves. Only 5% of respondents did not have a certified FMP, nor did they manage the land themselves (Figure 11).

CELLULOSIC ETHANOL

The view of respondents had towards cellulosic ethanol was the topic of question nine. One third of respondents would be willing to sell some of their harvested trees for cellulosic ethanol production, while 41% were not sure what they would do. Only 10% of respondents said they would not harvest their trees for use in cellulosic ethanol, or that they would not be willing to harvest any trees at all. Regardless of the reasoning, 10% of NIPF owners would not participate in this biofuel economy. If the positive responses were combined, including people who indicated they would sell all of their trees and the people who would sell some, then 47% of respondents had a positive view of selling their trees for cellulosic ethanol (Figure 12). In regards to the compensation for selling the trees to the biorefinery an exact amount was not suggested nor determined. Instead the question stated that the trees would be purchased at the market rate for timber.

CLIMATE CHANGE

Respondents that disagreed with the statement that climate change was occurring and that the net effect of humans was to warming the planet, as given by Intergovernmental Panel on Climate Change, or IPCC, was at 41%. Of those respondents who disagreed with the IPCC, 86% said climate change was occurring, but that human activities were not a primary driver of the change. The remaining 14% believed that climate change was not happening, and therefore humans' activities have not been warming the planet. Those agreeing with the IPCC's assessment that climate change was occurring and that human activities were the primary cause accounted for 38% of the respondents. Finally, 20% of respondents reported that they had not formed a view of the subject. The percentage of respondents who believed the climate was changing, but were not in agreement over the role humans played in the change, was quite close: 36% believed humans were not the primary driver of the change, while 38% believed humans were (Figure 13).

CARBON SEQUESTRATION

Question eleven asked about interest in the active management of forests to sequester carbon, and tied in the IPCC's assessment of climate change as a reason to sequester carbon. At 55%, just over half of respondents indicated they would either consider maintaining or would definitely maintain their forest to sequester carbon for compensation. Of those positive responses, 36% said they would definitely sequester carbon for compensation, while 64% said they would consider doing so. There were 15% of respondents who said that compensation would not impact their decision, although what the decision would be was not addressed in this survey. There were 22% of respondents who said they needed more time and information before they would be able to make a choice. Finally, 5% said they would not consider maintaining their forest stand to sequester carbon for compensation (Figure 14). For simplicity, the amount of compensation was described as “appropriate” and respondents were left to interpret the value of the amount accordingly.

QUESTION CORRELATION AND DECISION-MAKING

The goal of the survey was to determine how people make decisions about their forested land. Question twelve asked people what factors they would think about when managing their forest and multiple responses could be chosen. About 40% of respondents said they would consider the option that seemed like a more worthwhile goal to themselves and others. And 37% of respondents said they would consider compensation, but it would not be the only basis for the decision. Another 37% also said that they would consider how the land was currently being used. Only 8% felt that compensation would be the only consideration for them, while 21% said they were not sure how they would make their decision or that they would need to gain more information before moving forward (Table 3).

About one-fifth of respondents to question twelve said they would consider their beliefs regarding carbon and carbon sequestration when making a decision about cutting down trees for alternative fuel or maintaining them to sequester carbon, or do neither. To determine if the respondent's answers to questions nine, ten, and eleven had an impact on one another as the response to question twelve would indicate, a chi-squared contingency table was used. Contingency tables compare the expected distribution of paired response options given the total number of responses, with the observed distribution of paired response options. The null hypothesis tested for an independent distribution of responses to the two compared questions. Questions nine and ten did not have a significant relationship when $p = 0.5$, but questions ten and eleven and questions nine and eleven did have a significant relationship. To further analyze how the questions were significantly related, a table of the standardized residuals was created (Table 4).

Respondents who were willing to use their forest to sequester carbon were also more likely to agree that human-induced climate change was occurring (Table 4, column a, row 6). Similarly, respondents that believed in climate change were less likely to oppose using their land for carbon sequestration (Table 4, column c, row 6) and less likely to feel that compensation would not effect their decisions (Table 4, column b, row 6). NIPF owners who believed that the climate was not changing tended to be against using their land for carbon sequestration (Table 4, column c, row 4). Those who felt the climate was changing, but not due to human actions, were unlikely to agree to use their land to sequester carbon (Table 4, column a, row 5), but more likely to feel that compensation would not be a factor in their decision (Table 4, column b, row 5). In short, those who agreed with the IPCC were more likely to be interested in carbon sequestration, while those that disagreed were uninterested in sequestration and also felt that money was not a factor in their decision (Table 4).

Several relationships were also strong and significant between respondents' willingness to sell biofuel feedstock and willingness to manage forests to sequester carbon (Table 4, columns a-c, rows 1-3). However, these relationships were not as strong and significant as those between respondents' beliefs about climate change and their willingness to manage forests to sequester carbon (Table 4, columns a-c, rows 4-6). Respondents who would use their forest to sequester carbon were more likely to agree to sell their trees for cellulosic ethanol and similarly (Table 4, column a, row 1), also less likely to not sell their trees for cellulosic ethanol (Table 4, column a, row 3). Those respondents who felt that compensation would not effect their decision to use their trees to sequester carbon were less likely to agree to sell their trees for cellulosic ethanol production (Table 4, column b, row 1). Respondents who were supportive of using their trees for cellulosic ethanol were more likely to support using their trees for carbon sequestration, even though there is a direct trade-off between these two options (Table 4, column a, row 1). The responses to question twelve regarding how much climate change and carbon offset factors were taken into account when making forest land-use decisions were supported by the chi-squared contingency tables created for questions nine, ten, and eleven.

The participation rate of NIPF owners willing to sell biomass for use in the cellulosic ethanol refinery found in the survey, 47%, was used as an input to the CEBRAM model. The correlation data from questions nine, ten, and eleven showed that a decisions to use forest stand biomass for cellulosic ethanol do not occur in isolation. CEBRAM was designed to measure the net carbon balance of the cellulosic ethanol production chain, but included the action of nonindustrial private forest owner participation in selling trees for cellulosic ethanol as a key component that impacted the carbon balance. The NIPF owner participation rate came directly from the Private Landowner Forest Decisions Survey.

MODEL RESULTS

The modeling part of this study essentially examined two things. First, in a landscape that is heterogeneous in forest land use and ownership, given the most likely NIPF owner participation rate as determined by the survey (47%), what is the resulting net carbon balance of harvesting forest parcels for a cellulosic ethanol biorefinery? Three different accounting methods were used to determine the net carbon. The different accounting methods use a combination of different system boundaries in the analysis and different baselines for comparison. Second, the modeling analysis compares results from these three different carbon accounting schemes across the entire hypothetical range of NIPF owner participation rates. Generally, net carbon was calculated by taking the sum of carbon sequestered by trees or offset by using ethanol instead of gas and subtracting the carbon emitted. A negative net carbon would mean more carbon was emitted to the atmosphere than would have been without ethanol production, while a positive net carbon would mean less carbon was emitted to the atmosphere than would have been without the cellulosic ethanol biorefinery. Nonindustrial private forest owners had two choices in the model, to either participate by selling their trees for cellulosic ethanol or to not participate and maintain their forest to sequester carbon. By changing the parameters used to calculate net carbon, the value of trees that could be used either as biomass for ethanol or as the principle component in an ecosystem sequestering carbon, became clear.

NET CARBON CALCULATIONS

The three ways chosen to calculate net carbon were EB, for Energy Balance, EB+LU, for Energy Balance and Land Use, and CMOC, for Carbon Mitigation Opportunity Cost, and each used the same set of carbon emissions sources, since between the net carbon calculations there were no differences in ethanol production output—the only difference was in how unharvested trees were incorporated (Figure 16). These different net carbon calculations correspond to equations (19), (20), and (21), respectively, divided over the scenario area. The carbon emissions used to calculate each version of net carbon come from the following places: the harvesting process, the distance driven to transport the biomass, the biomass preparation, and the operation of the biorefinery. The assumptions behind each of these steps used to produce ethanol are described in the methods section.

With EB, only the energy balance of the ethanol production system was considered, and the inputs behind this value can be seen in equation (19), divided over the scenario area. EB was calculated using the carbon offset in the gasoline not used due to ethanol production along with the standard carbon emissions. Under this net carbon calculation only the energy balance of the system was accounted for in order to focus on the carbon impact of the biorefinery as it operated outside of the context of the landscape that surrounded it.

EB+LU included the carbon sequestered by land use of the NIPF not participating in selling to the refinery, along with the standard carbon emissions and gasoline offset that were included in EB. Again, equation (20) shows that the difference between this equation and (19) only was the addition of the carbon sequestered by the trees of non-participating NIPF owners. The rationale for having included unharvested stand carbon sequestration in EB+LU was to be able to examine the impact all NIPF owners, participating and non-participating, had on the carbon profile of a given simulation.

CMOC considered the carbon mitigation potential of the NIPF land, and came from equation (21), divided over the scenario area. The landscape use, which accounted for non-participating NIPF carbon sequestered, gasoline offset carbon, and standard emissions, were all included in this calculation just as EB+LU did. However, CMOC also included the opportunity cost in terms of the carbon that could have been sequestered in the landscape if all NIPF owners kept their trees growing and harvested none. Including the opportunity cost carbon for all NIPFs highlighted the importance of the choices of NIPF owners in determining the overall carbon balance of the landscape.

At the 47% participation rate, EB had a net carbon calculation of 0.03 MgC/ha over 40 years, indicating more carbon was offset by running the biorefinery than was emitted, leading to a slight decrease in carbon emissions over the 40 year period. The EB+LU calculation at the 47% participation rate had a net carbon calculation of 10.74 MgC/ha over the 40 year simulation length, again, indicating more carbon was offset or sequestered by running the biorefinery than was emitted. Finally, CMOC's net carbon calculation was -9.46 MgC/ha over 40 years, given the 47% participation rate as indicated by the survey. This net carbon value is negative, indicating that more carbon was emitted than was offset or sequestered by running the biorefinery. The three ways net carbon was calculated for the 47% participation rate as indicated by the survey allowed us to more closely examine the role the biorefinery alone played (EB) and the impact NIPF owner decisions had (EB+LU and CMOC) on the net carbon for a given simulation. However, to really get a sense of how NIPF owners impact the net carbon we need to look at a range of participation rates, and to do this we need a corresponding number of scenarios. The set of scenarios where one parameter was varied is referred to as a family. The only parameter varied in the family examined in this paper was that of the percent NIPF owner participation, and for each of these scenarios net carbon values, EB, EB+LU, and CMOC, were calculated.

NET CARBON

EB showed that there was a direct relationship between NIPF owner participation and net carbon accounting—more participation led to an increase in positive net carbon accounting. The range of net carbon, when looking at 100% participation through 5% participation, stretches from 0.08 to -0.001 MgC/ha over each 40 year scenario simulation (Table 6). When the unharvested forest land of NIPF owners were included in the analysis using EB+LU, the relationship between NIPF owner participation and net carbon accounting became more pronounced. The more participation the less carbon was offset because the magnitude of carbon sequestration that the forest was capable of was higher than that of cellulosic ethanol. Looking at the same spread of participation rates, from 100% through 5%, the range of net carbon runs from 0.08 to 19.19 MgC/ha over 40 years. This difference between forest carbon sequestration and cellulosic ethanol carbon offset was further exemplified under the CMOC analysis. CMOC assumes that all NIPF hectares could have been forested, but that this option was foregone in order to harvest some of the trees for cellulosic ethanol. The carbon sequestration potential of the system if all NIPF lands were forested had a much greater and positive impact on net carbon than using some of the trees for cellulosic ethanol did. The range of participation, 100% through 5%, yields a net carbon range of -20.12 to -1.01 MgC/ha over 40 years. By choosing to manufacture ethanol the net carbon balance became negative, by comparison with the CMOC baseline, and more carbon was emitted into the atmosphere than if no forests were harvested for feedstock use in a biorefinery (Figure 16).

Scenario Area and Percent Participation

In order to meet the assumption that the biorefinery was producing ethanol at maximum capacity, the percent participation decreasing caused the scenario area to increase, maintaining the biomass supply. It should be noted that extremely low levels of NIPF owner participation are highly unrealistic. Such widely dispersed participation would likely not be tolerated by the biorefinery from a practical perspective. Judging from the maximum radius from the biorefinery to the edge of the harvest area that would be practical from an economic standpoint, about 160 kilometers, NIPF owner participation rate would be around 30% (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). The numbers for percent participation went down to 5% simply to show the trend that developed under these low conditions (Table 5).

EMISSIONS AND OFFSETS

The majority of emissions that contributed to the calculation of EB, EB+LU, and CMOC came from the biorefinery, through its construction and the enzymes used (Table 6). The gasoline offset by producing ethanol to use instead, the carbon sequestered by non-participating NIPF, and the carbon sequestration foregone under CMOC were also included in this table. The non-participating NIPF owners growing trees to sequester carbon have the power in the system to determine whether the net carbon is positive or negative.

The role of forest growth carbon sequestration was significant in determining overall net carbon balance. The value used to calculate carbon sequestration per hectare over the 40 year simulation length came from averaging the change in carbon from forest stands that started at different ages and grew over the 40 year period (Figure 2). Because of the curve seen in figure 2 the average megagrams per hectare carbon must be accounted for over the 40 year period and not on a yearly basis.

RESULTS SUMMARY

In Michigan, at the most likely NIPF owner participation rate of 47%, a cellulosic ethanol biorefinery using harvested forest biomass as a feedstock has a very slight net positive carbon balance of 0.03 Mg C/ha over a 40 year period, when viewed in isolation from the landscape. Net positive carbon balance means more carbon was sequestered or offset than the carbon emitted; a negative net carbon balance indicates more carbon was emitted to the atmosphere than offset or sequestered. When forest growth in the landscape is included within the boundary of the carbon accounting, treating the forest landscape and biorefinery as a combined system, there is a greater positive net carbon accounting result at

47% participation, with 10.74 Mg C/ha over a 40 year period. However, ceasing all harvest of forest biomass and allowing these forests to grow instead would store a great deal of carbon in the landscape. When this foregone carbon sequestration is included in the system analysis, the biorefinery and forest landscape as a system have a negative carbon accounting result at 47% participation, -9.46 Mg C/ha over a 40 year period. My analysis also showed that lower rates of NIPF owner participation result in greater positive net carbon accounting in the combined biorefinery and forest landscape as a system. This resulted from the assumption that NIPF owners who did not participate would instead allow their forests to continue to grow.

DISCUSSION

SUMMARY OF SURVEY RESPONSES

The survey responses to the current survey provided some insight into how landowner beliefs or positions affect their management decisions, with important ramifications for development of feedstock sources from nonindustrial private forest, or NIPF, land. Almost half of survey respondents, at 47%, would sell some or all of their biomass for use in cellulosic ethanol production (Figure 12). More than half, at 55%, of respondents would at least consider maintaining their forest for carbon sequestration (Figure 14). Those who wanted more information about cellulosic ethanol before making a decision made up 41% of respondents, while 22% wanted more information about carbon sequestration before committing to such a program (Figures 12 and 14). Respondents who were interested in using their forest as feedstock for cellulosic ethanol were also likely to want to use their forest to sequester carbon, even though these two land use decisions are mutually exclusive (Table 4, column a, row 1). Additionally, respondents who wanted to use their forest to sequester carbon were also more like to believe that climate change was happening and human caused (Table 4, column a, row 6). Interestingly, similar correlations did not exist between climate change and cellulosic ethanol. The correlations from the standardized residuals process indicated that there were a group of people who were supportive of alternative uses for their biomass. A subset of the people interested in carbon sequestration were more likely to believe human-caused climate change is happening than the group of people who were interested in using their biomass for biofuel suggesting that those interested in cellulosic ethanol production and carbon sequestration were not homogeneous.

It should be noted that the correlation in interest between cellulosic ethanol and carbon sequestration means that respondents were not considering the two options to be a trade-off, as the CEBRAM model did. This correlation may be an indication that respondents were confused about what would be required under either program and did not realize they were mutually exclusive. The participation rate for cellulosic ethanol could be different if respondents were actually asked to decide to act in real-life, but it is unclear exactly how the rate might change. With so many undecided respondents, it is possible some of them would commit to the selling biomass for cellulosic ethanol, or it is possible that some respondents that expressed interest in both cellulosic ethanol and carbon sequestration would ultimately choose to sell biomass to produce ethanol. This conclusion is beyond the scope of this survey. The 47% of respondents interested in cellulosic ethanol overlapped significantly with the 55% that expressed interest in carbon sequestration (Table 4, column a, row 1). Therefore, there was also a substantial group of people who were uninterested in either option. The overall interest in these two programs has the potential to fluctuate above or below the levels reported by respondents.

COMPARISON TO OTHER NONINDUSTRIAL PRIVATE FOREST OWNERS

The nonindustrial private forest owners in other studies tend to be against harvesting their forest, although large-tract forest owners and those who inherited their forest are exceptions to this pattern (Smith et al 2007, Le Vert et al 2009, Kilgore et al 2008, Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Majumdar et al 2009). Enrollment in forest management programs, which would be similar to the requirements of a carbon sequestration program, remains low, between 2% and 18% nationally (Le Vert et al 2009). People in the NIPF owner community, specifically in

Kentucky and Iowa, have expressed enthusiasm for cellulosic ethanol programs but the lack of dependable economic outcomes for ethanol programs has made these same forest owners hesitant to commit (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). The NIPF owners in the present survey differ in some ways from the NIPF owners in these other studies.

