

## ABSTRACT

LAWLER, MEGAN E. Assessing Potential for Municipal Biomass Residue for Renewable Energy. (Under the direction of Dr. M. Nils Peterson and Dr. Melissa McHale).

Recent legislation and formal agreements have increased focus on utilizing the urban forest to reduce CO<sub>2</sub> emissions. One possibility being considered for urban areas to accomplish this end is use of municipal biomass residue (MBR) as renewable energy feedstocks to offset coal consumed for electricity generation. Adoption of urban wood residue utilization will depend on feedstock availability and market drivers which are ultimately related to public perceptions and acceptance. Further, the impact that shifting waste management strategies will have on CO<sub>2</sub> emissions is unknown. In this research I assessed the preferences that residents in Raleigh, NC hold for waste management and their willingness to pay (WTP) for burning yard waste to generate electricity. I also interviewed stakeholders involved with the management of urban yard wastes in Wake County, NC to uncover potential barriers to biomass utilization. Finally I modeled CO<sub>2</sub> emissions associated with current management practices and an alternative scenario in which wood wastes were co-fired with coal to generate electricity. My results indicated that urban wood wastes to energy in Raleigh, NC is poised to be socially and economically feasible. However, CO<sub>2</sub> models suggest that such a strategy is unlikely to significantly reduce fossil fuel use or CO<sub>2</sub> emissions.

Assessing Potential of Municipal Biomass Residue for Renewable Energy

by  
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## DEDICATION

To Dr. Wayne Frantangelo, in the name of science!

## BIOGRAPHY

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## **Introduction**

This thesis aimed to determine if it would be feasible to generate electricity from municipal biomass residues (MBR) in Wake County, NC. Feasibility is a broad term with a variety of explanations; therefore we selected three aspects of feasibility that would be relevant considerations for any community: public acceptance for the practice, barriers prohibiting stakeholder participation, and carbon emission implications. The first chapter uncovered public perceptions for yard waste utilization by surveying residents of Raleigh, NC the largest city in Wake County. Public acceptance for a practice is relevant to MBR feasibility because residents generate yard wastes on their landscapes and are the potential consumers for products that might come from the yard wastes. The second chapter uncovered the barriers to utilization through semi-structured interviews with MBR managers and regulators in Wake County, NC. This aspect of the work was relevant because stakeholders have stories that are not quantifiable, but that will need to be addressed regardless of the type of waste management strategy that is adopted. The third chapter explored the CO<sub>2</sub> emissions associated with the generation of electricity from yard wastes by modeling the emissions associated with two options for processing the wastes: creating landscape mulch or generating hog fuel. Through the exploration of these three chapters we were able to suggest that it would not be feasible to use MBR in Wake County NC, exclusively for electricity production. Finally, using MBR effectively was discussed in the fourth chapter which is a guidebook designed to assist urban and community forest decision makers in NC as they implement MBR waste management strategies most appropriate for their communities.

## **Assessing Public Interest in Renewable Energy from Urban Yard Wastes**

### **ABSTRACT**

Management of municipal solid wastes and providing for energy demands in sprawling urban areas contribute to anthropogenic greenhouse gas emissions from waste and energy sectors. Diverting urban wood biomass from the solid waste stream into renewable energy feedstocks holds the potential to reduce greenhouse gas emissions associated with municipal biomass residue (MBR) management. Adoption of MBR utilization in urban areas is dependent upon public perceptions and acceptance. This research sought to assess residential preferences for waste management and willingness to pay (WTP) for burning yard waste to generate electricity in Raleigh NC, one of the fastest growing sprawl centers in North America. We found that for all respondents, composting (54%) was preferred over both burning wastes for electricity (37%) and sending wastes to a landfill (9%). Gender and ethnicity were predictors of preference for waste utilization. Men (42%) preferred burning for electricity more often than women (32%). African Americans (44%) preferred burning for electricity more than Caucasians (32%). Mean willingness to pay (WTP) for burning wastes for electricity was \$5.57 ( $\pm$  \$0.70 SE) per month. Our results suggest that residents of Raleigh would be willing to support management practices that could potentially reduce greenhouse gas emissions in their communities.

## INTRODUCTION

Sprawling urban development in the United States is characterized by large residential lots and low density population growth outside of traditional, higher-density urban cores (Ewing, 1994; Johnson, 2001). Lot clearing and residential landscape maintenance activities in sprawl areas produce yard wastes (one type of municipal residue biomass or MRB) in greater amounts than in traditional urban centers (Sherrill, 2003; Speed et al., 1989; Gregg, 2010). Yard wastes have typically been buried in landfills along with other municipal solid wastes (Sherrill, 2003). Methane ( $\text{CH}_4$ ) is produced from the decomposition of these yard wastes (Lou and Nair, 2009). A greenhouse gas 20 times more powerful than  $\text{CO}_2$  (U.S. EPA, 2010a),  $\text{CH}_4$  from landfills accounted for 22% of all U.S. anthropogenic  $\text{CH}_4$  emissions in 2008 (U.S. EPA, 2010c). Municipalities started to ban yard wastes from traditional landfills for the purpose of decreasing  $\text{CH}_4$  emissions in the 1980's (Legislative Research Commission, 1989). The combination of regulations and increasing MBR have driven-up costs associated with processing yard waste (Sherrill, 2003).

A new yard waste management approach that reduces demands on landfills and associated  $\text{CH}_4$  emissions while offsetting  $\text{CO}_2$  is needed. Using yard waste to generate electricity has the potential to reduce  $\text{CH}_4$  emissions from landfills, broaden markets for waste management facilities, and offset  $\text{CO}_2$  emissions from burning fossil fuels (specifically coal) to generate electricity. As fossil fuel prices increase, fuels from biomass feedstocks become more competitive (Aguilar, 2009) thus increasing the potential success for a wood-waste feedstock market.

Wood and paper mills already burn wood biomass wastes (in place of fossil fuels) in boilers that power on site operations (Cooper and Mann, 2009; Hazel and Bardon, 2008; Welch and Bellamy, 1976; Weyerhaeuser, 2010). Wood residues can also be used in residential applications in the cogeneration of heat and power (CHP) (De and Assadi, 2009; Delattin et al., 2009; U.S. DOE, 2004). In communities with extant coal-fired boilers, co-firing of biomass with coal is implemented by simply mixing the two fuels (Hughes, 2000; U.S. DOE, 2004). Up to 20% of the coal burned in a single boiler can be replaced with wood biomass without any changes to the existing system (U.S. DOE, 2004). Residential CHP applications are used extensively throughout Europe (Mahapatra and Gustavsson, 2009; Rakos, 2005; Taylor et al., 2010; Vallios et al., 2009) but remain rare in the U.S. Examples of CHP in the U.S. are often limited to organizations with campuses, such as institutions of higher learning or hospitals, and most rely on fossil fuels not biomass feedstocks (U.S. EPA, 2010b). Studies suggest that the production of residential energy from yard wastes will increase the cost-effectiveness of urban forest management programs aiming to reduce their CO<sub>2</sub> footprints (McHale et al., 2007).

Residents are a critical component in the management of urban yard wastes because they produce the wastes, are potential consumers for the products created from the wastes, and are drivers of sprawl and energy consumption (Welsch and Kühling, 2009). The lack of residential CHP applications in the southern U.S. may be due to a lack of public support for the product (Borchers et al., 2007). We explored this supposition with a survey of residential

preferences for yard waste management in Raleigh NC. Specifically we compared preference for the common waste utilization strategies of mulching and burial in a landfill, and the rare strategy of CHP (which we called burning for electricity). In addition we estimated WTP for using urban yard wastes for electricity generation. As consumers, residents could significantly influence the viability of new waste to energy markets. Identifying the determinants of pro-environmental consumption is the first step to understanding actual and potential barriers to residential CHP (Welsch and Kühling, 2009).

Numerous studies have linked residential landscape preferences and yard management preferences to lifestyle behaviors within the neighborhood in which an individual lives, as measured by demographic factors and residential spending patterns (Grove et al., 2006b; Troy et al., 2007; Martin et al., 2003; Nassauer et al., 2009; Zhou et al., 2009). We hypothesized that preference for the management of vegetation removed from a resident's property would be predicted by the lifestyle associated with the neighborhood in which they reside, ethnicity (Caucasian or African American), ownership of the property on which the resident lives, gender (male or female), college graduate or not, and presence of children (under 18 years old) in the household.

## METHODS

### **Study Area**

With a population of 388,926 in 2009, and growth rates consistently above the national average, the city of Raleigh, NC is the heart of the burgeoning Raleigh-Durham

Research Triangle sprawl center (City of Raleigh, 2010b). Of 83 U.S. metro areas, Raleigh-Durham had the third worst sprawl index in 2009 (Smart Growth America, 2010). Raleigh, a city with extensive forest cover, has a largely un-tapped wood feedstock and typifies the waste and energy issues faced by other sprawling communities in NC and the SE U.S. (Rich, 2010).