OPINION ON FOREST HARVEST

The NIPF owners in the present survey are likely to be more comfortable with harvest than most other NIPF owners because at one time or another, all survey participates had at least some land enrolled in the Commercial Forest Program, or CFP (Figure 17). A condition of enrollment is that the forest will be set aside for commercial harvest, and this commitment to harvest is quite unlike most NIPF owners who tend not to support timber harvest on their land (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Smith et al 2007, Le Vert et al 2009, Kilgore et al 2008). There are some NIPF owners, nationally, that do engage in timber harvest, and broad indicators of a positive attitude towards harvest among NIPF owners are to have a large tract of forest and to have inherited your forest (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Majumdar et al 2009). The NIPF owners who took the present survey tend to have more land than the national NIPF owners do. The mode for NIPF owners who took the present survey was 40 acres, and for national NIPF owners, the most common parcel of land was between 1 and 9 acres (Figure 5)(Butler et al 2012). Of the NIPF owners that took the present survey, 23% inherited their forest land, compared to the national NIPF owner inheritance rate of 28% (Figure 6)(Majumdar et al 2009). Despite the larger most common tract size, it is unlikely these NIPF owners fall into the group of large tract landowners discussed in the Committee of the National Research Council that supply the majority of timber harvest each year, although just how a “large tract of forest land” is defined is not specified in the report (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Rossi and Hinrichs 2011). Additionally, the similarity in inheritance rate between the surveyed NIPF owners and those nationally makes enhanced timber harvest support unlikely to be due to this characteristic. What set these NIPF owners who decided to enroll in the CFP apart from other NIPF owners who seem opposed to timber harvest on their land, is unclear.

Opinion on Carbon Sequestration

Regarding the potential support for carbon sequestration, the NIPF owners who completed the present survey expressed 55% at least partial support for such a program (Figure 14). A carbon sequestration program could be run in a variety of ways, but all of them would require some minimum length of commitment a way to monitor the carbon in the landscape, and a management plan (Fahey et al 2010, Marland et al 2001). In these ways a carbon sequestration program would be similar to a forest management or conservation easement program, and among NIPF owners nationally these programs have very low enrollment, ranging from 2% to 18% of eligible land (Le Vert et al 2009). The study by Kilgore examined the factors NIPF owners consider when deciding to enroll in a forest conservation program or not, and concluded that one important factor was whether or not the landowner already had, or was planning to get in the near future, a certified management plan for the forest (Kilgore et al 2008). Indeed, having a forest management plan, or FMP, made you 5 times more likely to enroll in a conservation program than those NIPF owners that did not have and were not considering obtaining a FMP (Kilgore et al 2008). Nationally, only 5% of NIPF owners have a FMP, and given the low rate of participation in forest conservation programs, this is not surprising (Butler et al 2012). Of present survey NIPF owners, in contrast, 83% have a certified FMP, while an additional 12% actively manage their land without having their management actions certified (Figure 11).

If the results of Kilgore's study can be applied to a carbon sequestration program, then the NIPF owners who took the present survey would be more likely to enroll in such a program than most national NIPF owners (Kilgore et al 2008). It should be noted that the requirements for carbon sequestration program enrollment that were outlined above, such as minimum enrollment time, were not presented in the survey, and so the 55% positive response rate for carbon sequestration enrollment could not be assumed to include an understanding of these conditions. Knowing the conditions of enrollment could have inflated the number willing to consider enrolling in the carbon sequestration program over the likely national NIPF owner interest level, but the rate may already be inflated due to this difference in how the surveyed NIPF owners manage their land.

OPINION ON CELLULOSIC ETHANOL PRODUCTION

Enthusiasm for cellulosic ethanol production among NIPF owners nationally has been shown to be undercut by a lack of economic certainty, both long- and short-term, for such programs (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Rossi and Hinrichs 2011). NIPF owners in the present survey were told they would be compensated at the market rate for timber if they instead sold their biomass for cellulosic ethanol (Appendix A). Although no concrete dollar value was given per cubic meter wood, the survey essentially equated the economic value of the biomass to the ethanol industry with that of the timber industry. It is unclear if this suggestion alleviated some of the economic concerns that other NIPF owners, nationally, have expressed, and difficult to compare the 47% support for cellulosic ethanol response in the present survey with the qualitative interviews conducted nationally (Rossi and Hinrichs 2011). As well, the presently expressed level of support may be higher than a national rate for cellulosic ethanol production in part due to the heightened level of comfort with harvest the present NIPF owners surveyed likely have.

NONINDUSTRIAL PRIVATE FOREST OWNER OPINION SUMMARY

Both the rates of support for cellulosic ethanol production and carbon sequestration program enrollment may be inflated for the surveyed NIPF owners relative to NIPF owners nationally. The surveyed NIPF owners enrolled in the CFP are likely to have a more favorable view towards harvest, and in conjunction may feel more comfortable with harvest for cellulosic ethanol. These NIPF owners in the CFP were much more likely to have a certified management plan than national NIPF owners, and this could increase their willingness to commit to carbon sequestration, which would likely be run with a similarly monitored program (Figure 11) (Butler et al 2012). However, there are also high rates of reported uncertainty to both issues, with 41% wanting more information about the cellulosic ethanol program and 22% wanting more information about carbon sequestration before committing (Figures 12 and 14). The correlation between individuals who support using their biomass for cellulosic ethanol production and those that support using their forest to sequester carbon raises the issue of whether or not respondents understand the fundamental details of these two, mutually exclusive ways of using their biomass (Table 4). It may be that both choices are supported, but from this survey we have no way of knowing which choice these NIPF owners would chose over the other. The spread of age among respondents, rate of inheritance, and reliance on the forestland as a primary source of income are all about the same when compared to national NIPF owners (Butler et al 2012). More research is needed to determine the true rate of support for these two, mutually exclusive ways of using forest resources, with more concrete details for both programs included.

SURVEY LIMITATIONS

Issues with the format of the survey were either noted by respondents in the comments section, or became apparent as multiple surveys were returned with the same issue. There were two general categories of confusion with the surveys: the wording of the question, and the options given for response. The structure of the survey also ended up being an issue. Not counting those respondents who turned in a completely blank response with a comment, 17 people missed pages two and four, which were on the back side of pages one and three and were, for this reason, easy to miss. In addition to the 17 that missed both pages, 4 respondents missed only page two, while an additional 24 respondents missed the final page. No indication was made at the bottom of pages one and three that additional questions were located on the back, although page numbers at the base of each page were included. A simple note would likely have decreased the non-response rate associated with pages two and four.

LIMITATIONS OF QUESTION PHRASING

The issues with question phrasing began with question one, but were also present in questions six, seven, and twelve. In the first question many people reported what county their land was in and not the township, as the question asked. Additionally, there were township names given that were not in Michigan, and others, like “Lake township,” that exist in multiple places in the state and this further confused response interpretation.

Question six, a follow up to question five, asked how many years an activity was practiced by the respondent on the forested land. Several respondents listed years next to activities that were not chosen in question five, and others responded with numbers larger than a human lifespan, making interpretation of these responses difficult (Figure 9).

Question seven, another follow-up to questions five and six, asked if there were alternative areas where respondents could practice activities listed in question five. The issue here was that some activities listed in question five, such as timber harvest, cannot be conducted on land you do not own and therefore many people could not mark “yes,” but had to mark the more involved response “some of my activities, yes (please specify which).” Question seven should have made it clear that some activities would not apply, and it did not.

Finally, question twelve was trying to determine how individuals make decisions regarding their forest land, within the context of choosing between either cutting down the trees for ethanol or maintaining the forest to sequester carbon, or if neither of those options appealed to the respondent, what information would they consider in making a decision to manage the land in some other way. Question twelve tried to pack a lot of information into a small space, and not surprisingly lead to confusion. Some respondents did not see that the option to engage in neither carbon offsetting activity was available and commented that they refused to answer the question on these grounds. The lack of clarity in question twelve may have lead to confusion and some respondents may have answered the question differently if they had understood the intended query.

LIMITATIONS OF RESPONSE OPTIONS

The second issue, having to do with the response options given, arose for questions three, eight, nine, and eleven. In question 3 respondents were asked whether or not they had inherited their land, but no option was given for those who had inherited some, but not all of their land. The question either should have been rephrased so that an affirmative response would indicate some or all of the land was inherited, or an option should have been given for respondents to indicate this distinction. As written some individuals chose to check both the "yes" and "no" boxes, but this lack of clarity means that some respondents could have interpreted the question and answer options differently, and so it is unclear how many respondents might have inherited some of their land.

Question eight erroneously made the assumption that all land queried for this survey would fall under the same management. In asking if the forest had a certified management plan, a management plan, without certification, or no management plan, the option was never given for those who had some forest with a certified management plan and other land without one. As certification is a requirement of enrollment in the CFP, but not all respondents only owned land enrolled in the CFP, the response options should have been more varied. Given this omission from the response options it is unclear how individuals with some land under certified management and other land, not certified, would have responded.

Questions nine and eleven asked individuals if they would take specific action with their forested land—to either cut it down for cellulosic ethanol or to maintain the forest to sequester carbon. Certain respondents commented that they would not answer either question due to their obligations to maintain their forest for timber harvest under the CFP. It is unclear whether the best course of action would have been to change the wording of both questions or to change the response options given. Either way, the risk is run that respondents will not answer the question with realistic constraints in mind or that they would not fully consider the option in favor of the status quo. A problem with surveying NIPF owners who have already decided the fate of their trees is that not all NIPF owners have these limitations, and some respondents may interpret questions like nine and eleven given their current obligations differently than other respondents.

CRITIQUES OF THE SURVEY INSTRUMENT

Most survey data collected on natural resource preferences or used in conjunction with modeling relies on a style not used for this analysis, known as contingent valuation method, or CVM. This method asks respondents to place a monetary value on a non-market good, such as a forest. Forests can be harvested for timber, or people will pay a set amount of money and drive a specific distance to enter a national park, but to assess the monetary value of the forest as a whole goes beyond the metrics of the few resources that participate in a market. There are a lot of issues with the CVM, primarily that the value assessed can vary widely depending on the assumptions made by the author in both the presentation of response options and interpretation of the data (Plott and Zeiler 2005, Hite 2009, Lindhjem and Navrud 2009, and Schlapfer 2006). Spash has argued that the fundamental problem with CVM is not due to a lack of uniform style and interpretation of results, but rather with the premise that non-market goods can be viewed in purely market terms (Spash 2007). For all of the reasons that the CVM is an unreliable instrument, I chose to leave monetary values out of the survey I conducted. Translating value into monetary terms is quite useful when done well, as dollar figures can be translated into different units more easily through different sections of a model than specific answers to specific questions. In choosing to not assess the monetary value that NIPF landowners place on their forest biomass I forfeited the ability to use their preferences and feelings in numerous ways throughout the model.

DISCUSSION SUMMARY FOR THE SURVEY

From the survey we know that there was interest in both selling trees for cellulosic ethanol and being compensated for maintaining a forest stand to sequester carbon, but that significant overlap exists between people who expressed these two preferences. Additionally, there was a group of people that were hesitant to take action without knowing more, and these individuals could be open to using their forest to limit carbon emissions in either way if they had more information about the program, specifically. Understanding if there is a difference between the opinions of absentee landowners and present ones, as well as landowners who have inherited their land and those who have not, may also clarify what kinds of NIPF owners are interested in managing their forest resources with carbon in mind. In general, the NIPF owners surveyed for this project are similar to the NIPF owners surveyed by the US Forest Service with the NWOS, but differ when it comes to obligations of enrollment in the Commercial Forest program run by the State of Michigan. Specifically, CFP enrollees, as represented by the present survey, have a more positive attitude towards timber harvest and are much more likely to have a certified management plan in place for the forest than those surveyed by the NWOS. The margin by which present survey respondents reported having a management plan compared to those responding to the NWOS is so large that any error caused by a lack of clarity in the question wording would likely not change the outcome. With so few studies asking how NIPF owners feel about using their trees for cellulosic ethanol or carbon sequestration it is difficult to predict how the breakdown of interest shown in the present survey reflects the preferences of the wider NIPF owner community, but currently there are no indications that these survey results are not representative.

USE OF MODELS AND SURVEYS

The disciplines that rely on modeling and those that rely on survey data are largely separate and therefore the two technics for predicting future behavior and consequences do not have a long history of working in conjunction (McIntosh et al 2005). Increasingly, the two are combined, especially when it comes to research on CHANS, or coupled human and natural systems. CHANS models try to capture the dynamics of the natural world as it is impacted by and impacts human decision-making, and often will rely on surveys to inform the side of the model that deals with human preference (Egbendewe-Mondzozo et al 2010, Jeon and Herriges 2010, Scarpa 2009, and Shaikh et al 2007). These surveys tend to rely on the CVM to capture human preference and value and end up modeling people as rational economic actors (Shaikh et al 2007, Bermann et al 2008, Brey et al 2007, Kilgore et al 2008, and Garcia de la Fuente et al 2010). The CVM style survey works well with models because it captures something qualitative in how people feel about the natural world and turns it into something quantitative whose units can be translated across other sections of the model.

CVM was not the survey style I chose due to problems with this mode’s standardization and interpretation, but the preferences expressed in the survey that were incorporated with the model show what interest in cellulosic ethanol might exist now, what it could look like in the future, and what the carbon profile for both looks like.

CELLULOSIC ETHANOL

The conclusions drawn by my study are that interest in using biomass to make cellulosic ethanol is around 47% among NIPF owners enrolled in the Commercial Forest Program. Given the differences in attitudes towards timber management between NIPF owners at large and those who completed the present survey, overall NIPF owner interest in cellulosic ethanol timber harvest may be lower (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011, Smith et al 2007, Le Vert et al 2009, Kilgore et al 2008). From a carbon perspective, forest resources would sequester more carbon if they were maintained and not harvested for cellulosic ethanol. While cellulosic ethanol, from a purely energy perspective, does offset more carbon than it produces, managed forest land does a better job (Table 6). Few studies have examined the issue of cellulosic ethanol in conjunction with other ways to use forest resources, but those that have concluded the same thing: that forests sequester more carbon when growing than they offset when used for cellulosic ethanol (Righelato and Spracklen 2007, Seidl et al 2007, Seely et al 2002). The Righelato and Spracklen study showed that if one acre of land is used to grow biofuels, of any kind, it will sequester or offset 2 to 9 times less carbon than if that same acre is used to grow a forest (Righelato and Spracklen 2007). The problem with the conclusion that maintaining forests to sequester carbon is better than using the biomass for biofuel is that it excludes the very real need for both sustainable transportation fuel and carbon mitigation (Seidl et al 2007).

While my model concluded that producing cellulosic ethanol with NIPF took carbon out of the atmosphere, the conclusions from other studies do not always agree, nor do most studies agree on how best to quantify whether or not cellulosic ethanol is good for the environment. A popular way to quantify the benefits of cellulosic ethanol relative to fossil fuel is to report the ratio of either biofuel energy produced relative to fossil fuel energy used to make it, or a ratio of how much biofuel is produced given the amount of fossil fuel used to make it. A 2002 study using forest harvest residue and short-rotation tree farms concluded that 4 or 5 units of liquid bioenergy were produced for every unit fossil fuel energy that was used (IEA Bioenergy 2002). Another study using forest and grass biomass concluded that the biofuel to petroleum ratio was 10:1 (Unknown 2006 NREL Biomass to Biofuels). In reviews of biofuel studies the different ways of judging biofuels are standardized for comparison. NEV, or net energy value, ranks cellulosic ethanol at 4.52 megajoules m^{-2}, while the FER, or fuel energy ratio, ranges from 1.80 to 5.60 FER (Davis et al 2008). NEB, or net energy balance, for switchgrass and wood comes in at greater than 4 (Hill et al 2006). Each of these studies, using their own metric, conclude that cellulosic ethanol is better than fossil fuels in terms of the energy it takes to create the fuel.

A 2006 review of cellulosic ethanol studies concluded that the ratio of renewable energy produced relative to nonrenewable energy that was consumed ranged from between 4.40 to 6.61, with one study as an outlier finding cellulosic ethanol to have an energy return on investment of 0.69, where anything below 1 means that no renewable energy has been captured. (Hammerschlag 2006). This outlier study by Pimentel and Patzek found that making cellulosic ethanol from wood required 57% more energy from fossil fuels than the energy found in the cellulosic ethanol (Pimentel and Patzek 2005). Hammerschlag considers the finding of Pimentel and Patzek to be an outlier worth ignoring due to “a collection of conservative assumptions regarding efficiency, the inclusion of a few upstream energy burdens not accounted by other analysts, and a very small energy allocation to co-products” (Hammerschlag 2006, p1747). However, other studies of cellulosic ethanol, when including the carbon emissions from the land use changes caused by new switchgrass or fast-growing tree plantations, conclude that this biofuel has a negative impact on greenhouse gas emissions (Hattori and Morita 2010, Searchinger et al 2008, and Fargione et al 2008). The opportunity cost of foregoing maintaining the forest to sequester carbon and instead using it to grow biomass for cellulosic ethanol, the CMOC scenario in CEBRAM, leads to a negative carbon balance, where more carbon is emitted than sequestered (Figure 16).

CARBON SEQUESTRATION

Just as the assumptions about cellulosic ethanol inputs and technology change the conclusion of its effectiveness as a renewable, low-carbon technology, so do the assumptions about carbon sequestration programs change how successfully they might be implemented. The intergovernmental panel on climate change, or IPCC, has stated that in order for carbon sequestration to be counted as a true offset under the Kyoto protocol, new trees must be planted, and not to the detriment of current land that sequesters carbon (Fahey et al 2010). The offset may fall under the category of either afforestation or reforestation. Afforestation refers to land that has not been forested for 50 years or more now becoming forested, while reforestation refers to newly forested land that was not forested in 1990 (Fahey et al 2010).