Currently four facilities, recognized by the NC Department of Environment and Natural Resources (NC DENR) through Land Clearing and Inert Debris, and Treatment and Processing facilities (LCID) permits, serve the greater Raleigh area's yard waste needs. LCID activities include land-filling, processing of woody debris into mulch and fire wood, and separating out merchantable timber for sale to mills. Raleigh also has a state-permitted, city-operated yard waste composting facility which manages some residential yard wastes along with leaves (City of Raleigh, 2010a). Current conditions in Raleigh indicate that the time is ripe for the exploration of alternative management strategies. One of the four LCID processes all yard wastes received into mulch and topsoil. Another LCID has begun uncovering wood wastes formerly deposited in the landfill for processing into mulch. The other two LCID have approximately 20 years landfill capacity remaining. All LCID and municipal composting facilities serving Raleigh report operating seasonally at maximum capacity. Other common LCID challenges include the increasing costs of fuel and labor, stricter regulations, and complications from unexpected natural disasters (notably hurricanes). As Raleigh expands, conveniently located and inexpensive land becomes scarce thus impeding a facility's ability to meet continually increasing waste volumes. In total

358,166 m<sup>3</sup> were deposited in Wake County LCID in 2008 (Unpublished Data, 2010). Based on current facility loads and population growth estimates, the four LCID expect to see approximately 416,820 m<sup>3</sup> of residential yard waste materials in 2012 (Unpublished Data, 2010). While mulch is produced in response to market demands for the product, the practice is unresponsive to recent concerns over fossil fuels, CO<sub>2</sub> emissions and general sustainability. The North Carolina Renewable Energy Portfolio Standard, mandating that 12.5% of public electric utility's retail sales come from renewable sources, (Albertson, 2007) and the Mayor's Climate Action Agreement (U. S. Conference of Mayors, 2010) create additional need for urban biomass use alternatives that address greenhouse gas emissions in NC.

### **Data Collection**

We selected neighborhoods for the sample frame based on lifestyle as reported by the Potential Rating Index for Zipcode Markets (PRIZM). PRIZM is a classification system that uses an in-depth analysis of socio-demographic factors, and spending on goods and services to categorize census blocks, thus identifying residents with similar lifestyles (Claritas, 2007; Claritas, 2008). Other studies have successfully used PRIZM segmentation to predict resident's behaviors and preferences (Claritas, 2007; Grove et al., 2006a). We chose to sample two neighborhoods each from PRIZM segments 12 and 62 because they represented sprawling low-population density urbanized areas with distinctly different lifestyles and high incidences of single family dwellings (Claritas, 2008). We used Hawth's Analysis Tools for ArcGIS to generate random addresses within those four neighborhoods, thus allowing each address an equal chance for selection (Beyer, 2004).

The survey was administered door-to-door from February to March 2010, by students at North Carolina State University. One hundred eighty addresses were targeted, and households were visited until a response was received or up to three visits (including an evening and weekend visit). After the third attempt the proximate address that was not already part of the sample frame was targeted, resulting in  $n = 179$  interviews.

From three given options for disposing of their yard wastes (“composted by city waste facility,” “sent to a landfill,” or “burned for electricity production”) respondents were asked to order their preference from “1 = most preferred, 2 = moderately preferred and 3 = least preferred”. We asked respondents: “would you support your yard waste(s) being burned for electricity production if it meant you paid a monthly fee for collecting the wastes?”. Respondents who agreed to pay the monthly fee were then asked “how much would you be willing to pay (enter a single dollar amount)”. Demographic information was collected from each respondent to determine ownership status, education level, ethnicity, presence of children in the home, and gender.

### **Data Analysis**

We used SPSS 17.0 (SPSS Inc) to calculate descriptive statistics as well as to evaluate models. Preference for yard waste utilization was analyzed in a multinomial logistic regression. Support for burning yard wastes to generate electricity despite a monthly fee was evaluated in a binary logistic regression. Factors that influenced WTP for burning yard wastes were modeled using an ordinary least squares regression. All models evaluated six independent variables: ethnicity, gender, PRIZM group, education, ownership status, and presence of children in the household.

## RESULTS

Composting was the preferred use of yard wastes for 54% of respondents, followed by burning yard wastes for electricity (37%), and sending yard wastes to a landfill (9%). Forty-five percent of all respondents indicated that they would support their yard wastes being burned for electricity even if they were charged a monthly fee for it, while 54% indicated that they were not willing to pay additional costs. Mean WTP was \$5.57 ( $\pm$  \$0.70 SE) per month, but the amount jumped to \$11.45 ( $\pm$  \$1.15 SE) per month for the sub-sample of respondents who were willing to pay anything.

Ethnicity and gender predicted yard waste utilization preferences (Table 1). Women (62%) preferred composting more often than men (46%). Men (42%) preferred burning for electricity more often than women (32%). Men (12%) also preferred sending wastes to a landfill more often than Women (6%). Caucasians (65%) preferred composting more than African Americans (38%). African Americans (44%) preferred burning for electricity more than Caucasians (32%). African Americans (18%) also preferred sending yard wastes to a landfill more often than Caucasians (3%).

Ethnicity and gender also predicted whether an individual would agree to pay a monthly fee to have yard wastes burned to generate electricity (Table 1). Of the respondents that agreed to pay for burning their yard wastes to generate electricity, more were women (53%) than men (37%), and more were Caucasians (52%) than African Americans (33%). We found ownership predicted mean WTP (Table 1). Mean WTP for respondents who owned the property on which they lived was \$12.19 ( $\pm$  \$2.39 SE), while those who did not own the property was \$18.15 ( $\pm$  \$2.38 SE) per month.

## DISCUSSION

Overall our findings suggest that residents of Raleigh were generally interested in disposing of their yard wastes in ways that are popularly perceived to be environmentally friendly. Preference for composting over burning yard wastes or sending them to a landfill may have been influenced by familiarity with composting combined with negative attitudes towards burning garbage. Residents believed composting was the ‘best’ choice for yard waste management and deposition of materials in landfill as the ‘worst’ alternative. Burning waste for electricity production fell somewhere in between, indicating that demand for CHP is lacking. Past studies have focused on “green energy” as a generic product when considering WTP (Dwivedi and Alavalapati, 2009; Ethier et al., 2000; Gossling et al., 2005; Roe et al., 2001; Zarnikau, 2003). However when the type of green energy is specified, preferences for the product and willingness to pay (WTP) shift (Borchers et al., 2007). One study of green energy preferences found respondents were most familiar with wind, solar and green energy in general; because they were less familiar with biomass they preferred solar and wind energies to biomass (Borchers et al., 2007). The city of Raleigh operates a municipal composting facility at no additional cost to residents, and the benefits have been widely advertised to residents (City of Raleigh, 2010a). Whereas there are currently no municipal programs that burn yard wastes to generate electricity in Raleigh. It may be that residents not willing to pay to have yard wastes burned for electricity are content to rely on the option already in practice for the disposal of their yard wastes. Future research that

examines bases of knowledge and how preferences change with exposure to additional information could be used to validate this hypothesis.

Borchers' study also indicated that respondents perceived biomass as less useful than "green energy" in general (2007). It could be that in our case, burning is also perceived as less useful than composting. Further, burning may also share negative environmental connotations potentially associated with "incineration" (Huhtala, 1999; Zarnikau, 2003). As consumers, respondents may have considered the utilization options and determined that burning for electricity is an inferior strategy (Borchers et al., 2007).

A combination of political, economic and land-use histories may explain why African Americans preferred burning for electricity production more than Caucasians, yet were less willing to pay for that preference (Byrne and Wolch, 2009; Virden and Walker, 1999). Many studies have found that Caucasian's and African American's preference for the management of landscapes, open spaces and parks differ dramatically (Byrne and Wolch, 2009; Carlson et al., 2010; Elmendorf et al., 2005a; Elmendorf et al., 2005b; Gobster, 2002; Oh and Ditton, 2009; Virden and Walker, 1999; Zube and Pitt, 1981). Our results suggest that ethnicity, in addition to predicting environmental impressions, may also explain perceptions of yard waste management. This is a critical consideration for multiethnic communities looking to increase public participation in specific waste management practices. Research that examines Raleigh's history of ethnicity, environmental and waste management preferences could determine if this is an appropriate explanation for our findings.

Western norms for the role of gender in society is one potential explanation for why women most preferred compost, a potential form of the restoration of productivity over burning for electricity. Traditionally women, as mothers, have been associated with nurturing roles based on such ideas as ‘mother earth’ ‘Gaia’ (of Greek tradition) and ‘Eve’ (of Judeo-Christian origins) (Merchant, 1996). Traditionally men have been more involved with the building of economic markets than women (Blocker and Eckberg, 1997), possibly explaining their preference for burning yard wastes for electricity (a possible new economic market) over composting (an existing market in Raleigh). We found that while women preferred composting over burning the wastes, women were more likely than men to be willing to pay collection fees for burning the yard wastes. The apparent contradiction in agreeing to support a practice despite one’s own personal preference for a different practice suggests these women would rather pay than have the wastes deposited in a landfill. Generally women have been found to prefer any green power alternative to the status quo (Borchers et al., 2007). In other studies relating to the management of wastes, women who preferred recycling are more likely to pay for the preference than men who prefer recycling (Huhtala, 1999).

Decision importance or social norms may explain why renters were willing to pay more than owners (Janssen and Jager, 2002). The decision to pay more is potentially less important to renters than owners because renters would be tied to their decision for a shorter period of time than owners. In some cases renters are not responsible for the waste collection fees, therefore they may be less concerned about the charges. Conversely, owners are

typically responsible for their own waste collection fees and more concerned about increases in monthly fees. More research would be needed to validate these hypotheses.

Our finding of 45% agree, 54% don't agree to pay for their wastes to be collected and burned for electricity generation supports the assertion that different sources of energy offer diverse perceived benefits to consumers (Borchers et al., 2007). We acknowledge that if issues other than environmental quality are of daily concern to residents then goods and services that support high environmental quality become luxuries (Basili et al., 2006). Future research must explore the extent to which residents consider waste management a part of environmental management, as well as what residents qualify as luxuries in order to uncover factors that may keep communities from achieving their MBR utilization and renewable energy goals.

**Table 1.** Model prediction for most preferred yard waste utilization method where “1 = composted by city waste facility”, “2 = sent to a landfill”, and “3 = burned for electricity production” with burned for electricity the reference category (multinomial logistic regression), willingness to pay (WTP) for wastes being burned for electricity where “no = 0” and “yes = 1” (binary logistic regression) and amount willing to pay (ordinary least squares regression).