Given these two definitions and their restrictions, the forest as modeled in CEBRAM would not count towards new carbon sequestered, but could still be eligible for compensation under state-based programs to encourage well-maintained forests. While carbon pricing could affect the market in unforeseen ways, and the program might not be economically viable, there is no doubt that maintaining forested land as such effectively sequesters carbon (White et al 2005, Rhemtulla et al 2009, Wise et al 2009, Shaikh et al 2007).

MODEL AND REALITY

The reality of the cellulosic ethanol industry is significantly messier than the CEBRAM model captured. The first constraint on making a model that projects the future of the cellulosic ethanol industry is that while many commercial scale biorefinery projects are being funded and anticipated to become operational every few years, no such biorefineries exist yet (Unknown 2006 NREL Biomass to Biofuels, Mattingly et al 2008, Davis et al 2008, MacLean and Spatari 2009, Solomon and Johnson 2009, and Boundy et al 2010). Because of this constant but unmet goal to achieve an operational cellulosic ethanol biorefinery, research studies do not agree on the technology these biorefineries will rely upon, nor do they know what kind of energy it will take to construct and maintain the biorefinery once operational (Fulton et al 2004, Centrec Consulting Group 2006, MacLean and Spatari 2009, and Boundy et al 2010). These unknown details are critical to the successful operation of cellulosic ethanol biorefineries and will impact the amount of energy that is needed to operate the plant, effectively changing the energy and carbon balance of the industry in unknown ways. The data currently used in both my model and those published by Farrell et al and Schmer et al comes from Pimentel and Patzek 2005, a source with citation problems and old data (Farrell et al 2006, Schmer et al 2008, Pimentel and Patzek 2005). It is relied upon because it is one of the few sources that has aggregated the energy implications of building a cellulosic ethanol biorefinery and broken down the inputs in a manner that makes them usable in other models, although how well these numbers reflect the energy cost of current technology is not clear.

An additional problem related to the lack of commercial scale cellulosic ethanol biorefineries is a lack of consensus regarding the dominant fuel source. The fuel source used in CEBRAM, a multi-species forest dominated by aspen, is unusual, picked in large part because of the low energy inputs needed for a diverse forest to grow and regrow, the significant population of nonindustrial private forest owners in Michigan, and the forest's ability to highlight the carbon trade-off between cellulosic ethanol and carbon sequestration (Froese and Miller 2008). Many of the studies done on cellulosic ethanol look at corn stover, switchgrass, willow, aspen, or poplar, grown on either marginal agricultural land or in plantations (Aden et al 2002, Seely et al 2002, Shaikh et al 2007, De La Torre Ugarte et al 2000 DOE, Campbell et al 2008, Davis et al 2008, Egbendewe-Mondzozo et al 2010, Farrell et al 2006). The studies that do use forest biomass as the modeled biomass source tend to focus on forest waste, or residuals from other harvest activities (Centrec Consulting 2006, Froese and Miller 2008, Fulton et al 2004, Gan and Smith 2006).

Using multi-species forest land as the biomass source for cellulosic ethanol is not frequently modeled, but is also not unreasonable. About 40% of Michigan's land area is NIPF land (FIA) and the majority of timber harvest biomass has come from NIPF lands over the last 50 years (Renewable Fuel Standard 2011). The pulpwood industry in Michigan that was once strong is now in a state of decline, but given the infrastructure already in place within the industry they stand in a strong position to begin manufacturing ethanol, as the pulpwood industry in Europe is doing (Centrec Consulting 2006, Plantinga and Birdsey 1993, Froese and Miller 2008, Gonzales-Garcia et al 2011 JOIE). Indeed the pulpwood industry pioneered the process of turning waste products from trees, lignin, into a fuel that powers their manufacturing process, sometimes exceeding their energy needs by 30% (Hubbard et al 2007). In addition, this industry found a way to make numerous, small tract harvesting profitable, with 48% of logging firms for the paper and other wood industries in Michigan reporting that a majority of their supply, 87.5%, came from NIPF biomass (Rickenbach and Steele 2006). The proportion of land in Michigan under NIPF ownership, the infrastructure of the declining pulpwood industry that could transition to cellulosic ethanol production, and the industry relationship with NIPF landowners, makes this modeled supply chain reasonable as a possible future source of ethanol. The specifics of transitioning the pulpwood industry's infrastructure to cellulosic ethanol biorefineries were not part of the CEBRAM model, but the real potential for this transition does make the modeled system, which relies on biomass from NIPF owners in Michigan, justifiable.

CONCLUSION

In Michigan, the participation rate in the production of wood for cellulosic ethanol is predicted by survey response data to be about 47% (Figure 12). At this rate, over a 40 year period, the cellulosic ethanol biorefinery has a very slight net positive carbon balance of 0.03 Mg C/ha, when viewed in isolation from the landscape (Table 6). When forest growth in the landscape is treated as a combined system with the biorefinery there is a greater positive net carbon accounting result at 47% participation, with 10.74 Mg C/ha over a 40 year period

(Table 6). However, ceasing all harvest of forest biomass and allowing these forests to grow instead would store a great deal more carbon in the landscape. When this foregone carbon sequestration is included in the system analysis, the biorefinery and forest landscape as a system have a negative carbon accounting result at 47% participation, -9.46 Mg C/ha over a 40 year period (Table 6).

The nonindustrial private forest owners, or NIPF owners, in the survey are similar demographically to other NIPF owners as measured in comparable surveys (Butler et al 2012). The surveyed NIPF owners, all enrolled in Michigan's Commercial Forest Program, are perhaps more comfortable with timber harvest because it is a condition of their enrollment, than other NIPF owners are as other studies of NIPF owners indicate a general dislike toward timber harvest (Centrec Consulting Group 2006, Kilgore et al 2008, Le Vert et al 2009). The Committee of the National Research Council found that a majority of the timber harvested over the last 50 years was supplied by the NIPF community, but most of it was supplied by NIPF owners with large tracts of forested land (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). The unclear relationship that NIPF owners have with timber harvest could either increase or decrease the actual participation in selling biomass to the cellulosic ethanol biorefinery. That 41% of survey respondents wanted more information about the ethanol program before committing to a decision further suggests that participation in the bioenergy economy could either increase or decrease from the 47% level found in the present survey (Figure 12).

Given the negative economy of scale that cellulosic ethanol biorefineries face due to the cost of transporting wood long distances and the limitations on the rate at which forests grow, NIPF owners with a history of selling their wood to pulpmills have a powerful role to play in supporting the success of the cellulosic ethanol industry (Hubbard et al 2007, Simpkins et al 2006, and Gan and Smith 2006). These NIPF owners would not add to the biofuel carbon debt, and if concentrated in sufficient numbers near the biorefinery, could also minimize costs (Melillo et al 2009, Fargione et al 2008, Kroetz and Friedland 2008). The potential lack of significant carbon emissions from land use change does not mean that cellulosic ethanol production is the best way to use the land if the goal is to minimize net carbon emissions.

If NIPF owners care about limiting carbon emissions more than how it is accomplished, then using their trees to sequester carbon would be more effective than using them to offset gasoline consumption by producing cellulosic ethanol. Tree growth over a 40 year time horizon would sequester 20 megagrams of carbon per hectare, relative to the 0.03 megagrams carbon per hectare that cellulosic ethanol would offset over that same time period (Table 6). According to the survey, 55% of NIPF owners would consider using their forests to sequester carbon, with 20% definitely committing to it, and 21% requesting more information before they make a decision (Figure 14).

If policy-makers share the goal I have explored here, to use this forest resource in the way that most limits carbon emissions, then money would be well spent trying to construct an effective carbon market, such as the one suggest by Sohngen and Sedjo (Sohngen and Sedjo 2006). They recommend starting with a higher than predicted market price that encourages early landowner participation, but such a high price could be detrimental to other types of land use (Sohngen and Sedjo 2006). The present survey, along with Plantinga and Spash found that forest landowners do not only consider the economic value of their land when making decisions, and so an inflated value per hectare might be demanded to cover the non-monetary value of their land (Table 3). Future studies could investigate the connections between landowner demographics and preference for carbon sequestration programs. Cellulosic ethanol might still contribute to our renewable energy needs if it comes from waste biomass, but the amount of energy supplied would be so small that it could not be the only alternative energy source relied on (Gan and Smith 2006). In Michigan, privately-owned forest resources can limit net carbon emissions better through continued forest growth than through harvest for conversion to cellulosic ethanol, and those promoting cellulosic ethanol as the next generation of low carbon or carbon-neutral ethanol should keep this comparison in mind.

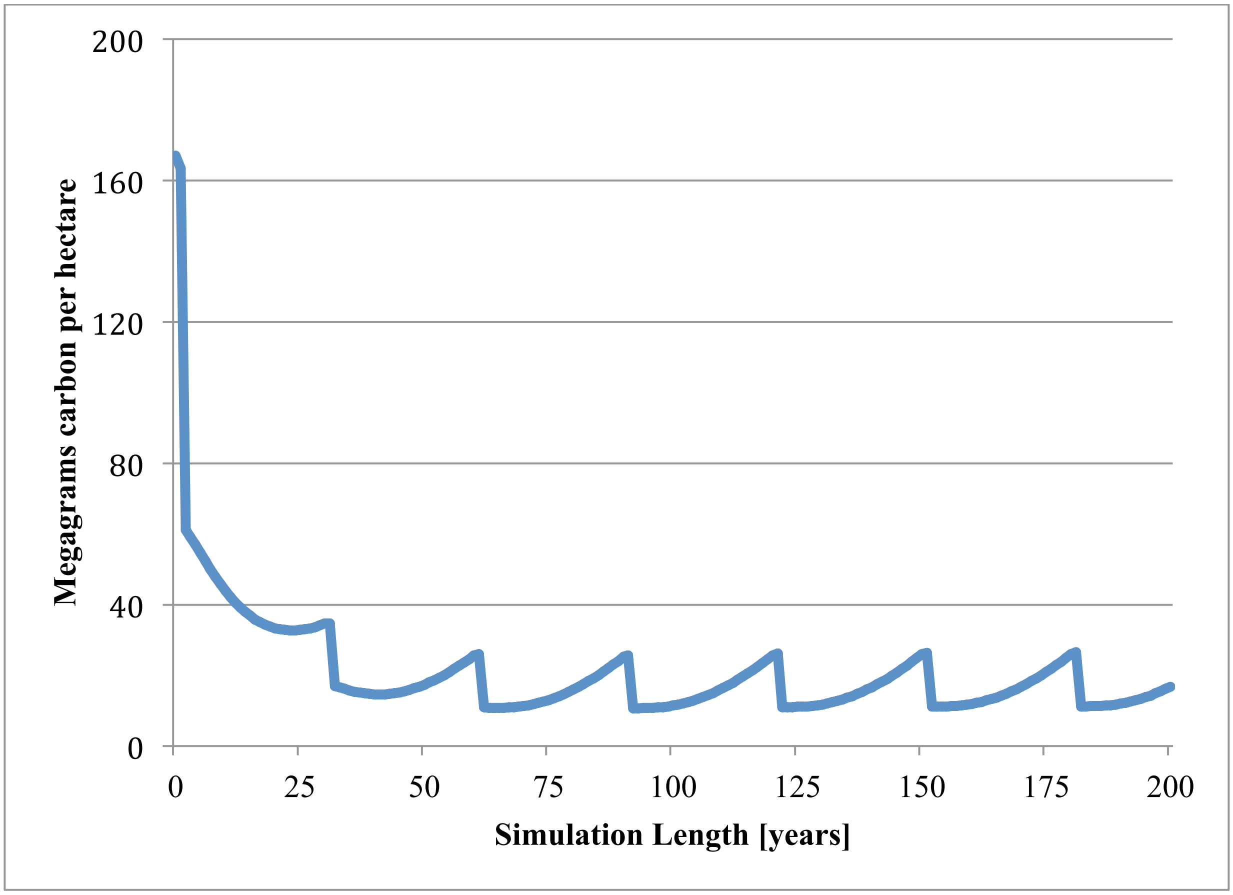


Figure 1. After several periods of repeated harvest and regrowth, a single forest stand reaches a repeating pattern of carbon dynamics. A 30-year rotation, as used in the present analysis, is shown (Lindauer-Thomson 2008).

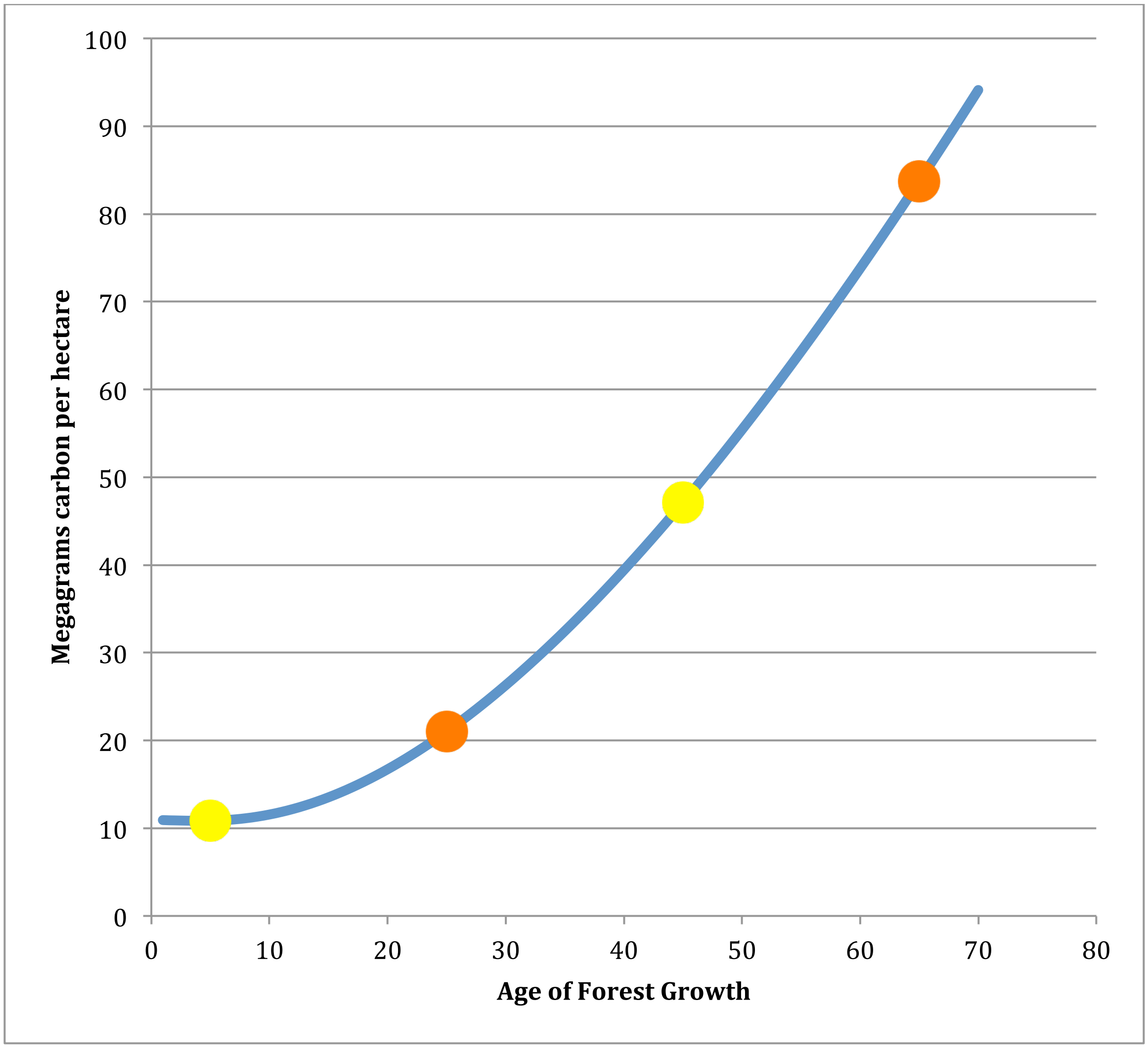
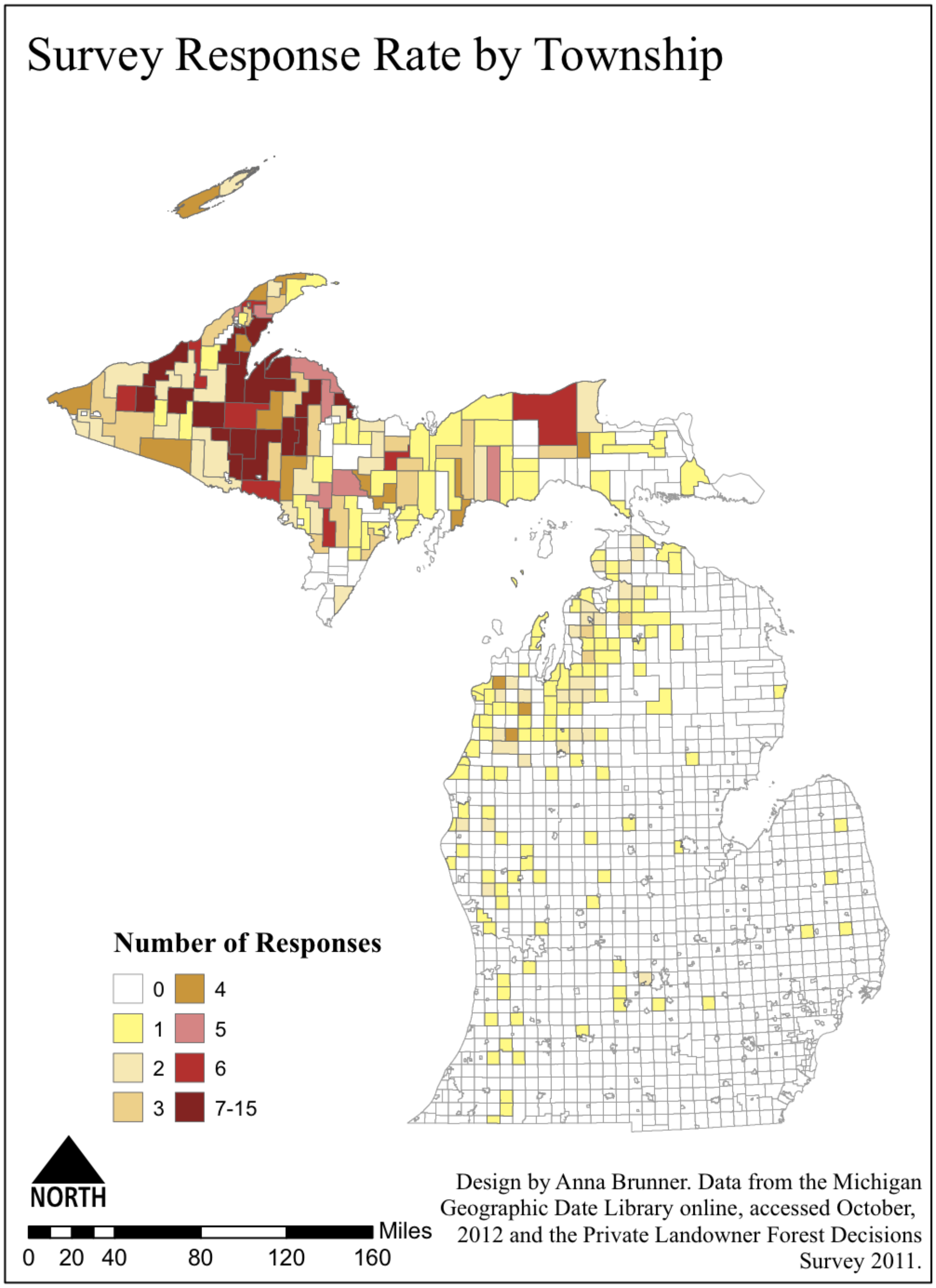


Figure 2. The blue line shows the trajectory of forest stand carbon sequestration over time. The yellow points reference starting and ending ages for a 30 year span of forest that began the Cellulosic Ethanol BioRefinery Accounting Model simulation at age five. The orange points, for comparison, also show the starting and ending ages for a 30 year span of forest growth as well, but this stand showed the dynamics of a stand of trees beginning the simulation at age 25. The difference in carbon accumulation between the two stands with different beginning ages shows the importance of considering the age distributions of forest stands in the landscape at the start of a simulation.