Independent Variable	Preference			Willing to Pay?		WTP	
	Compost <sup>g</sup>	Landfill <sup>g</sup>					
	$\beta$	$\beta$	p	$\beta$	p	$\beta$	p
Ownership <sup>a</sup>	-0.820	-0.530	0.081	-0.545	0.116	-5.864	0.013
PRIZM <sup>b</sup>	-0.088	.458	0.849	0.696	0.248	4.426	0.199
Ethnicity <sup>c</sup>	0.989	-2.114	0.006	-1.590	0.014	5.210	0.156
Presence of Children <sup>d</sup>	-0.452	-0.075	0.489	-0.175	0.618	2.304	0.323
Education <sup>e</sup>	-0.370	-0.314	0.617	-0.090	0.804	1.448	0.544
Gender <sup>f</sup>	0.814	-0.813	0.014	-0.769	0.023	-2.921	0.193

<sup>a</sup> Do not own = 0, Own = 1

<sup>b</sup> PRIZM 12 = 0, PRIZM 62 = 1

<sup>c</sup> African American = 0, Caucasian = 1

<sup>d</sup> No Children = 0, Children Present = 1

<sup>e</sup> No College Degree = 0, College Degree = 1

<sup>f</sup> Male = 0, Female = 1

<sup>g</sup> reference category = burned for electricity

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## **Barriers to Utilization of Urban Biomass Residues for Bioenergy: A Wake County, NC Case Study**

### **ABSTRACT**

Municipal biomass residue (MBR) feedstocks are plentiful in the southern U.S. and recent legislation has increased interest in their role in the production of bioenergy. Despite promising economic, technical, and environmental conditions, urban areas are not yet transitioning to generation of bioenergy from their wood residues. We hypothesized that implementation has been hindered by the perspectives and perceived barriers of the actors managing urban biomass residues. We conducted interviews among key stakeholders in Wake County, NC to investigate this issue. We identified stakeholder groups and their respective goals. Barriers that keep stakeholders from attaining their goals included lack of economic incentives for key practices and disconnect between stakeholder groups. We discuss these factors and the opportunities that exist for incorporating differing perspectives with respect to urban biomass utilization.

## INTRODUCTION

Across the U.S., woody residuals contribute to the municipal solid waste stream (MSW). In 2000, 12% of the overall U.S. MSW consisted of wood wastes produced from urban forest maintenance (McKeever and Falk, 2004; McKeever and Skog, 2003). Of the total discarded wood in the 2002 U.S. MSW, half consisted of wood chips, logs, stumps, tree tops and brush from the urban forest (McKeever, 2002). Sprawling urban centers (such as Raleigh-Durham, NC) have growing wood wastes because residential development patterns extend urban forest cover over formerly non-forested agricultural land (McKeever and Skog, 2003; Unpublished Data, 2010). In addition to regular urban forest maintenance, natural disasters (notably hurricanes and insect infestations in the Southern U.S.) produce sporadic volumes of nonmerchantable urban timber ideal for bioenergy use (Mayfield et al., 2007). Concurrently, demands for secure renewable energy feedstocks are on the rise. Sources of municipal biomass residue (MBR) are generally plentiful in the Southern U.S., and motivations to utilize MBR for bioenergy are numerous.

Instances of MBR to bioenergy outside the U.S. have demonstrated that they are economically feasible, attractive to investors, and important to residents for sustainability reasons (Madlener and Vögtli, 2008; Mahapatra and Gustavsson, 2009; Rakos, 2005; Vallios et al., 2009). In the U.S., the political impetus to encourage bioenergy use exists in Renewable Portfolio Standards, which have been adopted by 27 states and the District of Columbia (U.S. DOE, 2010). Despite benefits and motivations, a bioenergy industry has not been quick to emerge in the Southern U.S. (Mayfield et al., 2007), and MBR is generally

underutilized (MacFarlane, 2009). Understanding barriers to the development of an urban wood waste to energy industry could help move this nascent industry forward.

Little research has been conducted relating directly to MBR. Findings from studies of rural and industrial forest circumstances are most likely relevant to this understudied urban environment. Previous research suggests that the barriers to greater biomass utilization in rural sectors may not be technical or environmental but have to do with unanswered questions related to industry structure and supply chain management (Altman and Johnson, 2009; Bernetti et al., 2004; Duller and Valentine, 2008). In the Great Lakes Region, the utilization of biomass from private non-industrial land has been stalled by market prices and the need for specialized equipment (Campbell, 1988). In agricultural biomass contexts, the process of changing from food business perspectives to energy business perspectives has prevented alternative utilization (McCormick and Kåberger, 2007).

Specifically in the Southern U.S., barriers to rural and industrial biomass utilization have been generally categorized under six main themes: (1) marketing, (2) infrastructure, (3) community engagement, (4) incentive support, (5) collaboration, and (6) education (Mayfield et al., 2007). Among these themes, lack of incentives for landowners, consumers, and business development have been identified as significant barriers (Mayfield et al., 2007). Evidence suggests that awareness of renewable energy and bioenergy does not equate to an awareness of the potential of feedstocks for energy (Mayfield et al., 2007). In other words, stakeholders know that bioenergy is important, but they may not realize that the biomass they

produce or manage is a potential marketable resource. Other barriers included feedstock availability and cost competitiveness of forest biomass as a feedstock, the availability of appropriate production technologies, industry consolidation, and potential negative environmental impacts (Mayfield et al., 2007).

Barriers to the adoption of MBR for bioenergy in the southern U.S. have not been thoroughly investigated. Urban biomass uses are worthy of research because the South produces significant MBR as urbanization occurs consistently above the national average. Consequently, we identified stakeholders associated with MBR, and uncovered factors that may contribute to the lack of adoption of bioenergy in urban areas. We used a qualitative case study in Wake County, NC where sprawling urban areas have plentiful MBR, but do not generally divert them for the generation of electricity.

## METHODS

Data for this study were collected from semi-structured interviews with stakeholders in Wake County NC. Interviews ranged in length from 30 minutes to three hours. The initial exploratory approach occurred in the Fall of 2009, when interviews with eight key informants were conducted by graduate students at NCSU; two were conducted over the phone, six were conducted in person. We pursued a snowball approach while augmenting the suggested contacts with arbitrary selection from lists of businesses provided by the Raleigh Chamber of Commerce. In this way, informants that did not network with the

original key informants were targeted to acquire a more complete sample. Nineteen in-person interviews were performed by Meg Lawler from January to April 2010. A total of 27 interviews were completed and transcripts were created from interview notes and audio recordings.

Transcripts were entered in QSR Nvivo 8 for coding and analysis. A two-step approach was used to code the data. First, the seven defined categories of the Social Process Framework were used to create a definite hierarchy of categories for coding<sup>1</sup>. Use of the framework in this application allowed for a systematic analysis of the data, in such a way that problems, goals, and stakeholder perspectives were systematically identified. Next, the data were inductively coded, allowing for a less structured exploration of other emerging themes.

## FINDINGS

We identified four main stakeholder groups based on their association with MBR and categorized them as: state regulators, city managers, Land Clearing and Inert Debris Facility (LCID) owners/operators, and other producers/users of the wastes. We were able to identify goals for each group with respect to their current position in urban forest waste management. State regulators and city managers held common goals of public health and safety (Table 2). LCID owners/operators and producers/users of the wastes all had goals centered around economic incentives (Table 2). We were also able to identify factors that hindered the

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<sup>1</sup> The social process analysis is comprised of seven categories: participants, perspectives, values, situation, values, strategies, effects and outcomes (Clark, 2002; Lasswell, 1971). Problems and goals were two of the problem orientation analysis components used (Clark, 2002; Lasswell, 1971).

stakeholders from achieving their goals. Money was reported by all four stakeholder groups to be in some way involved with the barriers to their goals.

### **State Regulators**

Both of the state regulators interviewed indicated that their goal was to enforce the proper management of wood wastes such that the human health risks associated with the wastes was reduced. Their goal is based entirely upon the legislation (NC Senate Bill 111) which defines terms associated with the wastes, along with the proper management practices:

The state interests are several. The material [biomass residue] is viewed as a resource. Regulatoraly, it's viewed as a potential liability, problem in a landfill. It has a definite public health threat associated with it, an environmental threat associated with it when it's not managed properly. –*State interviewee B*

[We are]...responsible for insuring solid waste state laws are followed regarding facilities and so we, by definition, would be responsible for enforcement actions associated with non permitted facilities or places where wastes are being managed inappropriately that are not on a permit. –*State interviewee A*

Additionally, both interviewees indicated that barriers keeping them from attaining their goals are greed and ignorance on behalf of certain producers and managers of the wastes.

...the primary [goal] is to save money. Pure greed. And the second is ignorance to a much lesser degree. Some people are avoiding a tipping fee by not taking it to the proper place, or it's just inconvenient to take it to the proper place. So it's saving them time and money. Disposing of it or managing it correctly, sometimes it's ignorance that they didn't know that with a little bit of effort they could have mulch or compost. More often than not, it's my opinion that it's solely for money.” –*State Interviewee B*

This quote is consistent with the regulatory framing of their role. The state stakeholders

identified greed and ignorance barriers as the main factors causing people to manage wastes illegally or in ways potentially dangerous to human health.

### **City Managers**

Most of the city managers reported that their umbrella “mission is public safety and healthy sustainable urban forest”. –*City Interviewee A*

The achievement of the goal is limited by the lack of resources, explicitly in the form of money and personnel. All eight of the city employees agreed that resources limited their ability to maintain a sustainable forest:

There are about 122 park sites in six districts with eight people per district crew. We maintain 1100 miles of street right of way, 880 acres of parks, 63 miles of greenway trails. We also handle cemeteries, complaints, and neighborhoods. ...too many acres, not enough people. We are expected to do more on less money. –*City Interviewee A*

Well, we can stretch our resources as far as our dollars...well money of course. I think that there are days I'm just like we could do so much more, but I need one more person. Or I need another truck. It's resources. Eventually that's how we max out. –*City Interviewee V*

...we're understaffed because we lost positions. We just try to work smarter. Try to use volunteers. This is how we get work done. We can barely keep our heads above water... Sometimes we get so stretched out that you feel you can't do one thing really well because you're trying to do five things mediocre. –  
*City H*

### **LCID owners and operators**

All three LCID owners and operators shared the goals of generating profit and balancing economic feasibility with the requirements set out by their state-issued permits.