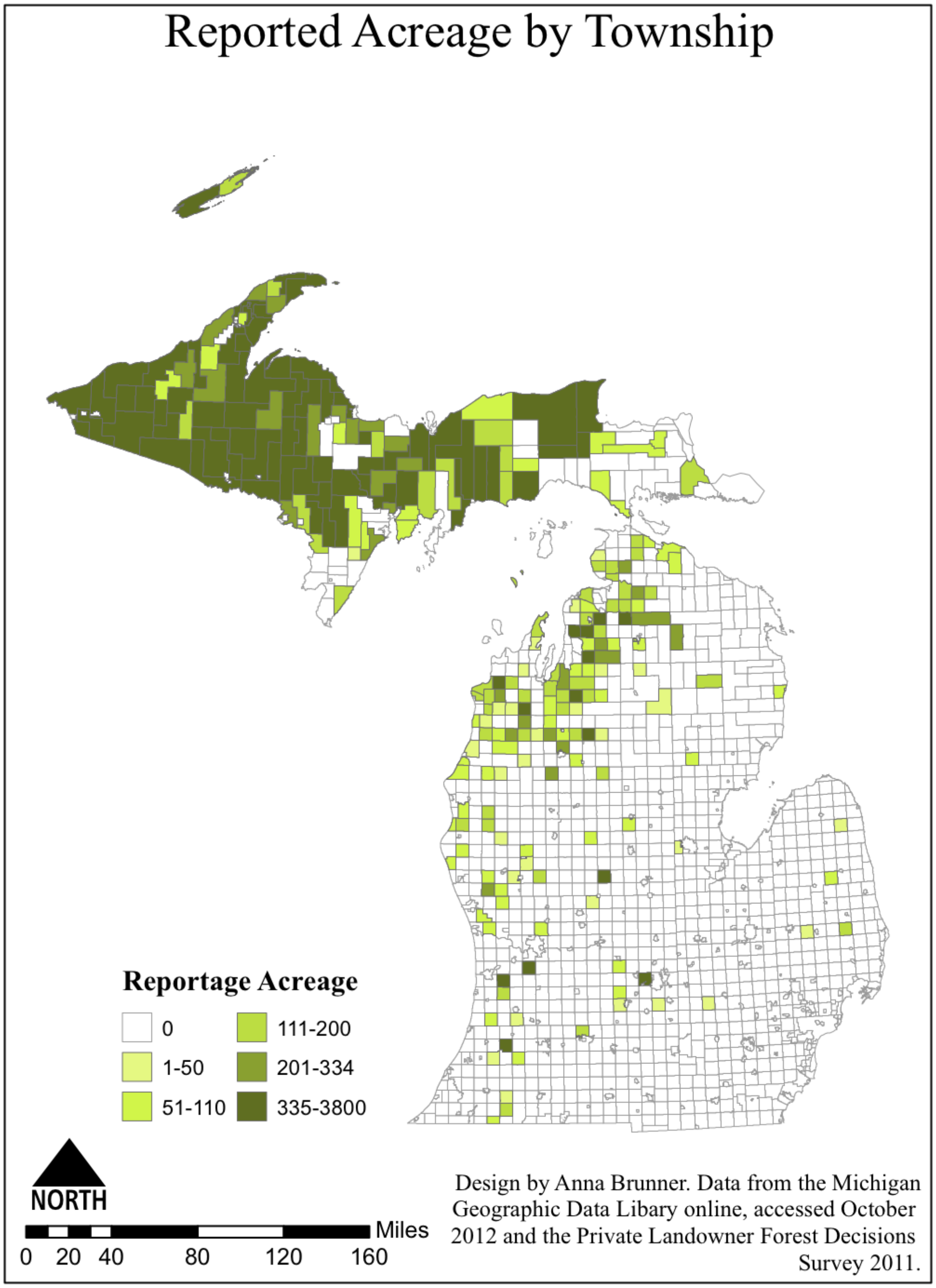
Table 1. The response rate for each question in the survey (Appendix A). The column "No Response" combines the number of people who did not mark any answer for a given question with those who marked the box "I prefer not to respond."

Question	Number of Responses	Response Rate	No Response
1	489	97%	24
2	492	97%	19
3	493	98%	16
4	496	98%	13
5	494	98%	14
6	463	92%	49
7	458	91%	61
8	451	89%	61
9	451	89%	65
10	480	95%	32
11	459	91%	57
12	447	89%	65
13	445	88%	68



Design by Anna Brunner. Data from the Michigan Geographic Date Library online, accessed October, 2012 and the Private Landowner Forest Decisions Survey 2011.

Figure 3. The number of survey respondents broken down by township. The Upper Peninsula was significantly more represented than the Lower Peninsula of Michigan.


Reported Acreage by Township

Design by Anna Brunner. Data from the Michigan Geographic Data Libary online, accessed October 2012 and the Private Landowner Forest Decisions Survey 2011.

Figure 4. The total acreage owned by survey respondents at the township level. The coverage follows a pattern similar to the one seen in Figure 3, with a few exceptions.

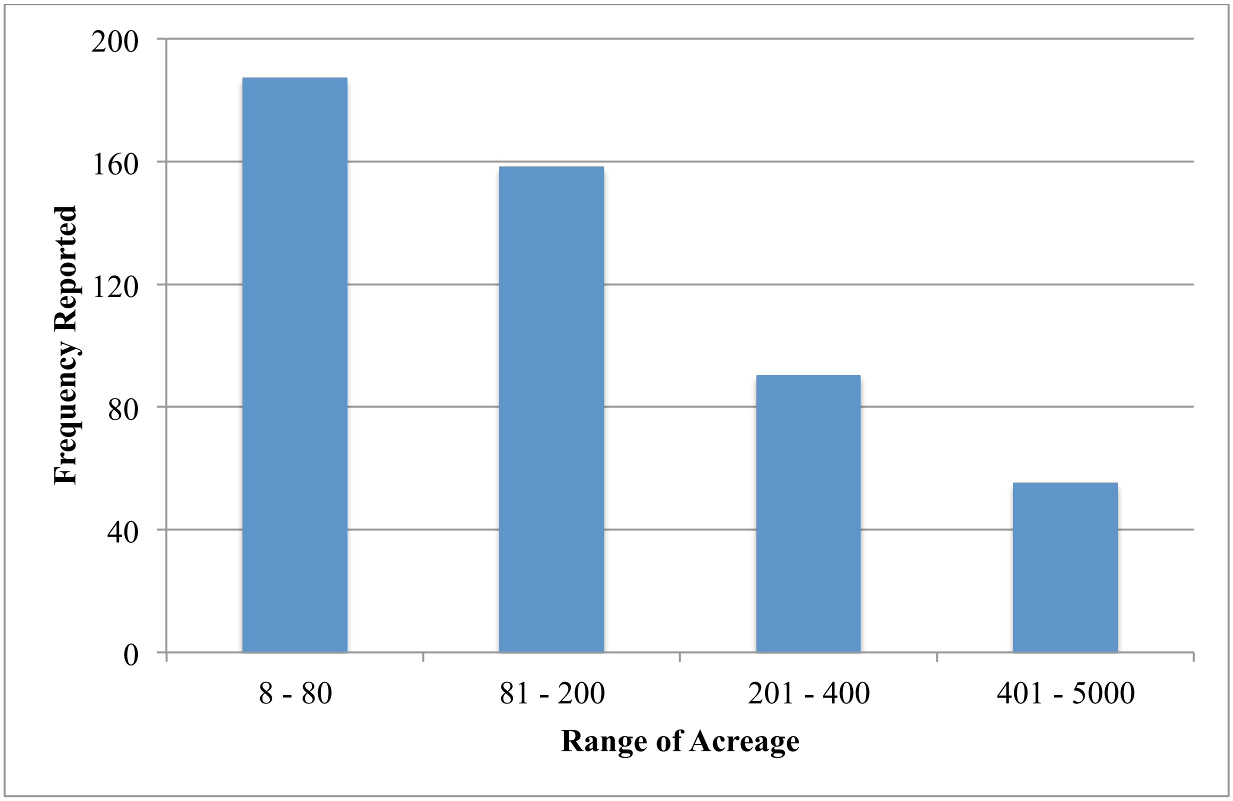


Figure 5. The frequency of reported acreage from survey question two (Appendix A): "How much forested land do you own?" The median ownership was 120 acres and the mode was 40 acres.

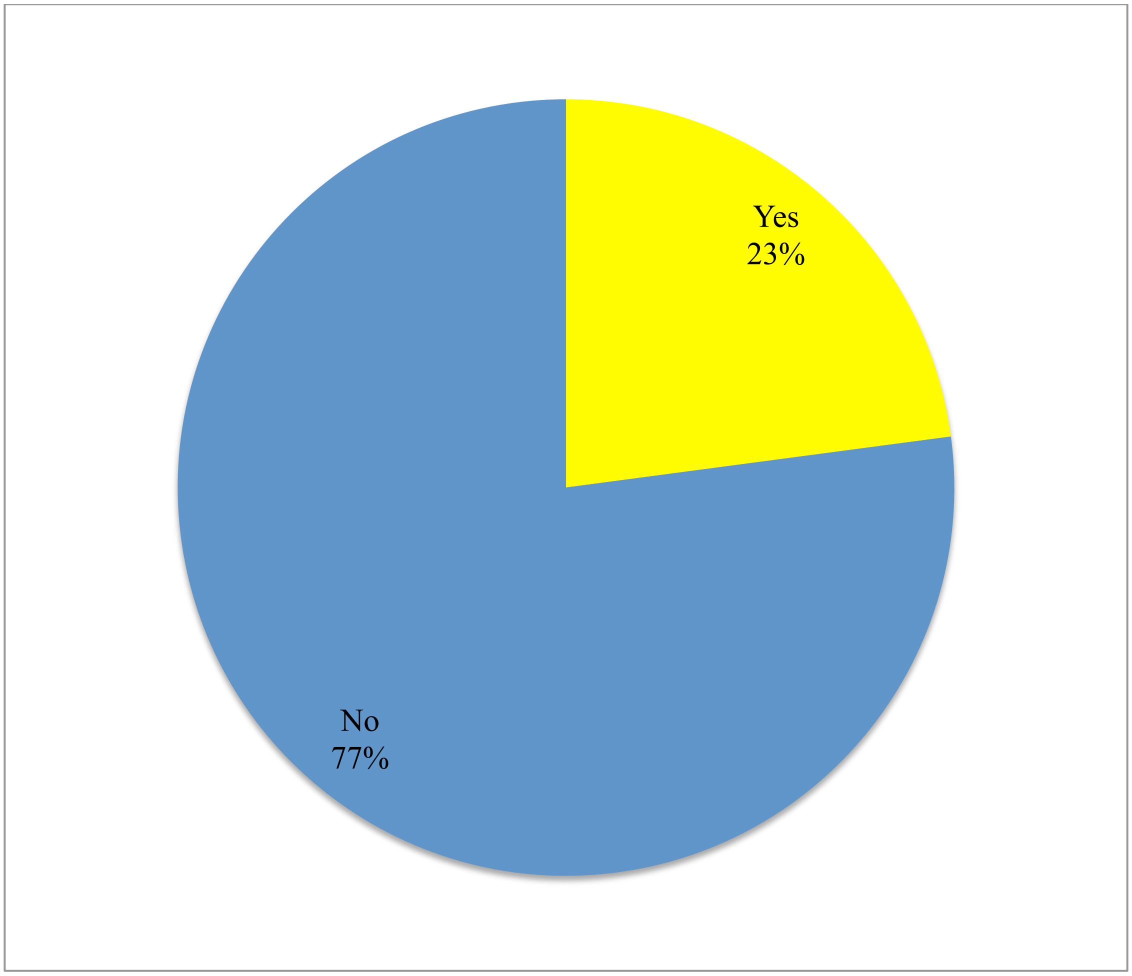


Figure 6. The breakdown of responses to survey question three (Appendix A): "Did you inherit your forested land?" Most individuals had not inherited their forested land. People who answered both "yes" and "no" were placed into the "yes" category, to indicate that some of their land had been inherited.

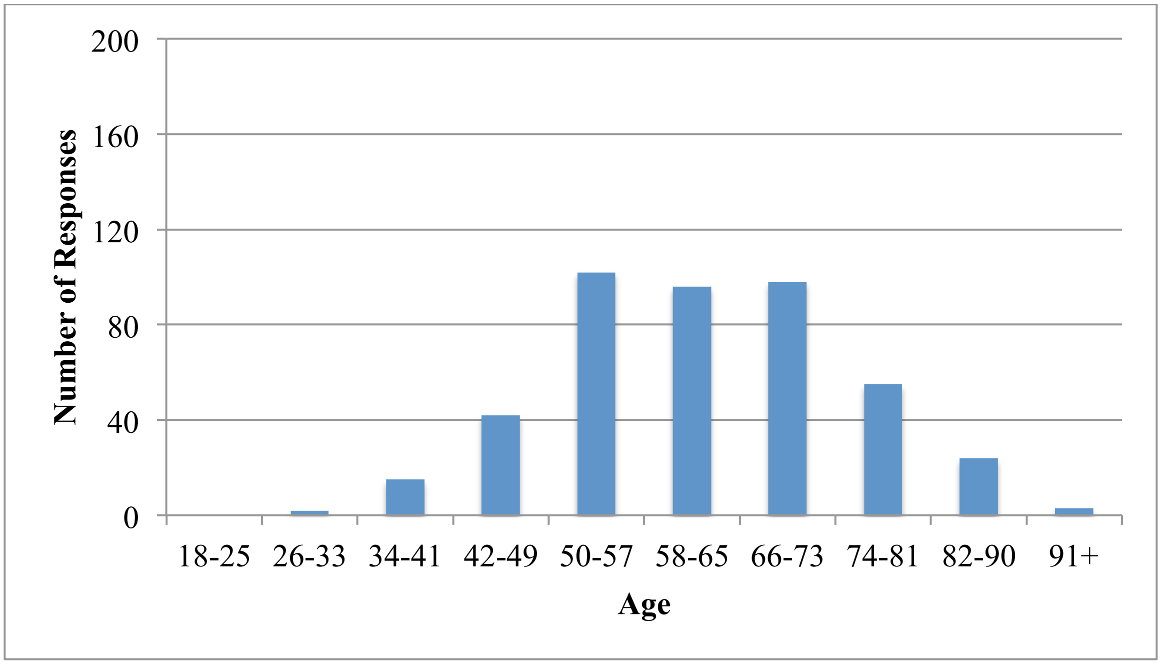


Figure 7. The breakdown of the age categories of the survey respondents. There were few individuals younger than 40 or older than 90.

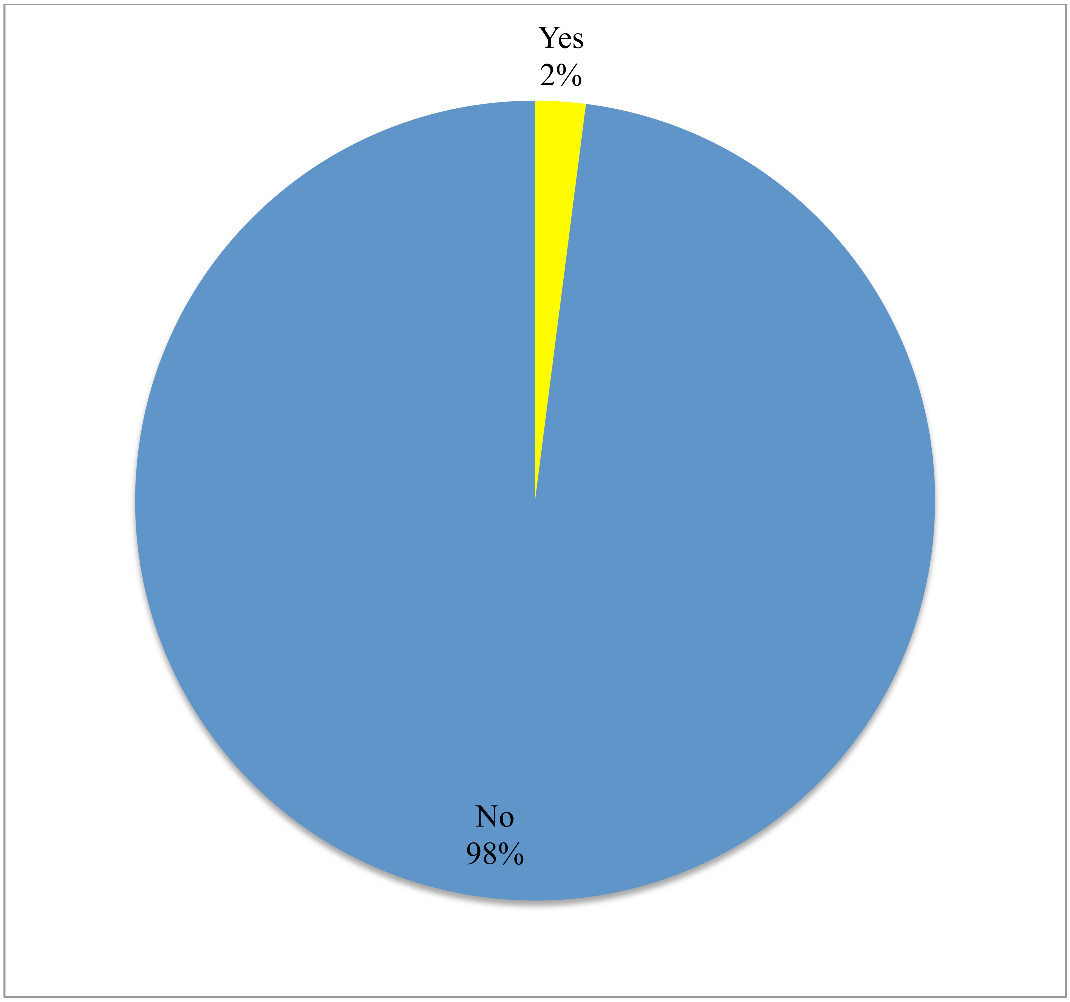


Figure 8. The breakdown of responses to survey question four (Appendix A): “Would you consider any income you generate from your forested land to be your main source of income?” Most respondents, overwhelmingly, did not rely on their forested land to financially support them.

Table 2. The response rate for each option available to survey question five (Appendix A): “What activities do you, or others, use your forested land for? (please check all the apply)” Most respondents used the land for “hunting/fishing/trapping” and the least frequently-reported activity was a tie between not using the forest and using it to produce woody biomass for ethanol.

Response Option	Number of Responses	Response Rate
Hunting/fishing/trapping	405	82%
Alternative fuel (ethanol) harvest	19	4%
Camping/hiking/birding	255	52%
Just being around nature	338	68%
Timber or firewood harvest	339	69%
Driving All Terrain Vehicle (ATV)	193	39%
Conservation purposes, such as wildlife habitat	344	70%
Other:	38	8%
I do not use the forested land	19	4%

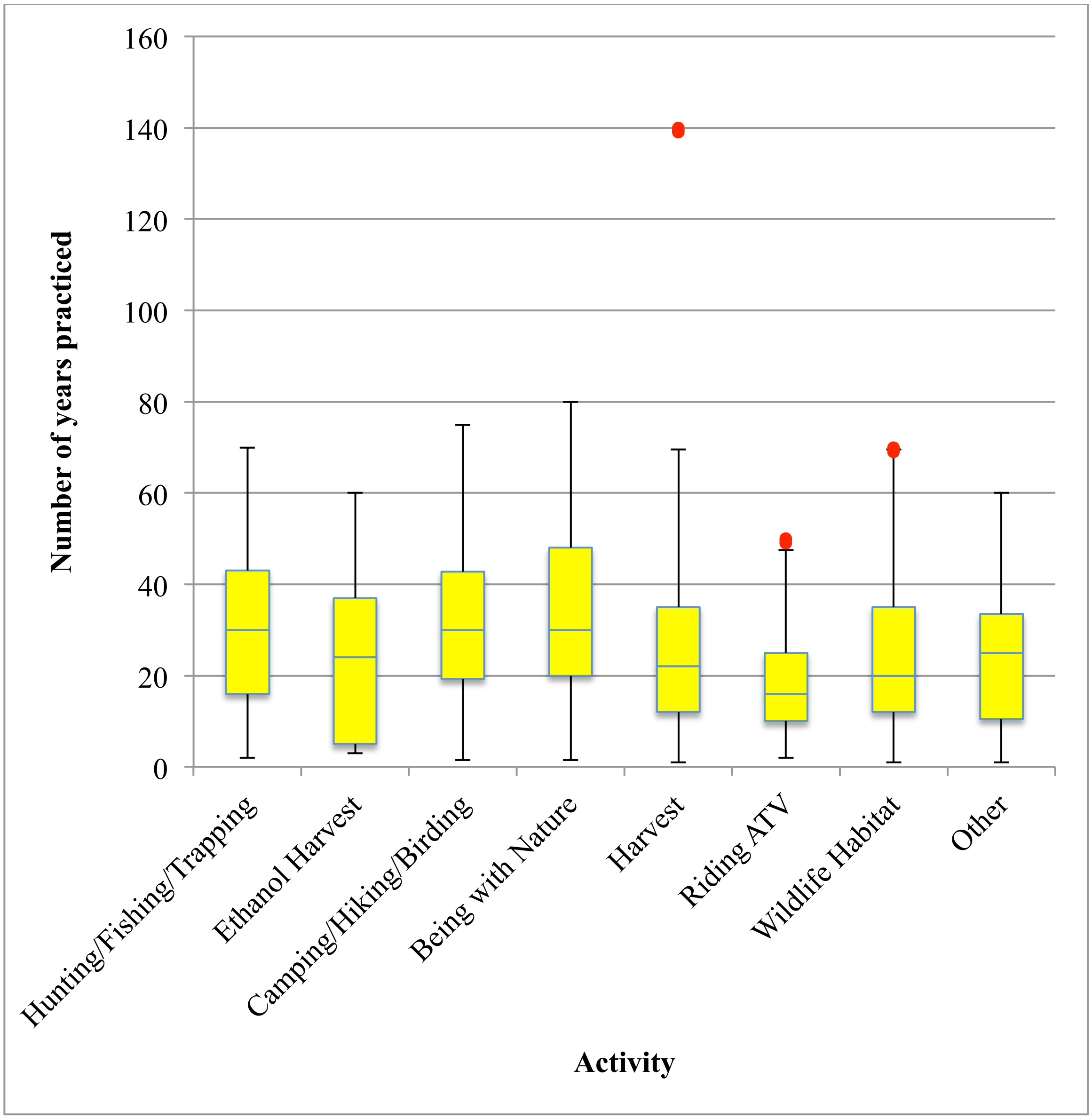


Figure 9. The spread of years over which an activity was reported as practiced (survey question six, Appendix A). The boxes mark the spread between the 25th percentile and the 75th percentile of the data, while the band through the middle marks the median. The whiskers mark the minima and maxima of the data, provided they fell within the interquartile range. The red dots indicate outliers in the data.

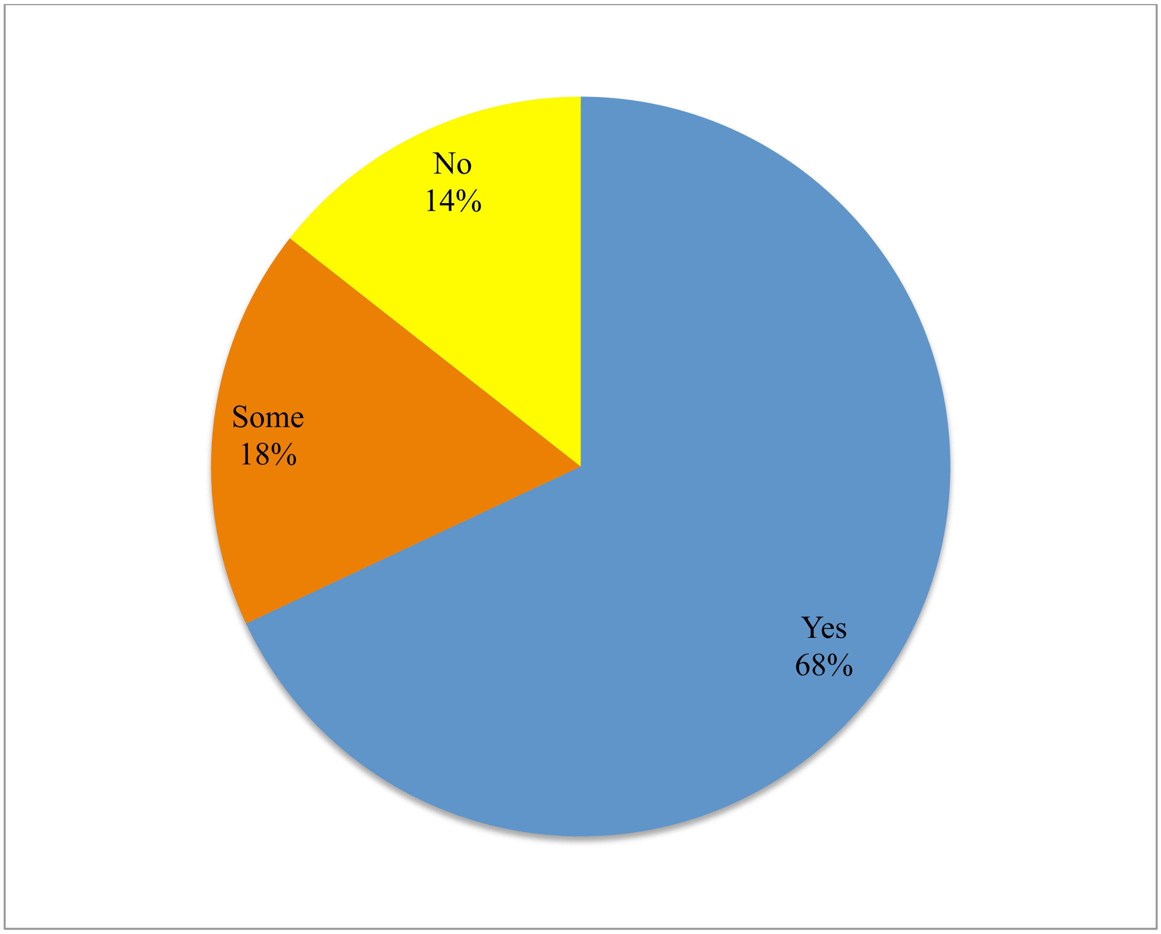


Figure 10. The breakdown of responses to survey question seven (Appendix A): "Are there nearby areas where you are also able to pursue the activities from question 5?" Most respondents would be able to pursue their activities elsewhere if they could no longer continue them on their land.

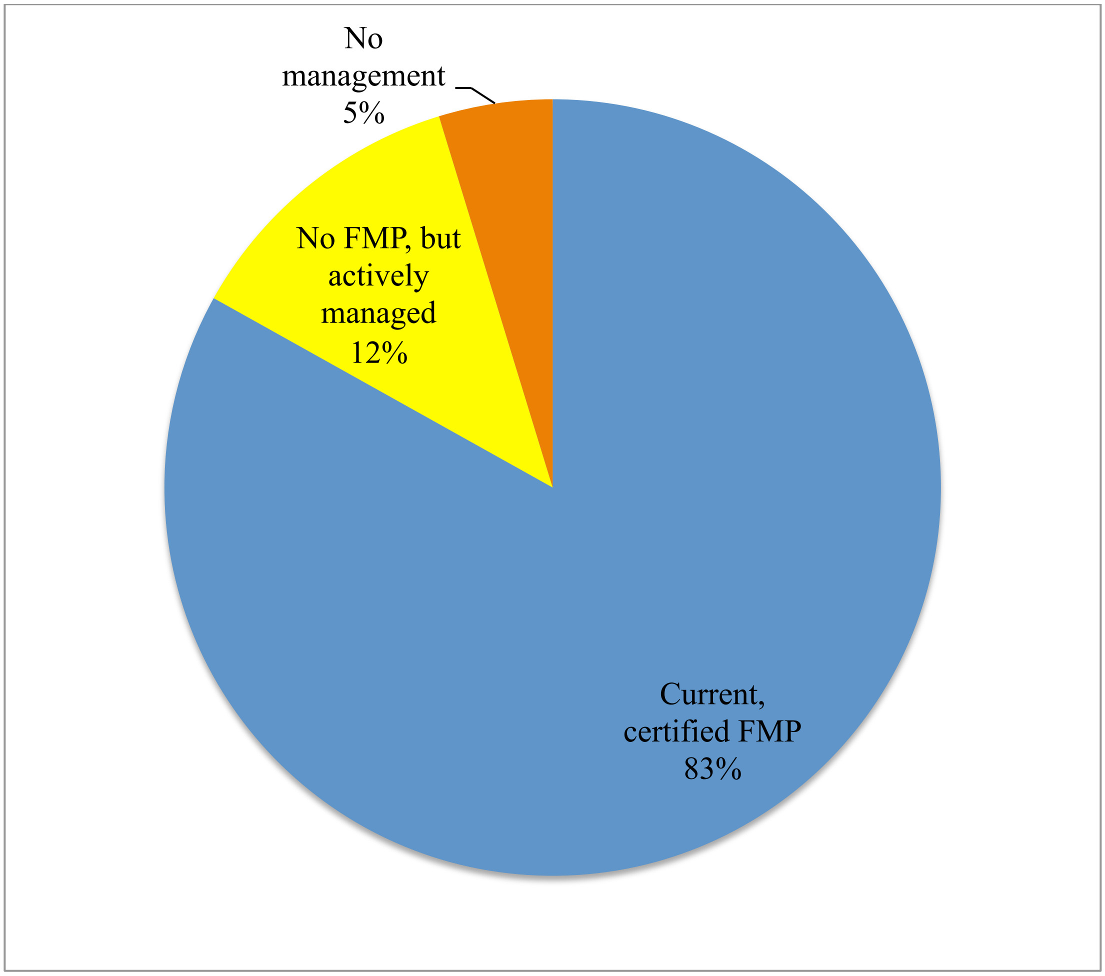


Figure 11. The breakdown of responses to survey question eight (Appendix A): “Which statement best describes your forest management planning?” Most respondents had a current forest management plan, or FMP, that they followed.

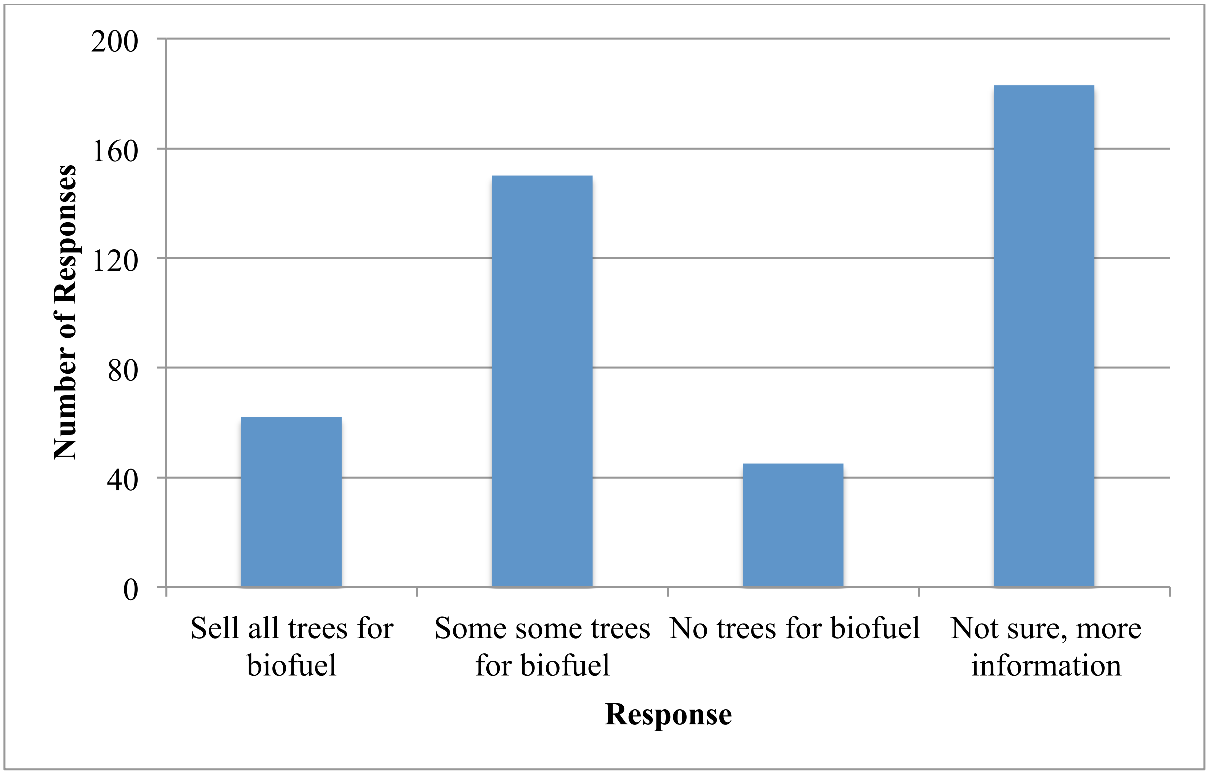


Figure 12. The number and content of responses to survey question nine (Appendix A): “Recently the Energy Independence and Security Act became federal law, which states that 'In 2010, 12.95 billion gallons of renewable fuel must be used, increasing to 36 billion gallons by 2022.' One such renewable source comes from trees through a harvesting process similar to timber, but with a different end use—as cellulosic ethanol, a replacement for gasoline. If you were compensated at the market rate for timber, would you:” Most respondents wanted more information about ethanol before they made their decision.