One LCID owner indicated that a factor keeping his operation from making money was a lack of awareness on the part of state agencies. As a manufacturer of mulch and hog fuel (a common term for wood chips that are burned to generate electricity), the LCID is exempt from paying sales tax on the nearly one million dollars worth of equipment. The owner was, unexpectedly, required to pay sales tax on the equipment. He was forced to educate the state regulators about the regulation that applied to LCID owners/operators:

It took me a year and a half to get where I was tax exempt from sales tax on my equipment. I argued with them [the State] 'til I turned blue in the face. Well, the little guy that worked for the government didn't know what I was. All he knew was that I was a mad old man, that's all he knew. But see, I am a producer, I'm making hog fuel, and I'm making triple shredded mulch. I am a manufacturer like it or not. They said you're not manufacturing that wood! I said no, you knuckle head, but you take that stump and get out there and chew it up as fine as I'm doing and you'll see I'm manufacturing something!" -*LCID Operator C*

A further disconnect between what the state regulators think is happening and what the LCID owners/operators are experiencing limits the ability of all participants to manage wastes in a cost-effective manner. State regulators believe that there is a market for hog fuel, while LCID actors report otherwise:

The [LCID/T&P] facilities support a big boiler fuel market where those ground up stumps or ground up trees are used as a boiler fuel. -*State interviewee A*

This fuel [hog fuel] right here for me to sell it, I only get \$50. A whole tractor trailer load, that's it. What I do is I sell it to a company that hauls it to Plymouth for boiler fuel. So that's what I'm saying there's no money. I was losing my rear end trying to do it. It's cheaper to bury it [yard wastes]. I can bury it for probably 1/8 the cost of recycling it. -*LCID Operator C*

The *LCID Operator C* also indicated in this statement that there is a lack of economic incentives for owners and operators to explore other management strategies. All LCID owners/operators reported that economic considerations were central to their waste management strategies.

The public's perceptions of waste management were an additional barrier limiting the cost-effectiveness of alternative management. According to one LCID operator, the public is not doing their part to properly separate wastes. This means more man-hours are spent by LCID operators, and thus more money spent and less profit generated for the businesses, when they pick up the slack.

I think the general public just puts things at the curb, and they don't really care. They just throw it to the curb, and how it gets taken care of and what happens to it is just immaterial to them. –*LCID Operator A*

### **Producers/Users of Urban Biomass Residues**

The stakeholders involved with the production and utilization of the wood biomass residues include tree service companies, artisans and urban sawyers. As business owners, generation of profit was a common goal for all three types of producers/users.

Because if it's not economical, private industry's just not going to do it. Not for long anyway. –*Producer of Residue L*

All tree services reported being limited by other producers and users of the residues who were not following the rules. This complaint was specifically targeted toward perceived illegal immigrants and non-licensed businesses.

They're working cheap. They don't have the equipment to do it properly. A lot of the competition, and I'm seeing it with a lot of the 'illegals', a bob cat and a dump truck and that's it. I mean that's what I'm seeing. They're fast and furious and they don't care what it hits when it falls. They're not paying taxes, most of them aren't insured. There's big factors here. I'm insured, workman's comp, general liability, plus all my guys are on payroll, so they're paying taxes and we're withholding, we're matching. So I can't work as cheap as them, and I lose a lot of work because of them. *-Producer of Residue L*

Because Producer L follows the rules, it puts him at an economic disadvantage in the market place. Other Producers shared his complaint:

We're finding that the 'illegals' are causing a lot of harm to the businesses. I mean in the tree business, they come in and cut a tree, it falls on the power lines, they pack up and leave and they're never heard of again. That has happened several times in Raleigh. In the tree business, I tell folks, you get what you pay for. I'm not the most expensive, but I'm not the cheapest. All my guys pay taxes and, I say to the customer: look, you hire us and your money stays in Wake County. It doesn't go to Mexico. *-Producer of Residue J*

...it irritates me to see them working there with no safety equipment, no hard hats, no glasses, no chaps and there's a climber up in the tree with no safety gear on. And if those people get hurt then, even though they're not on our [workers compensation] policy, it affects the state rates and that affects our workers comp policy. And we play a fortune in that anyway. We have a phenomenal record but people doing stupid stuff like that are hurting us. *-Producer of Residue B*

These producers and users also indicated that the fees charged by the LCID owners/operators are a barrier to their ability to generate profit. Consequently, many producers and users indicated that they have an incentive to avoid LCID to be cost-effective.

...it boils down to money and how we can do it cheaper...occasionally we have customers that flag us down and want the raw mulch, and we'll dump it with them, but ...I've been with the company for six years and I think we may have dumped at a [LCID] maybe once or twice during that entire time. So it is very rare for us to do that. *-Producer of Residue B*

The name of the game is to try to reduce the number of dump fees you have at the [LCID]. One thing is it gets very expensive dumping in the [LCID], not to mention the buildup of waste in there anyways. Not to mention that for us, with the volume that we do, it would be so much money bottom line going straight out it does not make sense. –*Producer of Residue L*

Anytime you can leave material on a site it's going to lessen the cost of the job. –*Producer of Residue J*

Similar to the perspectives of the LICD owners/operators, some producers/users see a disconnect in communication between themselves and the state. The lack of understanding inhibits the cost-effective management of wastes.

All the misinformation and powers that be that sit behind their desk and have great administration skills don't know the difference between pecan and pine. Those are always going to be the same communication issues. –*User of Residue W*

## DISCUSSION

This study uncovered problems rooted in the regulation of MBR. The current state regulatory process has clearly defined purposes and goals. It specifies rules and describe how those rules will be applied. However, the producers/users' complaints about "illegal" competitors suggest that enforcement of those rules is limited. Producers/users and LCID owners/operators report being penalized for complying with the rules. State regulators expect producers/users to utilize permitted facilities for waste management. Yet LCID tipping fees create the incentive for producers/users to avoid LCID. The state regulators explain this phenomenon as "greed", when by another perspective it may be a rational

business practice. By complying with tax and safety rules, compliant producers/users are more expensive when compared with other businesses that do not abide by the law. Consequently, compliant producers/users look for additional ways to keep costs down, including not paying tipping fees. Better enforcement of producers/users could result in a more even playing field for all businesses involved. The creation of good will on behalf of the regulators toward the producers/users and LCID owners/operators could perhaps contribute to a greater willingness to pay tipping fees.

A critical tendency exacerbating the regulatory enforcement problem is the fact that communication between stakeholder groups is historically faulty and in some cases non-existent. Specifically, lack of effective communication was evidenced by LCID owners/operators' and producers/users' reports of significant misunderstandings with one another and with the state regulators. If good communication is lacking, stakeholders cannot have reliable perceptions of one another (Buttoud, 2009). The difference of opinions illustrated by the interviewees are symptomatic of issues within the lines of communication between stakeholders. Further evidence was given in the disconnect between the LCID owners/operators and the 'public', as explained by interviewees as the public's apparent unwillingness to 'do their part'. The communication barriers we identified are consistent with Mayfield's collaboration, community engagement, and education barriers (2007).

Misplaced and ill-managed economic incentives, described by all stakeholder groups, are a result of inadequate inter-stakeholder contact. Our results suggest that management

rules are abused or avoided by stakeholders because economic incentives are misplaced. A solution to this problem would be for a neutral party to nurture open communication between stakeholders. We suggest a forum in which the stakeholders could meet face-to-face could ameliorate some of these challenges. With mediation by the NC State Cooperative Extension Community and a well-defined decision space, it may be possible for stakeholders to collectively address the urban waste management issues they face, but may not be aware of. We would expect the success of such an endeavor would be dependent upon stakeholder's commitment to the process.

Our results suggest that creating an arena for the participants to come together will be the critical factor in improving the circumstances surrounding MBR utilization and sustainable cities. We suggest that an "open active debate about what to do" (Clark, 2002) would begin to address the key issue of sharing knowledge about key misperceptions and the lack of communication between stakeholders. We expect that increasing an exchange of ideas would allow stakeholders to develop a common goal because city management, LCID owners/operators and producers/users' individual goals already include similar perspectives. Further, the urban biomass arena is well positioned for a waste-to-energy market. The new common goal must be adaptive and consider the issue of misplaced economic incentives.

Further, it should consider a 'cradle to grave' view of urban biomass in terms of greenhouse gasses, business finances, and marginal social costs. We suggest that efforts be made at state and municipal levels to clearly define emerging goals in terms of urban wood to

energy management at local scales. After the lines of interaction are opened through goal-sharing, it may be more easily ascertained how and where to create incentives such that the current infrastructure can be most efficiently shifted to forward those goals.

This analysis enabled the clarification of stakeholder-defined barriers to alternative urban forest waste management. Our results, when compared with those of Mayfield (2007) suggest that barriers resulting from communication issues will be consistent in rural and urban areas. Physical aspects, such as infrastructure, of biomass utilization will vary uniquely by region and municipality. The use of urban wood biomass to generate electricity is one way to achieve the objective of increasing energy production through renewable resources (Bernetti et al., 2004). Addressing the stakeholder barriers, whether perceived or real, is a means to advance the utilization of urban wood wastes to generate electricity. Barriers may be overcome with increased stakeholder collaboration and properly managed economic incentives. Management strategies that are resource maximizing and cost-effective will be beneficial to all stakeholders involved in urban wood wastes. Ultimately, economic hardships as induced by poor or nonexistent stakeholder exchanges severely limits change in waste management strategies. It is therefore critical on part of all stakeholders to maintain and nurture open lines of communication.

**Table 2. Overview of the reported goals and barriers for each stakeholder group interviewed in this study.**

Stakeholder Group	Number of Interviews	Goals	Reported Barriers
State Regulators	2	enforce the proper management of the wood wastes such that the human health risks associated with the wastes was reduced	greed and ignorance on behalf of producers/users of the wastes
City Managers	8	“mission is public safety and healthy sustainable urban forest”	lack of money and personnel
LCID Owners/Operators	3	balancing economic feasibility with the requirements set out by their state-issued permits	disconnect with state regulators, public indifference to waste management, lack of economic incentives
Producers/Users of Urban Biomass Residues	14	generating profit	other businesses not following the rules and lack of economic incentives to properly manage wastes

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Vallios, I., Tsoutsos, T., Papadakis, G., 2009. Design of biomass district heating systems, Biomass Bioenergy 33, 659-678.

## **Generating Electricity from Urban Biomass May Not Reduce Carbon Dioxide Emissions**

### **ABSTRACT**

Reductions in anthropogenic carbon dioxide (CO<sub>2</sub>) emissions must be achieved in order to mitigate the adverse effects of global climate change. The majority of anthropogenic CO<sub>2</sub> emissions originate from energy use and transportation, especially in urbanized areas. Recent legislation regarding energy related emissions has prompted interest in managing urban forests to reduce these emissions. A proposed strategy is the use of wood wastes from the urban forest (also known as municipal biomass residue, or MBR) to replace coal for electricity generation. The apparent abundance of MBR in combination with proximity to processing facilities makes this an attractive option. However, adoption of this strategy would typically require reallocation of MBR from landscape mulch production. This study investigated the potential for cities to reduce CO<sub>2</sub> emissions by replacing landscape mulch production with burning MBR to generate electricity. We identified the volume of yard wastes (one form of MBR) generated in Wake County, NC in 2008. We quantified emissions associated with creating landscape mulch and co-firing MBR with coal to generate electricity. According to our models, reallocating MBR from landscape mulch production to electricity generation resulted in a 0.12% reduction in CO<sub>2</sub> emissions. We conclude that

exclusive use of MBR for electricity generation may not be a desirable management strategy because available wood resources do not have a substantial reduction on energy related emissions.

*Keywords: biomass, urban forest, carbon dioxide emissions*

## INTRODUCTION

Reducing anthropogenic carbon dioxide (CO<sub>2</sub>) emissions is vital for the successful mitigation of global climate change (Pachauri and Reisinger, 2007, Solomon et al., 2007). In the U.S. approximately 50 % of CO<sub>2</sub> emissions are from urban transportation and residential energy sectors (U.S. EIA, 2009). Municipal leaders nationwide have signed the U.S. Mayors' Climate Protection Agreement, pledging to reduce CO<sub>2</sub> emissions below 1990 levels (U. S. Conference of Mayors, 2010), but few cities have specific plans for achieving that goal.

The standing urban forest is an obvious means for achieving promised CO<sub>2</sub> emission reductions because trees sequester carbon. However, when compared to total CO<sub>2</sub> emissions, the amount of carbon stored by urban trees is minimal (Nowak, 1993). Further, an urban forest's ability to sequester and store carbon is checked by decomposition and maintenance activities that require fossil fuel-burning equipment (Nowak, 1993; Nowak et al. 2007). Researchers have demonstrated the ability of various urban forest management strategies, (e.g. planting, shading, wind shields) to reduce urban energy demand (Donovan and Butry, 2009; McPherson and Rowntree, 1993; McPherson and Simpson, 2003; Simpson and McPherson, 1996; Simpson and McPherson, 1998), thus reducing fossil fuels burned to generate energy. Tree plantings also have the potential to increase energy demands and outside of modeling studies plantings have not been proven to produce significant reductions.

Another suggested strategy of using biofuels to generate electricity in place of fossil

fuels has been spurred by the adoption of Renewable Portfolio Standards by 27 states and the District of Columbia (U.S. DOE, 2010). In the Southern U.S., where urban lot clearing and residential landscape maintenance activities produce abundant wood-waste, using municipal biomass residues (MBR) as replacement fuel for coal is a potential way to meet both Renewable Portfolio Standards and The U.S. Mayors' Climate Protection Agreement requirements (Gregg, 2010; Mayfield et al., 2007; Sherrill, 2003; Speed et al., 1989). It has also been suggested that MBR feedstocks are an appealing option due to their inherent proximity to processing facilities, which increases market potential (Aguilar, 2009).

MBR also has market potential because residents generate wood wastes while maintaining their landscapes and they are also potential consumers of the products generated from those wastes. Evidence suggests that residents in Raleigh, NC would be willing to pay a collection fee to have their wastes burned for electricity generation (Lawler et al., In Review, 2011). Despite general public support for alternative wood-waste management strategies, adoption in Wake County, NC has been hindered by lack of economic incentives and lack of communication between managers and regulators of the MBR. Lawler et al. (in Review, 2011) suggested that mitigation from a neutral third party would reduce the influence of these barriers and improve the likelihood of successful MBR utilization.

Although replacing coal with MBR appears socially acceptable and economically promising, to our knowledge, no empirical evidence exists to suggest it would reduce CO<sub>2</sub> emissions. The amount of MBR needed for a city to achieve CO<sub>2</sub> emissions reductions is also unknown. Regulations that establish standards for bioenergy use (U.S. DOE, 2010) and

literature that describe options for meeting those standards (Abt et al., 2010; Hazel and Bardon, 2008; Rich, 2010) can only assume that increasing the use of renewable fuels, such as MBR, will decrease CO<sub>2</sub> emissions (Giampietro et al., 1997). Further, literature suggests that reductions in CO<sub>2</sub> emissions are best achieved by reducing energy demands, rather than simply replacing or supplementing fossil fuels with biomass (Gustavsson et al., 2007; Walker, 2009). A basic understanding of CO<sub>2</sub> emissions associated with MBR utilization is needed to clarify the best options for achieving CO<sub>2</sub> reductions.

This study aimed to determine if CO<sub>2</sub> emission reductions are achieved by replacing the current landscape mulching strategy with a strategy in which MBR is co-fired with coal to generate electricity. Wake County is an ideal choice for this study because the rapidly developing urban-suburban matrix has extensive urban forest cover, thus characterizing sprawling urban centers in the South East (Wake County Government, 2010). We conducted a series of interviews with MBR managers to determine the volume of yard wastes, the primary type of MBR which consists of debris from land-clearing for development and urban forest maintenance activities, in Wake County, NC. We modeled the primary sources of CO<sub>2</sub> emissions associated with processing yard wastes into landscape mulch and processing yard wastes into hog fuel, a common term for wood chips that are co-fired with coal to generate electricity. Our results provide the empirical evidence needed to support claims that replacement of fossil fuels with MBR will achieve CO<sub>2</sub> emissions reductions. Clarification of the best options for cities to achieve emissions reductions will assist decision makers across the U.S., as they direct the future of markets, policies, and ultimately the sustainability of their communities.

## METHODS

### **Study Site**

Wake County, NC is rapidly urbanizing and has population growth rates consistently above the national average. The climate is suitable for management of highly productive forests and a significant portion of the county's 2,212 km<sup>2</sup> is forested (Wake County Government, 2010). Four of the largest municipalities in Wake County currently have formal commitments to greenhouse gas reduction (U. S. Conference of Mayors, 2010). Additionally, North Carolina was the first Southern state to adopt Renewable Portfolio Standards that require the generation of electricity from renewable resources including biofuels (Abt et al., 2010).

### **Interviews**

Data for this study were collected from semi-structured interviews that ranged in length from 30 minutes to three hours from February to May of 2010. Interviewees were guaranteed confidentiality in accordance with NC State University Internal Review Board standards. Owners from 3 of the 4 Land Clearing and Inert Debris Treatment and Processing (LCID) facilities in Wake County, NC were interviewed and made MBR deposition records available to researchers.

Privately owned and operated, LCID facilities are permitted by the NC Department of Environment and Natural Resources (NC DENR) to manage yard wastes. LCID operating permits are issued state-wide based on facility size therefore data from this study are comparable to communities across NC. This study used only urban yard wastes as reported

in LCID facility records for 2008; other types of MBR and wastes that were illegally dumped were not included.

## **Model**

We modeled CO<sub>2</sub> emissions associated with the management of yard wastes for a mulch production scenario and a hog fuel production scenario. We assumed the primary sources of emissions for both models were: 1) emissions from diesel fuel used in equipment to process mulch ( $\epsilon_M$ ) or hog fuel ( $\epsilon_H$ ), 2) emissions from decomposition of mulch ( $R_m$ ) or hog fuel ( $R_h$ ), 3) emissions from burning coal to generate electricity ( $C_e$ ), or emissions from co-firing coal ( $C_0$ ) with hog fuel ( $H_0$ ) to generate electricity. Total emissions for the mulch scenario ( $E_t$ ) and the hog fuel scenario ( $E_h$ ) were the sums of respective emission sources,

$$\text{(Eq. 1) } E_t = \epsilon_M + R_m + C_e,$$

$$\text{(Eq. 2) } E_h = \epsilon_H + R_h + H_0 + C_0.$$

### **(Eq. 1) Landscape Mulch Model**

First we calculated the emissions from diesel fuel burned by equipment at LCID facilities ( $\epsilon_M$ ). According to LCID facility interviewees, landscape mulch was processed through two phases: an initial chipping to achieve a consistently sized material, and a rotation of chipping, resting, and turning required to achieve a final product. Estimate ranges of gallons of diesel fuel burned per day for the multi-step process were provided by LCID facility interviewees, from which the average was extrapolated for 2008 based on 48 weeks

of operating 8 hour days, 6 days a week. We multiplied the average gallons per year by 0.01tCO<sub>2</sub>/gallon of diesel fuel burned (U.S. EPA, 2010, U.S. EPA, 2004) to find total tCO<sub>2</sub> emitted from the processing equipment.