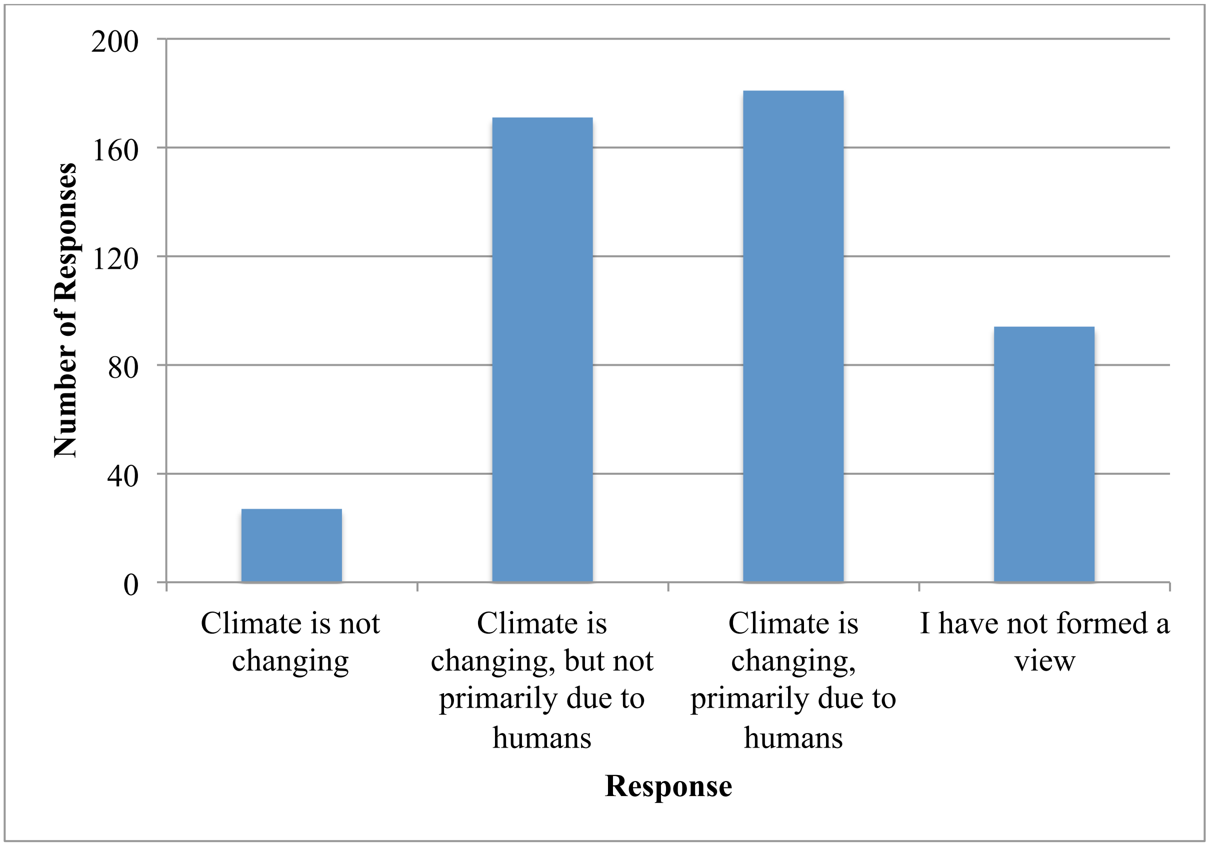


Figure 13. The breakdown of responses to survey question ten (Appendix A): “We are interested in understanding how forest land owners view the issue of global climate change given what Intergovernmental Panel on Climate Change (IPCC) has to say: 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level' and 'There is very high confidence that the net effect of human activities since 1750 has been one of warming.' Which option best describes your views on this subject?” There was a near tie between respondents who believed the climate was changing, but that humans were not the primary cause and respondents who believed the climate was changing and that humans were the primary cause.

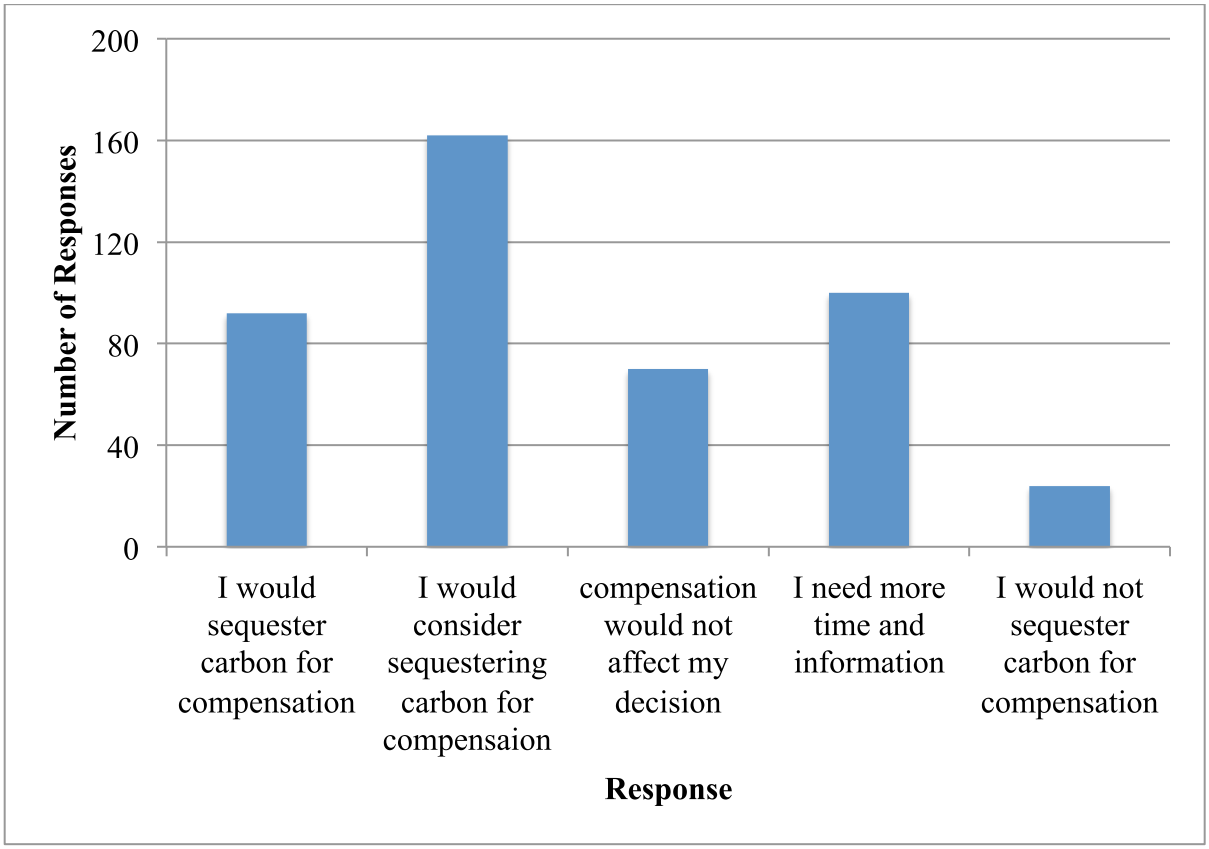


Figure 14. The breakdown of responses to survey question eleven (Appendix A): "The IPCC suggests one way to reduce negative impacts of global climate change is through a process called carbon sequestration, something that forests do naturally as they grow. Since this carbon storage is seen as a benefit by some, consideration is being given to paying land owners for maintaining their forest stand for the carbon it can store as it grows. What are your views regarding payments for carbon sequestration?" Only a minority of respondents would not consider carbon sequestration.

Table 3. The breakdown of responses given to survey question twelve (Appendix A): "What factors would you take into account if you were deciding between harvesting trees from your forest for alternative fuel (question 9) or managing your forest to sequester carbon (question 11), or deciding to not do either? (please check all that apply" Most respondents seemed to consider price, which choice would be a worthwhile goal, and how the land was currently used.

Response Options	Number of Responses	Response Rate
I would only focus on price; I would pick whichever option gave me the greatest compensation	34	8%
I would consider price, but it would not be the only basis for my decision	167	37%
I would consider which option seemed like a more worthwhile goal to myself and others	178	40%
I would consider my beliefs regarding the role of carbon sequestration and alternative fuels	96	21%
I would consider how I currently use the land, whether for recreation, conservation, or other uses	166	37%
I am not sure or I would need to gain additional information	93	21%

Table 4. The standardized residuals for the chi-squared contingency test comparing survey questions nine and ten with survey question eleven (Appendix A). Rows 1, 2, and 3 and columns a, b, and c compare responses to questions nine and eleven, while rows 4, 5, and 6 and columns a, b, and c compare responses to questions ten and eleven. Values above 1.0 are an indicator of significance, while the sign on the number is an indicator of the direction of the relationship.

				Q. 11	
			Yes, sequester C for $	**$ is not an influence**	**No C sequester for $**
			a	b	c
Q. 9	**All harvest for ethanol**	1	2.68	-2.38	-0.63
	Some harvest for ethanol	2	-0.14	0.88	-1.11
	No harvest for ethanol	3	-2.41	1.27	1.89
Q. 10	**Climate is not changing**	4	-2.48	-0.05	3.87
	Changing, not due to humans	5	-3.49	2.34	1.90
	Changing, due to humans	6	5.02	-2.29	-4.31

NET CARBON CALCULATIONS

EB – Net carbon mitigation through energy balance analysis.

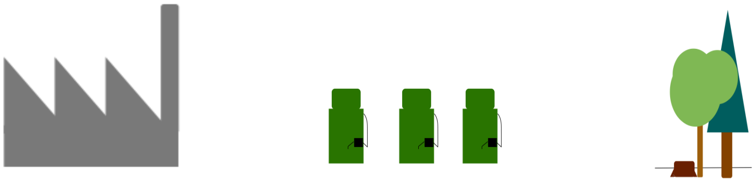
Equation (19) $T = \left(c_g \cdot \upsilon \cdot \tau\right) - \left[\upsilon \cdot \tau \cdot \left(c_h + c_d + c_l + c_i + c_e\right)\right]$ divided by scenario area

Ethanol Production (-)
$[\upsilon \cdot \tau \cdot (c_h + c_d + c_l + c_i + c_e)]$

Gas offset (+)
$(c_g \cdot \upsilon \cdot \tau)$

EB + LU – Net carbon mitigation through energy balance analysis and forestland use.

Equation (20) $T_b = \left[F + \left(c_g \cdot \upsilon \cdot \tau\right)\right] - \left[\upsilon \cdot \tau \cdot \left(c_h + c_d + c_l + c_i + c_e\right)\right]$ divided by scenario area



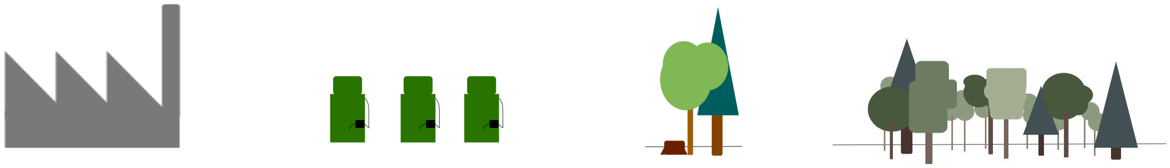
Ethanol Production (-)
$[\upsilon \cdot \tau \cdot (c_h + c_d + c_l + c_i + c_e)]$

Gas offset (+)
$(c_g \cdot \upsilon \cdot \tau)$

Forest (+)
F

CMOC – Carbon mitigation opportunity cost of using the land to produce cellulosic ethanol.

Equation (21) $T_o = T_b - \left(A_\varphi \cdot f\right)$ divided by scenario area



Ethanol Production (-)
$[\upsilon \cdot \tau \cdot (c_h + c_d + c_l + c_i + c_e)]$

Gas Offset (+)
$(c_g \cdot \upsilon \cdot \tau)$

Forest (+)
F

100% Forest (+)
$(A_\varphi \cdot f)$

Figure 15. The different net carbon calculations, Energy Balance (EB), Energy Balance and Land Use (EB+LU), and Carbon Mitigation Opportunity Cost (CMOC), are summarized, their differences displayed, and their corresponding equations identified. EB was a pure energy balance calculation, EB+LU included the effects of the nonindustrial private forest, or NIPF, owners that kept their forest growing and did not harvest for ethanol (Forest, or *F*). CMOC determined the net carbon if all the NIPF owners used their land to grow forest (100% Forest, or $(A_\varphi \cdot f)$), and then subtracted this land potential from the EB+LU version of cellulosic ethanol net carbon. The negative and positive signs next to each symbol indicate whether that system alone had a negative or positive effect on net carbon.

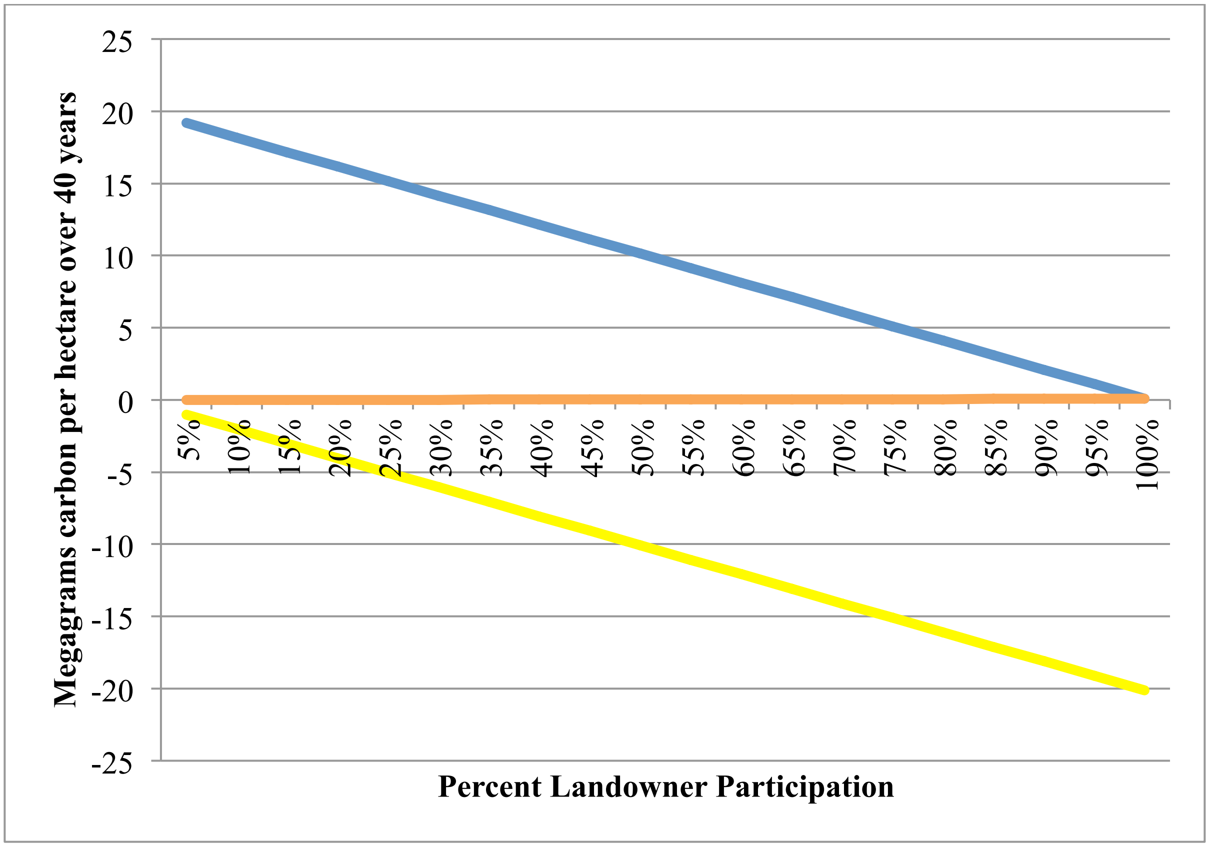


Figure 16. The net carbon accounting trends for the biorefinery under different rates of nonindustrial private forest, or NIPF owner participation in sales of biomass to the biorefinery. There were three net carbon accounting methods, Energy Balance (EB), Energy Balance and Land Use (EB+LU), and Carbon Mitigation Opportunity Cost (CMOC) (as in Fig. 15). Here, the orange line shows the result of the EB accounting method, a small positive value of net carbon independent of NIPF owner participation. The blue line shows the result of the EB+LU accounting method, where the net carbon decreases as NIPF participation increases, and the yellow line shows the CMOC result, where the net carbon result is greatest where NIPF participation rate is lowest. A negative value for net carbon (as in the CMOC results) indicates more carbon emissions were produced under that scenario than under a scenario in which the cellulosic ethanol refinery were not built and used.