Next, we calculated the emissions from decomposition of the mulch (R<sub>m</sub>). According to LCID facility interviewees, during and after processing 100% of mulch is lost to decay through two steps. First, during the 4-6 month processing period that is required to generate a finished mulch product, 40% of the material by volume is lost to decay. The remaining mulch decomposes over the 1-2 year period during which the mulch would be transported and applied to landscapes. To calculate the emissions from decay, we first approximated the volume of solid wood in the mulch by dividing by Briggs estimation of 2.74 ft<sup>3</sup> of solid wood (Briggs, 1994). We multiplied ft<sup>3</sup> of solid wood by 18.36 gC/ft<sup>3</sup> and estimated gCO<sub>2</sub> using 3.66 gCO<sub>2</sub>/gC. We converted gCO<sub>2</sub> to pounds CO<sub>2</sub> using 2,204.62 lbsCO<sub>2</sub>/gCO<sub>2</sub>. Finally, we converted to tCO<sub>2</sub> using 4.5359 x 10<sup>-4</sup> tCO<sub>2</sub>/lb (U.S. EPA, 2004) the result was the input factor for R<sub>m</sub>.

Finally we estimated the emissions from coal burned to generate electricity (C<sub>e</sub>). In 2008 the Electric Power Sector in North Carolina consumed 760,100,000 Million British thermal units (MMBtu) of coal (U.S. DOE/EIA, 2010). Wake County comprised 9.2% of North Carolina's population in 2008 (U.S. Census Bureau, 2010). We therefore estimated coal consumed to provide electricity for Wake County to be 9.2% of the state total, or 69,930,000 MMBtu. We used a standard factor of 205.8 lbsCO<sub>2</sub>/MMBtu (Hong and Slatick, 1994), to convert the energy from coal consumed in Wake County to pounds. Then we

converted pounds to t using  $4.5359 \times 10^{-4}$  tCO<sub>2</sub>/lb (U.S. EPA, 2004) the result of which was input for C<sub>e</sub>.

### **(Eq. 2) Hog Fuel Model**

We accounted for each of the primary processing sources at LCID facilities and the emissions from co-firing coal with hog fuel to generate electricity to determine the amount of CO<sub>2</sub> associated with the hog fuel model (E<sub>h</sub>). First we estimated the emissions from diesel fuel burned by equipment to generate hog fuel (ε<sub>H</sub>). According to LCID interviewees, hog fuel was not generated in 2008 but had it been generated it would have required approximately one third the amount of diesel burned to produce mulch. This is because only the initial chipping would be required to achieve a final hog fuel product, whereas the mulching process required the additional rotation of chipping, resting, and turning to achieve a final product. Therefore we multiplied one third of the average gallons of diesel fuel which we had extrapolated for mulch for 2008 by 0.01tCO<sub>2</sub>/gallons of diesel fuel burned (U.S. EPA, 2010, U.S. EPA, 2004) to find total tCO<sub>2</sub> emitted from the processing equipment that would be used if hog fuel were produced (ε<sub>H</sub>)

Next we accounted for decomposition of the hog fuel (R<sub>h</sub>). According to LCID interviewees, after initial chipping the finished hog fuel product would be ready for use or sale. Because additional processing time would not be required we assumed no loss of material to decay, and therefore no emissions from R<sub>h</sub>.

Finally, we calculated the emissions from co-firing coal (C<sub>0</sub>) and hog fuel (H<sub>0</sub>) to

generate electricity. When hog fuel and coal are co-fired, the heat energy from the hog fuel replaces a portion of the heat energy from coal. Therefore, the amount of coal burned with hog fuel that would be required to generate electricity equivalent to the amount consumed in 2008 is equal to the difference between the MMBtu of coal consumed to produce electricity in 2008 and the MMBtu of hog fuel available, or 69,890,000 MMBtu. We converted MMBtu to pounds CO<sub>2</sub> using the conversion factor 205.8 lbsCO<sub>2</sub>/MMBtu coal (Hong and Slatick, 1994), and then converted to tCO<sub>2</sub> using  $4.5359 \times 10^{-4}$  tCO<sub>2</sub>/lbCO<sub>2</sub> (U.S. EPA, 2004) to determine the emissions from coal co-fired with hog fuel (C<sub>0</sub>).

To determine the CO<sub>2</sub> emissions from burning hog fuel (H<sub>0</sub>) required an estimate of the amount of heat energy available in the wood, known as recoverable heat (RH). We first confirmed the typical composition and condition for the wastes with interviewees, and thus determined the yard wastes were an even mix of half hardwood and half softwood species processed through shredder to three inches or less within 24 to 168 hours of removal from the growing site. This base information allowed for the definition of the conditions that are required to calculate RH which are specifically,

- 1) A higher heating value of 8,650 Btu/lb based on an average of 9,000 for softwoods and 8,300 for hardwoods (Smith 1982),
- 2) Moisture content (MC<sub>w</sub>) of 37.5% based on the average MC<sub>w</sub> for Hardwood (35%) and Pine chips (40%) in U. S. South (Harris and Phillips 1989),
- 3) Combustion temperature (T<sub>3</sub>) of 450 degrees F (Briggs 1994),
- 4) Ambient temperature (T<sub>1</sub>) of 70 degrees F (Briggs 1994),

- 5) Fiber saturation point wet basis (MCb) of 23% (Briggs 1994),
- 6) Exhaust temperature (T2) of 470 degrees F (Briggs 1994),
- 7) Excess air of 20% (Briggs 1994),
- 8) Other losses of 4% (Briggs 1994).

The abovementioned assumptions were applied to the RH equation from Briggs (1994),

$$RH = GHV - (H1+H2+H3+H4+H5+H6+H7+H8),$$

where the green heating value (GHV) is,

$$GHV = ((1-MC_w)/100),$$

and other RH contributing factors are defined as,

$$H1 = (212-T1) * MC_w / 100,$$

$$H2 = 970 * MC_w / 100,$$

$$H3 = 136 * MC_b / 100,$$

$$H4 = 0.46 * (T2-212) * MC_w / 100,$$

$$H5 = 0.54 * (212-T1) + 0.54 * (970) + 0.54 * (142 * 0.46),$$

$$H6 = (T-T2)(1-MC_w/100)[1.44EA/100 + 1.56],$$

$$H7 = (T3-T1)[0.266 + 0.000322 (T1 + T3 - 64)],$$

$$H8 = 0.04 GVH.$$

The amount of solid wood in the chips was approximated by dividing by a conversion factor of 2.74 ft<sup>3</sup> (Briggs, 1994), and the pounds of carbon in the hog fuel were determined using 25.14 lbs/ft<sup>3</sup> solid wood. Using RH (0.0071 MMBtu/lb), the MMBtu available in the hog fuel was determined to be 39,805 MMBtu. MMBtu were converted to CO<sub>2</sub> using an emissions factor of 116.7 lbsCO<sub>2</sub>/MMBtu hog fuel (Briggs, 1994), which was then converted to tCO<sub>2</sub> using 4.5359 x 10<sup>-4</sup> tCO<sub>2</sub>/lbCO<sub>2</sub> (U.S. EPA, 2004) to determine CO<sub>2</sub> emissions from co-firing hog fuel with coal to generate electricity (H<sub>0</sub>).

### **(Eq. 3) Model Comparison**

We compared the total emissions for each model to determine if reductions are likely to be achieved by co-firing MBR with coal,

$$\text{(Eq. 3) } \Delta E = E_t - E_h.$$

## **RESULTS**

LCID facility recorded yard wastes were 1,175,100 ft<sup>3</sup> (figure 1), of which approximately 80% by volume or 940,080 ft<sup>3</sup> originated from land-clearing for development. When topsoil, rocks, concrete and metal were removed from the land-clearing wastes, such that only useable wood residues remained, approximately 40% of the land-clearing waste was retained by volume. Residues from urban forest maintenance practices made up the remaining 20% of the total wastes, approximately 235,020 ft<sup>3</sup>, and because removal of excess materials is not required there is no percent loss of material. Total wastes available for the production of mulch or hog fuel in 2008 were 611,052 ft<sup>3</sup> (Figure 1).

### **(Eq. 1) Landscape Mulch Model**

Total emissions from the diesel burned in processing equipment to generate mulch ( $\epsilon_M$ ) were 9,518 tCO<sub>2</sub>, with 3,141 tCO<sub>2</sub> and 6,377 tCO<sub>2</sub> emitted from the initial processing and secondary processing respectively (Figure 1). Total emissions from the decomposition of mulch ( $R_m$ ) were 3.082 tCO<sub>2</sub> with 1.233 tCO<sub>2</sub> emitted from the decomposition of mulch during the 4-6 month processing periods and 1.849 tCO<sub>2</sub> emitted from remaining decomposition (Figure 1). Emissions from the burning of coal for electricity in 2008 were  $C_e = 6,528,000$  tCO<sub>2</sub> (Figure 1). In the mulch model, total emissions were  $E_t = 6,538,000$  tCO<sub>2</sub>.

### **(Eq.2) Hog Fuel Model**

Emissions from diesel burned in processing equipment to generate hog fuel ( $\epsilon_H$ ) were 3,141 tCO<sub>2</sub> (Figure 1). We assumed no decomposition of the hog fuel during or after processing, therefore emissions from decomposition ( $R_h$ ) were 0 tCO<sub>2</sub>. The emissions from the hog fuel co-fired with coal ( $H_0$ ) were 2,107 tCO<sub>2</sub>, and from coal co-fired with hog fuel  $C_0$  were 6,524,000 tCO<sub>2</sub> (Figure 1). The total emissions associated with the hog fuel model ( $E_h$ ) were 6,529,000 tCO<sub>2</sub> (Figure 1).

### **(Eq. 3) Model Analysis**

A reduction of  $\Delta E = 8,210$  tCO<sub>2</sub> or 0.12% would be realized if the hog fuel scenario replaced of the mulch scenario.

## DISCUSSION

Upon initial reflection, results of this analysis support the assumptions implied in RPS and associated literature, that increasing renewable energy will decrease CO<sub>2</sub> emissions. According to our models, burning yard wastes to generate electricity in place of mulching would result in a fraction of a percent reduction in CO<sub>2</sub> emissions. Albeit nominally small, the reduction was realized through an elimination of decomposition emissions and a fraction of a percent decrease in coal consumption (Figure 1). Each of these components have been suggested as critical to an urban forest's ability to sequester and store carbon (Nowak, 1993; Nowak et al. 2007). Further, utilization of MBR to offset coal emissions accomplishes reductions in the residential energy sector, a significant contributor to total U.S. CO<sub>2</sub>

emissions (U.S. EIA, 2009). However, it is unlikely that the CO<sub>2</sub> reductions illustrated in our model would be viable in the long-term for two reasons. First because the source of the majority of MBR is permanent forest removal, indicating that a majority of the MBR is not renewable. Second because altering the demand for landscape mulch has uncertain outcomes.

In this study only 20% of the yard wastes considered were from management practices, such as pruning, that promote the continued existence of the urban forest (LCID personal communication, 2010). The remaining 80% of the yard wastes reported produced in Wake County come from practices that clear land for new development (LCID personal communication, 2010), thus permanently removing forest from the landscape and permanently removing that source of renewable fuel from the landscape. As opposed to forest industry operations where harvests for fuel or other purposes are replanted to promote sustained use. In this circumstance it is critical to remember that although wood is a renewable resource, renewable quantities are of finite supply (Gustavsson et al., 2007; Timmons and Mejía, 2010).

Further, additional evaluation of the sustainability of a resource requires some consideration of ‘carbon neutrality’. In our study, even the 20% of yard wastes that may be categorized as *renewable* are not necessarily *carbon neutral*, they were generated through forest maintenance activities that potentially emit more CO<sub>2</sub> than the forest is able to offset (Nowak, 1993). Therefore we suggest that it is necessary to critically examine the source of

every supposed resource in terms of ‘renewable’ and ‘carbon neutrality’ alongside the CO<sub>2</sub> emissions associated with the use of that resource before management decisions are made (Giampietro et al., 1997).

Our models indicate that use of MBR, to achieve CO<sub>2</sub> emissions reductions as hog fuel, will require urban forest management for higher MBR production. It is possible that the urban forest is already producing volumes that would result in CO<sub>2</sub> reductions greater than the 0.12% demonstrated here because our models did not consider illegally dumped or otherwise unrecorded wastes. However, because no records of these wastes exist, we can only guess at their volumes. Even if accounting for unrecorded wastes were to double the volume of total available wastes, the CO<sub>2</sub> reduction would still be less than 1%. Assuming a significant but potentially feasible 20% reduction target, approximately 2,941,850m<sup>3</sup> of yard wastes yearly or nearly 170 times 2008 available waste volumes would be required to realize the goal. An investigation of potential wastes production rates under varying management strategies is required to determine if and under what circumstances the 20% reduction could be achieved using MBR exclusively.

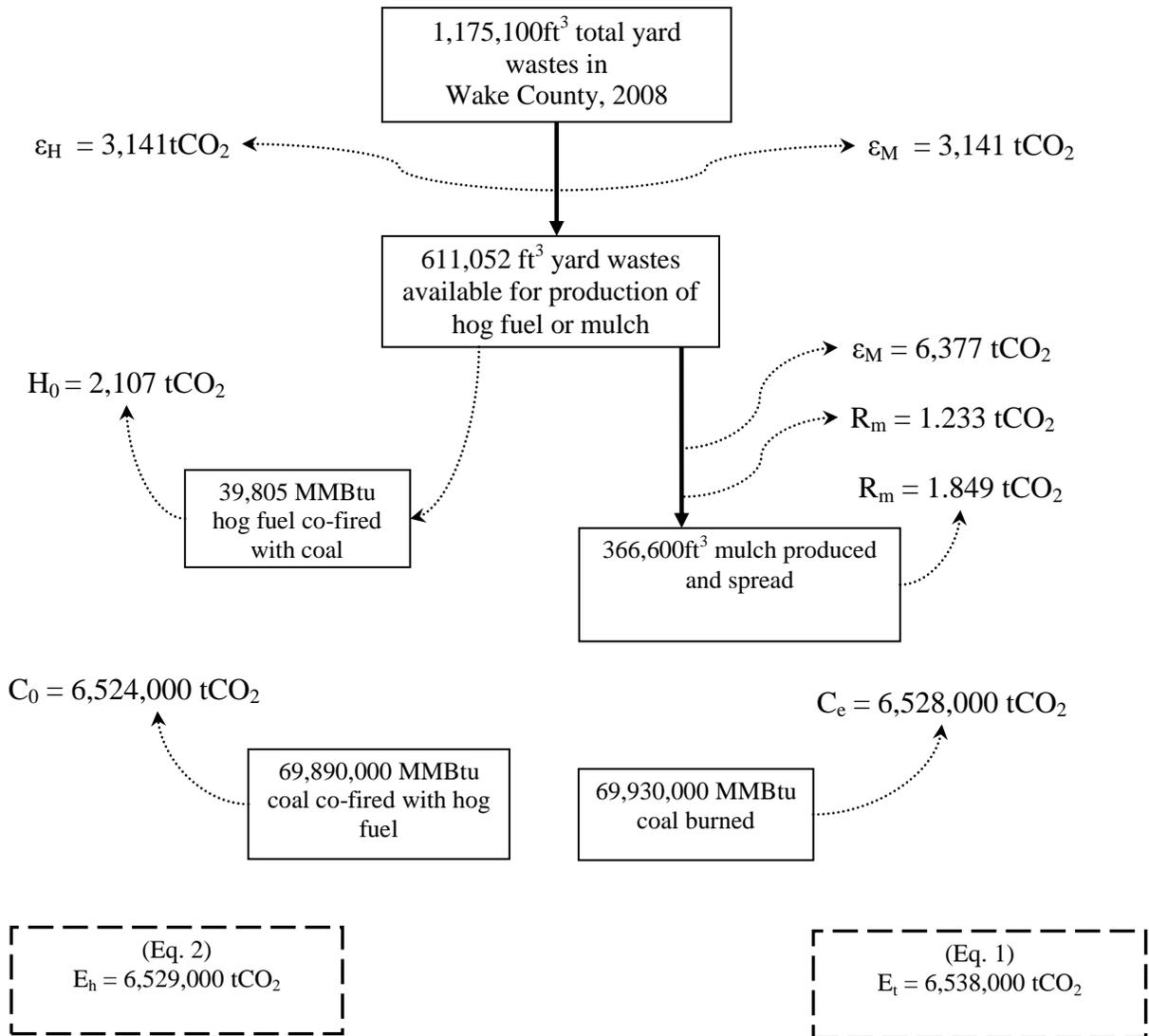
An alternative option to achieve 20% CO<sub>2</sub> reduction is to supplement or replace MBR with biomass residues from forest industry such as *Pinus taeda* (Loblolly Pine), a common timber resource in NC. These plantations are typically on a 20 year rotation, from which the stem residues (biomass left after harvest) are collected at a rate of at least 0.86 tons/ac (Gou, 2010). We can assume that they have a higher heating value of 9,000 btu/lb (Briggs, 1994)

and a recoverable heat of 0.0078 MMBtu/lb (calculated using RH equation from Briggs, 1994) because the stem residue is exclusively pine. If we assume energy consumption remains at 2008 levels, over 400km<sup>2</sup> of plantation would be harvested every year to reduce 20% of the coal burned to produce electricity. Multiplying that yearly estimation by 20 accounts for the forest rotation length thus the residues could be harvested every year from a different plot such that at the end of 20 years the first plot would be ready for harvest again. Under those circumstances, 8,000km<sup>2</sup> would be required to make 20% reduction. In other words, stem residue harvests from a *Pinus taeda* plantation 3 times the size of Wake County on a 20 year rotation would be needed to offset 20% of coal permanently.

Our results demonstrated the potential for bioenergy to decrease CO<sub>2</sub> emissions; it is critical to acknowledge that altering a current management regime has uncertain outcomes, which were not accounted for in this study. For example, landscape mulch in Wake County produced from MBR is a local resource. Depleting a local mulch source (by reallocating wastes to the hog fuel scenario) may encourage residents to turn elsewhere for the product. Mulch could be potentially imported from farther away, thus increasing transportation emissions and negating any CO<sub>2</sub> savings realized in the hog fuel scenario. Further, future unseen circumstances may reduce total long-term feedstock availability, (such as hurricanes or insect infestations that destroy forest) thus influencing the renewable and carbon neutrality factors. Additionally, attempting to increase MBR produced by the forest has the potential to increase CO<sub>2</sub> emissions associated with maintenance. We suggest that strategies to reduce CO<sub>2</sub> emissions associated with maintenance activities be investigated at length.