Table 5. The rate of nonindustrial private forest, or NIPF, owner participation in selling their tree biomass to be used for cellulosic ethanol production is compared with the scenario area radius. This radius increased as the participation rate decreased due to an assumption in the model that the biorefinery would always be supplied with enough biomass to run at maximum capacity. The radius is the distance from the biorefinery to the edge of the circle in which available biomass was harvested. The bold text under participation rate, 47%, indicates the rate that surveyed NIPF indicated they would participate in selling their biomass to a biorefinery, while the bold text under scenario area radius, 154.06 km, corresponds to the maximum radial distance from a biorefinery where it is still economically feasible to harvest wood (Committee on Economic and Environmental Impacts of Increasing Biofuels Production, 2011.)

Landowner Participation [%]	Scenario Area Radius [km]
100%	84.38
95%	86.57
90%	88.94
85%	91.52
80%	94.34
75%	97.43
70%	100.85
65%	104.66
60%	108.93
55%	113.78
50%	119.33
47%	123.08
45%	125.79
40%	133.42
35%	142.63
30%	**154.06**
25%	168.76
20%	188.68
15%	217.87
10%	266.83
5%	377.36

Table 6. The carbon emissions and offsets used to calculate the energy balance of the biorefinery and the land use of the nonindustrial private forest, or NIPF, owners that do not participate in harvesting their trees for the biorefinery are shown in this table. The assumption that the biorefinery would always operate at maximum capacity caused the scenario area to increase in response to a drop in NIPF participation. In turn, this drop caused the amount of non-participating land to increase ("growing trees") and more carbon was sequestered. The category "100% Forest" indicates the rate of carbon sequestration that would occur if the entire area of NIPF lands were forested. The bold numbers indicate the levels that were closest to the actual NIPF owner participation rate, 47%, as determined by the Private Landowner Forest Decisions Survey 2011.

	Negative Net Carbon [MgC/ha over 40 years]					**Positive Net Carbon [MgC/ha, 40 y]**		
Participation	Harvesting	Driving	Loading	Chipping	Refining	Replacing Gasoline	Unharvested Trees	100% Forest
100%	0.130	0.027	0.003	0.120	1.327	1.688	0.000	20.202
95%	0.123	0.027	0.003	0.114	1.261	1.604	1.010	20.202
90%	0.117	0.026	0.002	0.108	1.194	1.520	2.020	20.202
85%	0.110	0.025	0.002	0.102	1.128	1.435	3.030	20.202
80%	0.104	0.025	0.002	0.096	1.062	1.351	4.040	20.202
75%	0.097	0.024	0.002	0.090	0.995	1.266	5.050	20.202
70%	0.091	0.023	0.002	0.084	0.929	1.182	6.061	20.202
65%	0.084	0.022	0.002	0.078	0.863	1.097	7.071	20.202
60%	0.078	0.021	0.002	0.072	0.796	1.013	8.081	20.202
55%	0.071	0.020	0.001	0.066	0.730	0.929	9.091	20.202
50%	0.065	0.019	0.001	0.060	0.664	0.844	10.101	20.202
47%	**0.061**	**0.019**	**0.001**	**0.056**	**0.624**	**0.794**	**10.707**	20.202
45%	0.058	0.018	0.001	0.054	0.597	0.760	11.111	20.202
40%	0.052	0.017	0.001	0.048	0.531	0.675	12.121	20.202
35%	0.045	0.016	0.001	0.042	0.465	0.591	13.131	20.202
30%	0.039	0.015	0.001	0.036	0.398	0.507	14.141	20.202
25%	0.032	0.014	0.001	0.030	0.332	0.422	15.151	20.202
20%	0.026	0.012	0.001	0.024	0.265	0.338	16.161	20.202
15%	0.019	0.011	0.000	0.018	0.199	0.253	17.171	20.202
10%	0.013	0.009	0.000	0.012	0.133	0.169	18.182	20.202
5%	0.006	0.006	0.000	0.006	0.066	0.084	19.192	20.202

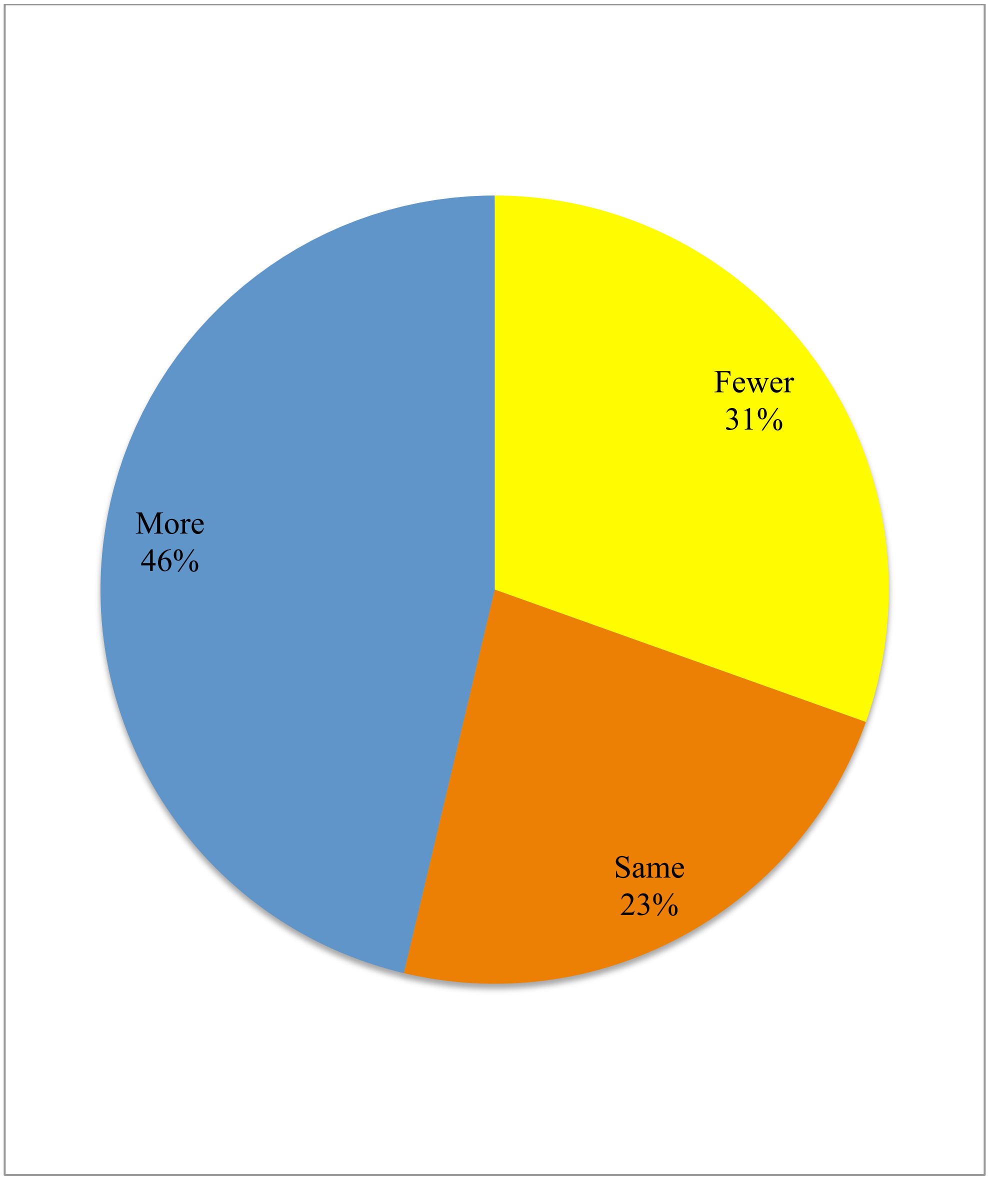


Figure 17. The breakdown of respondents who reported having the same, more, or fewer acres than the amount listed as enrolled in Michigan's Commercial Forest Program. Survey respondents were contacted using the public database of this program's enrolled land. Most respondents own forested land that was not enrolled in the program.

REFERENCES

Aden A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, and J. Lukas. 2002. "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover." A report prepared for the National Renewable Energy Laboratory, U.S. Department of Energy. Golden, Colorado: National Renewable Energy Laboratory.

Agriculture, Forestry, and Waste Management Technical Work Group. 2008. "Draft Priorities for Analysis—2015 and 2025." A report prepared for the Michigan Climate Action Council. Lansing, Michigan: Department of Environmental Quality.

Akbari, H., D.M. Kurn, S.E. Bretz, and J.W. Hanford 1997. "Peak Power and cooling energy savings of shade trees." *Energy and Buildings* 25: 139-148.

Akbari, H. 2002. "Shade trees reducing building energy use and CO_2 emissions from power plants." *Environmental Pollution* 116: S119-S126.

Bermann, Ariel, Sergio Colombo, and Nick Hanley. 2008. "Rural versus urban preferences for renewable energy developments." *Ecological Economics,* 65: 616 – 625.

Boundy, Bob, Stacy C. Davis, Lynn Wright, Philip C. Badger, and Bob Perlack. 2010. "Biomass Energy Data Book: Edition 3." A report prepared for the Office of the Biomass Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Bowyer, Jim, Jeff Howe, Phil Guillery, and Kathryn Fernholz. 2005. "Bio-Energy: Momentum is Building for Large Scale Development." A report prepared for Dovetail Partners, Inc. White Bear Lake, MN: Dovetail Partners, Inc.

Brey, Raul, Pere Riera, and Joan Mogas. 2007. "Estimation of forest values using choice modeling: An application to Spanish forests." *Ecological Economics*, 64: 305 – 312.

Butler, Brett J., Patrick D. Miles, and Mark H. Hansen. 2012. National Woodland Owner Survey Tabler web-application version 1.0. Amherst, MA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [Available only on Internet: http://fiatools.fs.fed.us/NWOS/tablemaker.jsp] Accessed 09/18/2012.

Campbell, J. Elliott, David B. Lobell, Robert C. Genova, and Christopher B. Field. 2008. "The Global Potential of Bioenergy on Abandoned Agriculture Lands." *Environmental Science and Technology*, 42: 5791 – 5794.

Caspersen, John P., Stephen W. Pacala, Jennifer C. Jenkins, George C. Hurtt, Paul R. Moorcroft, and Richard A. Birdsey. 2000. "Contributions of Land-Use History to Carbon Accumulation in U.S. Forests." *Science*, 290:1148 – 1151.

Centrec Consulting Group, LLC. 2006. “Preparing for the Future of Michigan's Bioeconomy: Recommendations for the Office of Biobased Technologies.” A report prepared for the Office of Biobased Technologies at Michigan State University. East Lansing, Michigan.

Committee on Economic and Environmental Impacts of Increasing Biofuels Production. 2011. “Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy.” A report prepared for the National Research Council of the National Academies. Washington, D.C.: The National Academies Press.

Davis, Sarah C., Kristina J. Anderson-Teixeira, and Evan H. DeLucia. 2008. “Life-cycle Analysis and the Ecology of Biofuels.” *Trends in Plant Science,* 14:140 – 146.

De La Torre Ugarte, Daniel G., Marie E. Walsh, Hosein Shapouri, and Stephen P. Slinsky. 2000. “The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture.” A report prepared for University of Tennessee Agricultural Policy Analysis Center (APAC), and Department of Energy Oak Ridge National Laboratory, and United States Department of Agriculture Office of Energy Policy and New Uses. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Dietz, Thomas, Paul C. Stern, and Amy Dan. 2009. “How Deliberation Affects Stated Willingness to Pay for Mitigation of Carbon Dioxide Emissions: An Experiment.” *Land Economics*. 85: 329-347.

EBAMM 1.1 “ERG Biofuel Analysis Meta-Model.” Accessed 04/22/12 http://rael.berkeley.edu/sites/default/files/EBAMM/

Egbendewe-Mondzozo, Aklesso, Scott M. Swinton, R. Cesar Izaurralde, David H. Manowitz, and Xuesong Zhang. 2010. “Biomass Supply from Alternative Cellulosic Crops and Crop Residues: A Preliminary Spatial Bioeconomic Modeling Approach.” A report prepared for Michigan State University Department of Agricultural, Food, and Resource Economics. East Lansing, Michigan: Michigan State University.

Environmental Protection Agency. Energy Independence and Security Act of 2007 www.epa.gov/otaq/fuels/renewablefuels/index.htm and http://www.epa.gov/otaq/fuels/renewablefuels/compliancehelp/rfs2-lca-pathways.htm accessed November 2012.

Executive Committee of IEA Bioenergy. 2002. “Sustainable Production of Woody Biomass for Energy: A Position Paper Prepared by IEA Bioenergy.” A report prepared for IEA Bioenergy.

Fahey, T.J., Peter B. Woodbury, John J. Battles, Christine L. Goodale, Steven P. Hamburg, Scott V. Ollinger, and Christopher W. Woodall. 2010. “Forest Carbon Storage: Ecology, Management, and Policy.” *Frontiers in Ecology and the Environment*, 8: 245 – 252.

Farigone, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. 2008. “Land

Clearing and the Biofuel Carbon Debt." *Science*, 319:1235 – 1238.

Farrell, Alexander E., Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O'Hare, and Daniel M. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science*. 311: 506-508.

Forest Inventory Analysis website. "Forest Inventory Data Online." Accessed April 2012 http://apps.fs.fed.us/fido/

Froese, Robert E. and Chris A. Miller. 2008. "Biomass Co-Firing for the Wolverine Clean Energy Venture: An Assessment of Potential Supply, Environmental Limitations, and Co-Benefits through Carbon Sequestration." A report prepared for the School of Forest Resources and Environmental Science. Houghton, Michigan: Michigan Technological University.

Fulton, Lew, Tom Howes, and Jeffrey Hardy. 2004. "Biofuels for Transport: and International Perspective." A report prepared for the International Energy Agency.

Gan, Jianbang, and C.T. Smith. 2006. "Availability of logging residues and potential for electricity production and carbon displacement in the USA." *Biomass and Bioenergy*, 30:1011 – 1020.

Garcia de la Fuente, Laura, Arturo Colina, Ana Colubi, and Gil Gonzalez-Rodriguez. 2010. "Valuation of Environmental Resources: The Case of the Brown Bear in the North of Spain." *Environmental Model Assessment*, 15: 81 – 91.

Gonzáles-García, Sara, Almudena Hospido, Roland Agnemo, Patrik Svensson, Eva Selling, Ma Teresa Moreira, and Gumersindo Feijoo. 2011. "Environmental Life Cycle Assessment of a Swedish Dissolving Pulp Mill Integrated Biorefinery." *Journal of Industrial Ecology* 15: 568-583.

Gonzáles-García, Sara, Carles Gasol, Maria Moreira, Xavier Gabarrell, Joan Rieradevall i Pons, and Gumersindoet Feijoo. 2011b. "Environmental assessment of black locust (*Robinia pseudoacacia* L.)-based ethanol as potential transport fuel." *The International Journal of Life Cycle Assessment* 16: 465-477.

Gonzáles-García, Sara, Gumersindo Feijoo, Petri Widsten, Andreas Kandelbauer, Edith Zikulnig-Rusch, and Ma Teresa Moreira. 2009. "Environmental performance assessment of hardboard manufacture." *The International Journal of Life Cycle Assessment*. 14: 456-466.

Gonzáles-García, Sara, Staffan Berg, Gumersindo Feijoo, and Ma Teresa Moreira. 2009b. "Environmental impacts of forest production and supply of pulpwood: Spanish and Swedish case studies." *The International Journal of Life Cycle Assessment*. 14: 340-353.

Google Earth version 6.1. http://www.google.com/earth/index.html

Groves, Robert M. 1990. "Theories and Methods of Telephone Surveys." *Annual Review of Sociology*. 16: 221-240.

Hammerschlag, Roel. 2006. “Ethanol's Energy Return on Investment: A Survey of the Literature 1990 – Present.” *Environmental Science and Technology*, 40:1744 – 1750.

Hattori, Taiichiro, and Shigenori Morita. 2010. “Energy Crops for Sustainable Bioethanol Productions; Which, Where and How?” *Plant Productivity Science*, 13:221 – 234.

Hanley, Nick, Robert Wright, and Vic Adamowicz.1998. “Using Choice Experiments to Value the Environment.” *Environmental and Resource Economics*. 11: 413-428.

Haug, M. and C. Difiglio, project leaders, T. Malyshev, M. Custodio, C. Hayworth, B. Sadin, and V. Consoli, editors. 2004. “Biofuels for Transport: An International Perspective.” A report prepared for the International Energy Agency Office of Energy Efficiency, Technology, and Research and Development.

Haugen, David E. and Anthony Weatherspoon. 2002. “Michigan Timber Industry - An Assessment of Timber Product Output and Use, 1998.” A report prepared for the United States Department of Agriculture Forest Service. Saint Paul, Minnesota: North Central Research Station, Forest Service.

Hill, Jason, Erik Nelson, David Tilman, Stephen Polasky, and Douglas Tiffany. 2006. “Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels.” *Proceedings of the Natural Academy of Sciences* 103:11206-11210.

Hite, Diane. 2009. “Factors Influencing Differences between Survey and Market-based Environmental Value Measures.” *Urban Studies*, 46:117 – 138.

Houston, Michael J. and John R. Nevin. 1977. “The Effects of Source and Appeal on Mail Survey Response Patterns.” *Journal of Marketing Research*. 14: 474-378.

Hubbard, W., L. Biles, C. Mayfield, and S. Ashton, Eds. 2007. “Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook.” A report prepared for Southern Forest Research Partnership, Inc. Athens, Georgia: Southern Forest Research Partnership, Inc.

Humbird, D., R. Davis, L. Tao, C. Kinchin, P. Schoen, J. Lukas, B. Olthof, M. Worley, D. Sexton, and D. Dudgeon. 2011. “Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover.” A report prepared for National Renewable Energy Laboratory. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Jenerette, G.D., S.L. Harlan, A. Brazel,N. Jones, L. Larsen, and W.L. Stefanov. 2007. “Regional relationships between surface temperature, vegetation, and human settlement in a rapidly urbanizing ecosystem.” *Landscape Ecology* 22: 353-365.

Jeon, Yongsik, and Joseph Herriges. 2010. “Convergent Validity of Contingent Behavior Responses in Models of Recreation Demand." *Environmental and Resource Economics*, 45:223-250.

Kalogo, Youssouf, Shiva Habibi, Heather L. MacLean, and Satish V. Joshi. 2007. "Environmental Implications of Municipal Solid Waste-Derived Ethanol." *Environmental Science and Technology*. 41: 35-41.

Kilgore, Michael A., Stephanie A. Snyder, Joseph Schertz, and Steven J. Taff. 2008. "What does it take to get family forest owners to enroll in a forest stewardship-type program?" *Forest Policy and Economics*, 10:507 – 514.

Kroetz Kailin M., and Andrew J. Friedland. 2008. "Comparing costs and emissions of northern New England space heating fuel options." *Biomass and Bioenergy*, 32:1359 – 1366.

Krutilla, K. and R. Reuveny. 2006. "The systems dynamics of endogenous population growth in a renewable resource-based growth model." *Ecological Economics* 56: 256-267.

Lazarus, Richard J. 2010. "Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future." *Environmental Law and Policy Annual Review*, 40: 10749-10756.

LeVert, Michael, Thomas Stevens, and Dave Kittredge. 2009. "Willingness-to-sell conservation easements: A case study." *Journal of Forest Economics*, 15:261 – 275.

Levin, K., B. Cashore, Steven Bernstein, and G. Auld. 2009. "Playing it forward: path dependency, progressive incrementalism, and the "Super Wicked" problem of global climate change." *IOP Conference Series: Earth and Environmental Science* 6: 1-2.

Lindauer-Thompson, A. (2008). "Incorporating Carbon Storage into Forest Management in Michigan: A Modeling Based Scenario Analysis." Master's Thesis, School of Natural Resources and Environment, University of Michigan. Ann Arbor, Michigan

Lindhjem, Henrik, and Stale Navrud. 2009. "Asking for Individual or Household Willingness to Pay for Environmental Goods?" *Environmental and Resource Economics*, 43:11-29.

Loibl W., and T. Toetzer. 2003. "Modeling growth and densification processes in suburban regions—simulation of landscape transition with spatial agents." *Environmental Modelling & Software* 18: 553-563.

MacLean, Heather L. and Sabrina Spatari. 2009. "The contribution of enzymes and process chemicals to the life cycle of ethanol." *Environmental Research Letters*. 4: 1-10.

Majumdar, Indrajit, David Laband, Lawrence Teeter, and Brett Butler. 2009. "Motivations and Land-Use Intentions of Nonindustrial Private Forest Landowners: Comparing Inheritors to Noninheritors." *Forest Science*, 55:423 – 432.

Marland, Gregg, Kristy Fruit, and Roger Sedjo. 2001. "Accounting for sequester carbon: the question of permanence." *Environmental Science and Policy* 4: 259-268.

Mattingly, Justin, Fahran Robb, and Jetta Wong. 2008. “Cellulosic Biofuels Fact Sheet.” A report prepared for the Environmental and Energy Study Institute.

McIntosh, Brian S., Paul Jeffrey, Mark Lemon, and Nick Winder. 2005. “On the Design of Computer-Based Models for Integrated Environmental Science.” *Environmental Management*, 35:741 – 752.

Melillo, Jerry M., John M. Reilly, David W. Kicklighter, Angelo C. Gurgel, Timothy W. Cronin, Sergey Paltsev, Benjamin S. Felzer, Xiaodong Wang, Andrei P. Sokolov, and C. Adam Schlosser. 2009. “Indirect Emissions from Biofuels: How Important?” *Science*, 326: 1397 – 1399.

Michigan Department of Natural Resources. 2010. Michigan's Commercial Forest Program Overview. http://www.michigan.gov/dnr/0,4570,7-153-30301_39170-261777--,00.html and http://www.michigan.gov/dnr/0,4570,7-153-10366_34947-34016--,00.html accessed June 2010.

Michigan Department of Natural Resources. Price, D.L., Ed. 2008. “Michigan State Forest Management Plan.” A report prepared for Michigan Department of Natural Resources, Forest, Mineral, and Fire Management Division and Wildlife Division. Lansing, Michigan: Department of Natural Resources.

Monticino, M., M. Acevedo, B. Callicott, T. Cogdill, and C. Lindquist. 2007. “Coupled human and natural systems: a multi-agent-based approach.” *Environmental Modelling & Software* 22: 656-663.

Moore, Michael R. 2010. Professor, School of Natural Resources, University of Michigan. Personal Communication.

Pachauir, R.K., A. Reisinger (Eds.). 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html accessed February 2011.

Pataki, D.E., R.J. Alig, A.S. Fung, N.E. Golubiewski, C.A. Kennedy, E.G. McPherson, D.J. Nowak, R.V. Pouyat, and P.R. Lankao. 2006. “Urban ecosystems and the North American carbon cycle.” *Global Change Biology* 12: 2092-2102.

Pickett, S.T.A., M.L. Cadenasso, and J.M. Grove. 2005. “Biocomplexity in coupled natural-human systems: a multidimensional framework.” *Ecosystems* 8: 225-232.

Pimentel, David and Tad W. Patzek. 2005. “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower.” *Natural Resources Research*. 14: 65-76.

Plantinga, Andrew J. 1997. "The Cost of Carbon Sequestration in Forests: A Positive Analysis." *Critical Reviews in Environmental Science and Technology*, 27:269 – 277.

Plantinga, Andrew J., and Richard A. Birdsey. 1993. "Carbon fluxes resulting from U.S. private timberland management." *Climatic Change*, 23:37-53.

Plevin, R.J. and S. Mueller. 2008. "The Effect of CO_2 Regulations on the Cost of Corn Ethanol Production." *Environmental Resource Letters*, 3:1-9.

Plott, Charles R., and Kathryn Zeiler. 2005. "The Willingness to Pay-Willingness to Accept Gap, the 'Endowment Effect,' Subject Misconceptions, and Experimental Procedures for Eliciting Valuations." *The American Economic Review*, 95: 530-545.

Rhemtulla, Jeanine M., David J. Mladenoff, Murray K. Clayton, and B.L. Turner. 2009. "Historical Forest Baselines Reveal Potential for Continued Carbon Sequestration." *Proceedings of the National Academy of Sciences of the United States of America*, 106:6082-6087.

Rickenbach, Mark, and Thomas W. Steele. 2006. "Logging Firms, Nonindustrial Private Forests, and Forest Parcelization: Evidence of Firm Specialization and its Impact on Sustainable Timber Supply." *Canadian Journal of Forest Research*, 36:186 – 194.

Righelato, Renton and Dominick V. Spracklen. 2007. "Carbon Mitigation by Biofuels or by Saving and Restoring Forests?" *Science*. 317: 902.

Rossi, Alissa M. and C. Clare Hinrichs. 2011. "Hope and skepticism: Farmer and local community views on the socio-economic benefits of agricultural bioenergy." *Biomass and Bioenergy* 35:1418-1428.

Seely, Brad, Clive Welham, and Hamish Kimmins. 2002. "Carbon sequestration in a boreal forest ecosystem: results from the ecosystem simulation model, FORECAST." *Forest Ecology and Management* 169:123-135.

Scarpa, Riccardo, Timothy J. Gilbride, Danny Campbell, and David A. Hensher. 2009. "Modelling attribute non-attendance in choice experiments for rural landscape valuation." *European Review of Agricultural Economics*, 36:151-174.

Schäfer, Andreas, John B. Heywood, Henry D. Jacoby, and Ian A. Waitz. 2009. *Transportation in a Climate-Constrained World.* Cambridge, Massachusetts: MIT Press.

Schlapfer, Felix. 2006. "Survey protocol and income effects in the contingent valuation of public goods: A meta-analysis." *Ecological Economics*, 57:415 – 429.

Schmer, M.R., K.P. Vogel, R. B. Mitchell, and R. K. Perrin. 2008. "Net Energy of Cellulosic Ethanol from Switchgrass." *Proceedings of the National Academy of Sciences of the United States of America*. 105: 464-469.

Searchinger, Timothy, Ralph Heimlich, R.A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change.” *Science*, 319:1238 – 1240.

Seely, Brad, Clive Welham, and Hamish Kimmins. 2002. “Carbon sequestration in a boreal forest ecosystem: results from the ecosystem simulation model, FORECAST.” *Forest Ecology and Management*. 169:123-135.

Seidl, Rupert, Werner Rammer, Dietmar Jager, William S. Currie, and Manfred J. Lexer. 2007. “Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria.” *Forest Ecology and Management*, 248: 64 – 79.

Shaikh, Sabina L., Lili Sun, and G. Cornelis Van Kooten. 2007. “Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Forest Carbon Sinks?” *Canadian Journal of Agricultural Economics*, 55:97-114.

Simpkins, D., N. Allard, and J. Patrick. 2006. “Clean Energy from Wood Residues in Michigan.” A report prepared for the Michigan Biomass Energy Program. Lansing, MI: Department of Labor and Economic Growth.

Smith, W. Brad, Patrick D. Miles, Charles H. Perry, and Scott A. Pugh. 2007. “Forest Resources of the United States, 2007.” A report prepared for the United States Department of Agriculture Forest Service. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Sohngen, Brent, and Roger Sedjo. 2006. “Carbon Sequestration in Global Forests Under Different Carbon Price Regimes.” *The Energy Journal*, Multi-Greenhouse Gas Mitigation and Climate Policy Special Issues: 109 – 126.

Solomon, Barry D., and Nicholas H. Johnson. 2009. “Valuing climate protection through willingness to pay for biomass ethanol.” *Ecological Economics*, 68:2137 – 2144.

Spash, Clive L. 2007. “Deliberative monetary valuation (DMV): Issues in combining economic and political processes to value environmental change.” *Ecological Economics*, 63:690 – 699.

Sun, Ye and Jiayang Cheng. 2002. “Hydrolysis of lignocellulosic materials for ethanol production: a review.” *Bioresource Technology*. 83:1-11.

Unknown. 2006. “From Biomass to Biofuels.” A report prepared for the National Renewable Energy Laboratory. Golden, CO: National Renewable Energy Laboratory.

Wang, M.Q. 2001. “Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies.” A report prepared for the Center for Transportation Research, Energy Systems Division. Argonne, Illinois: Argonne National Laboratory.

Werner, B.T. and D.E. McNamara. 2007. “Dynamics of coupled human-landscape systems.” *Geomorphology* 91: 393-407.

White, Molly K., Stith T. Gower, and Douglas E. Ahl. 2005. “Life cycle inventories of roundwood production in northern Wisconsin: Inputs into an industrial forest carbon budget.” *Forest Ecology and Management*, 219: 13 – 28.

Wise, Marshall, Katherine Calvin, Allison Thomson, Leon Clarke, Benjamin Bond-Lamberty, Ronald Sands, Steven J. Smith, Anthony Janetos, and James Edmonds. 2009. “Implications of Limiting CO_2 Concentrations for Land Use and Energy.” *Science*, 324:1183 – 1186.

APPENDIX A. PRIVATE LANDOWNER FOREST DECISION SURVEY 2011

February 25, 2011

Dear Forest Land Owner,

Researchers at the School of Natural Resources and Environment at the University of Michigan are conducting a survey about how small forest land owners in Michigan use, value, and manage their forested land. Throughout the state of Michigan individuals like you make land use decisions on a daily basis that impact the state's overall forest health and economic future. This study is hoping to clarify how private forested land owners use their land and view their land use options. With this knowledge, companies that rely on forest resources will be able to make more informed decisions, based on how you, the forested land owner, think forest resources could be used best. Researchers at the University of Michigan will also be able to make improved forecasts of future forest condition across the state under various economic conditions. We will make the results of this survey available to you, which could help you to see how other small private land owners in the state manage their forested land.

Participation in this survey is voluntary and you may skip any question or stop at any time. Your responses will be kept anonymous and survey results will only be presented in the aggregate, never associated with individual names or addresses. If you are interested in the results of this survey, you may find them online here by May 1, 2011: (http://www-personal.umich.edu/~wcurrie), or you may request a hard copy by using the contact information below.

If you choose to participate, please return the survey by March 31st, 2011 in the enclosed, postage-paid envelope. If you have any questions or concerns, please feel free to contact me at: aebrunne@umich.edu.

The professor supervising this research is Dr. William S. Currie who can be contacted at wcurrie@umich.edu. The following contact information is the University of Michigan oversight committee (Institutional Review Board) for survey research:
IRB Health Sciences and Behavioral Sciences
540 East Liberty
Suite 202
Ann Arbor, MI 48104
(734) 936-0933
irbhsbs@umich.edu
Fax: (734) 998-9171

Thank you for your time,

Anna Brunner

1. In which township or townships is the forested land that you own?

____

____

☐I prefer not to respond

2. How much forested land do you own?

_____________________________acres

☐I prefer not to respond

3. Did you inherit your forested land?

☐ Yes

☐ No

☐I prefer not to respond

4. Would you consider any income you generate from your forested land to be your main source of income?

☐ Yes

☐ No

☐I prefer not to respond

5. What activities do you, or others, use your forested land for? (Please check all that apply)

☐Hunting/fishing/trapping

☐Alternative fuel (ethanol) harvest

☐Camping/hiking/birding

☐Just being around nature

☐Timber or firewood harvest

☐Driving All Terrain Vehicle (ATV)

☐ Conservation purposes, such as wildlife habitat

☐Other:_____________________

☐I do not use the forested land

☐I prefer not to respond

6. Of the activities checked in question 5, how long, in years, have you been doing each of these?

Hunting/fishing/trapping ____________

Alternative fuel (ethanol) harvest _____

Camping/hiking/birding _____________

Just being around nature ____________

Timber or firewood harvest __________

ATV __________________

Conservation purposes_______________

Other:_____________________

☐I do not use the forested land

☐I prefer not to respond

7. Are there nearby areas where you are also able to pursue the activities from question 5?

☐ Yes

☐Some of my activities, yes (please specify which): _____________________

☐No

☐I prefer not to respond

8. Which statement best describes your forest management planning?

☐I have a current forest management plan (FMP) prepared by a certified forester

☐I do not have a current certified FMP, but I actively plan the management of the forest myself

☐I do not have a current FMP and do not actively plan the management of the forest myself

☐I prefer not to respond

9. Recently the Energy Independence and Security Act became a federal law, which states that "In 2010, 12.95 billion gallons of renewable fuel must be used, increasing to 36 billion gallons by 2022." One such renewable source comes from trees through a harvesting process similar to timber, but with a different end use—as cellulosic ethanol, a replacement for gasoline.

If you were compensated at the market rate for timber, would you:

☐ Be willing to sell all the trees I would harvest, for this alternative fuel

☐ Be willing to sell some of the trees I would harvest, for this alternative fuel

☐ Not be willing to harvest any trees, or sell any of the trees I would harvest, for this alternative fuel

☐ I am not sure what I would do, or it would depend on additional factors

☐ I prefer not to respond

10. We are interested in understanding how forest land owners view the issue of global climate change given what Intergovernmental Panel on Climate Change (IPCC) has to say:

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level"* and *"There is very high confidence that the net effect of human activities since 1750 has been one of warming."*

Which option best describes your views on this subject?

☐I disagree; the climate is not changing

☐ I disagree; the climate may be changing, but human activities are not the primary cause

☐ I agree; the climate is changing, and human activities are the primary cause

☐ I have not formed a view one way or the other

☐ I prefer not to respond

11. The IPCC suggests one way to reduce negative impacts of global climate change is through a process called carbon sequestration, something that forests do naturally as they grow. Since this carbon storage is seen as a benefit by some, consideration is being given to paying land owners for maintaining their forest stand for the carbon it can store as it grows. What are your views regarding payments for carbon sequestration?

☐ I would definitely maintain my forest stand to sequester carbon for appropriate compensation

☐ I would consider maintaining my forest stand to sequester carbon for appropriate compensation

☐Compensation for carbon storage would not affect my forest use or management decisions

☐ I need more time to consider my options and gain more information

☐ I would not consider maintaining my forest stand to sequester carbon for appropriate compensation

☐ I prefer not to respond

12. What factors would you take into account if you were deciding between harvesting trees from your forest for alternative fuel (question 9) or managing your forest to sequester carbon (question 11), or deciding to not to do either? (Please check all that apply)

☐I would only focus on price; I would pick whichever option gave me the greatest compensation

☐I would consider price, but it would not be the only basis for my decision

☐I would consider which option seemed like a more worthwhile goal to myself and others

☐I would consider my beliefs regarding the role of carbon sequestration and alternative fuels

☐I would consider how I currently use the land, whether for recreation, conservation, or other uses

☐I am not sure or I would need to gain additional information

☐I prefer not to respond

13. Which age bracket would you categorize yourself in?

☐18-25 ☐26-33 ☐34-41 ☐42-49 ☐50-57 ☐58-65 ☐66-73 ☐74-81 ☐82-90

☐91+

☐I prefer not to respond

Thank you, again, for your time. Please feel free to add any additional comments you would like, below. Additional comments will be very helpful to researchers in understanding the decisions you make and the factors that are important to you.