We conclude that it would not be feasible for municipalities to decrease carbon emissions exclusively by creating hog fuel rather than landscape mulch from MBR. At present, the generation of bioenergy from urban wood residues doesn't lead to any significant reduction of CO<sub>2</sub> emissions that could not be accomplished by energy conservation (Walker, 2009). That is not to say that exploration of bioenergy from urban wastes is futile. Rather we suggest that changes in the management of MBR be made only where life cycle assessments deem it appropriate and only in combination with overall reduced energy consumption. We agree with Kaul et al., that each community should consider short-term benefits of MBR management strategies with long-term views in mind (2010). These findings and considerations are critical for investors, managers, residents and policy makers in urban ecosystems as they develop ways to decrease CO<sub>2</sub> emissions and comply with state, national, or global legislation and agreements. We conclude that bioenergy should continue to be considered in mitigation efforts only as a springboard to larger more significant lifestyle and cultural changes, which would ultimately impact CO<sub>2</sub> emissions.

FIGURES AND TABLES



**Figure 1:** Illustration of the scenarios considered side-by-side; the hog fuel model is on the left-hand side and the mulch model is on the right-hand side. Solid arrows indicate a processing of physical product; dotted arrows indicate emissions released in tCO<sub>2</sub>. Boxes with solid lines represent a physical amount of a product, specified within the box. The bottom-most boxes with bold dotted lines represent the sum of all emissions in tCO<sub>2</sub> for each model.

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## Using Wood Wastes to Maximize Urban and Community Forest Resources

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Improved urban wood-waste management can reduce CO<sub>2</sub> emissions, develop resilient urban forests and decrease forest management costs. Effective wood-waste management plans are often administered by the community's urban forester or urban forestry board as one part of a comprehensive urban forestry effort. To develop successful urban wood waste utilization programs, urban forest decisions makers need to understand the benefits and limitations of waste management strategies, as well as state regulations regarding waste management.

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Trees in parks, cemeteries and greenways, in both private and public areas within or adjacent to urban and suburban landscapes are part of the urban forest. In NC, the wood wastes produced from these landscapes are called yard wastes. Yard wastes are made up of two types of wastes: land clearing debris and yard trash. Land clearing debris consist of trees and other vegetation cleared for the building of homes or businesses. Yard trash consists of leaves, tree and shrub limbs, logs and wood from routine landscape maintenance and storm debris. In rapidly growing communities debris from land clearing can make up 80% of yard wastes. Yard wastes are subject to regulation under North Carolina Senate Bill 111 (Speed et al., 1989).

### WHY A WOOD WASTE PLAN?

The strategies adopted in wood waste plans can reduce urban forest maintenance costs by increasing efficiencies and reducing wastes. This is a critical tactic in the current funding climate where municipal budget cuts have led to reduced funding of urban and community forestry programs, and staff reductions. Meanwhile communities and their associated forest areas are rapidly expanding in NC resulting in additional

resources to be managed without increasing personnel.

*If a wood waste utilization plan exists in your community:*

- Is the current plan formally part of the urban forestry program? Review the Wood Waste Plan Components section starting on page 2.
- Does the current plan put wood wastes to the best use?
- Does the current plan account for both routine wood wastes and emergency situations such as severe storms or insect infestations?
- Does the current plan generate funds and/or offsets operating costs? Is there room for improvement?
- Do staff have the resources they need to follow plan procedures and achieve plan goals?
- Can the plan be altered or adapted to make up for the lacking resources?
- Review the management strategy section of this guide starting on page 3 for ideas on expanding the plan.

*If a wood waste utilization plan does not exist in your community:*

- What types of wastes are generated in your community? Quantify the amount of each type of waste by approximating from facility records and from expert ‘best-guesses’. Are the wastes underutilized? How?
- Identify individuals and groups that are currently involved in generating and managing the wastes. Who within the community works with each type of waste? Are LCID T&P facilities currently used? Which ones? To what extent? What is the cost? Does the community contract with tree services? Under what circumstances? What is the cost?
- What funding/budgeting restraints are there?
- What funding opportunities exist?
- What local regulations or ordinances impact management options?
- Does a nearby community have an existing plan that could be adapted to suit your community’s needs? What aspects of their plan can be borrowed to create your plan?

## WOOD WASTE PLAN COMPONENTS

A wood waste plan is one part of a larger comprehensive urban forestry program. The plan details the procedures for routinely managing yard wastes such that the wastes are utilized in the most efficient and cost effective ways. Routine yard wastes include wastes from utility line clearings, hazardous tree removals, landscaping maintenance and other daily activities that support sustained forest health. The plan also describes a procedure for handling emergency situations that produce unexpected volumes of wood wastes (e.g. hurricanes, ice storms and insect infestations). The overall goal of the plan is

to maximize urban forest resources. Communities that formally administer plans will achieve maximum benefits. Formally written and adopted plans ensure community recognition, increase community involvement, and facilitate access to grant funding. The plan format can take any form that accomplishes the overall goal, however, at minimum a plan will contain:

- *Title* – describes the plan.
- *Purpose Statement* – defines the goals to be achieved through plan procedures and management strategies.
- *Procedures for Routinely Processing Wood Wastes* – specifies the preferred management strategies for wood wastes based on daily or routine circumstances. This section also details appropriate uses of funds generated. For examples of management options see the management strategy section of this guide starting on page 3.
- *Emergency Wood Waste Processing Procedures* – details the steps to be taken in cases of storm debris management or severe insect infestations when large volumes of wood wastes are generated. In addition to details for effectively managing the wastes, this part of the plan includes a list of arborists, tree services, and urban sawyers that are to be contacted to assist in clean up efforts. This section also has pre-determined locations for emergency debris storage and processing.
- *Documenting Procedures* – outlines protocol for documenting volumes of wastes generated, partnerships

developed and funds generated. Documentation allows for monitoring the plan, such that non-effective strategies are easily identified. The plan can be adapted as community needs shift, ensuring long-term success of the plan.

## MANAGEMENT STRATEGIES

### *Leaving wood wastes on the landscape*

A simple and cost effective strategy is to leave wood wastes such as downed limbs on the landscape. This strategy has several benefits: 1) it is the lowest cost option, 2) materials left on site provide wildlife habitat, 3) decomposition of wastes improves soil nutrients, and 4) it may be the best option for reducing urban CO<sub>2</sub> emissions (Lawler 2011). The Town of Wake Forest uses this strategy in parks and greenways to reduce costs associated with collecting, transporting and processing downed limbs. This strategy is not appropriate for downed wood from street trees or in areas where leaving debris creates public safety risks. If this strategy is adopted into a formal plan, the conditions under which it is appropriate to leave wastes on the landscape must be defined.

### *Strategies that Pay Back*

When wood wastes must be collected and transported, the costs can be decreased by generating products that can be sold or donated rather than disposed of.

#### 1. Fire Wood Programs

Hardwood logs, such as those from hazardous tree removals, can be sold for firewood, or donated to community members in need of the product. The city of Raleigh donates hardwood logs from

hazardous tree removals to the Warmth for Wake program.

(<http://www.wakegov.com/humanservices/economic/assistance/warmth.htm>).

This decreases the disposal cost for the City of Raleigh while addressing community needs.

Movement of firewood can spread insects and disease (e.g. pine beetle and hemlock woolly adelgid), which threaten the health of urban forests. If the firewood strategy is adopted, protocol to minimize the transportation of insects and disease should be defined. For example, using wood only in the community from which it was collected.

#### 2. Merchantable Timber

Hardwood and softwood logs 12-16 feet in length can be sold to mills to generate funds offsetting urban forestry program costs. The City of Raleigh uses monies generated from log sales to fund the ‘*NeighborWoods*’ program to extend the urban forest canopy by planting trees in public rights of way.

(<http://www.raleighnc.gov/government/content/PRecParks/Articles/NeighborWoodsProgram.html>)

The town of Wake Forest uses proceeds from merchantable timber to purchase forestry equipment and train personnel. Logs used in local community projects (e.g. park benches, fences, decorative features) can reduce commercial wood purchases and disposal fees for the community. Logs that are turned into timber continue to store carbon reducing CO<sub>2</sub> emissions associated with decomposition of wood. The disadvantage to this strategy is that demands and prices for logs vary based on mill quotas, therefore income can be variable and unreliable. This strategy requires that logs be removed in large sections.

*Strategies that build community and pay back*

These strategies maximize resources by engaging community members in creative wood waste management.

1. Artisan Woodworker Partnership

Local woodworkers and artisans apply to the urban forester to obtain wood from tree removals for the creation of two specific projects. The wood is provided free or at significantly reduced costs. Woodworkers and artisans first create an object or product which is donated to the forestry program. This donation is sold or auctioned to support the continuation of urban forestry efforts. Next the woodworkers and artisans use remaining wood to create an object or product for their personal use or sale.

2. High School Wood Shop Partnership

Local high school wood shop participation in the wood wastes plan is similar to the artisans partnership described above. Wood that would not be acceptable for merchantable timber or artisan use is donated to local schools for practical uses in woodshop. This provides schools free resources, while decreasing disposal costs for the community. Alternatively, students could use wood wastes to create objects for use in urban forests, such as picnic tables or park benches. This strategy also engages students in community service through urban and community forestry.

*Strategies that require LCID T&P facilities*

Mulch, compost, and hog fuel strategies require processing facilities that operate in compliance with NC DENR issued permits or notifications. Communities can pay existing LCID facilities ‘tipping fees’ to deposit urban wood wastes. Alternatively, communities can establish their own

facilities for turning urban wood wastes into mulch, compost or hog fuel. These facilities require potentially high start up investments in equipment, fuel, trained staff, and land. Additionally, NC DENR issued permits and notifications are required depending on the amount of wastes that will be processed and the overall size of the facility. Communities must weigh the start up and maintenance costs associated with creating their own facilities against paying tipping fees to use established LCID facilities.

NC SENATE BILL 111

North Carolina Senate Bill 111 (Speed et al., 1989) was a landmark bill that instigated a state-wide comprehensive program for managing solid wastes, including wood wastes. Specifically, the bill banned yard wastes from traditional landfills (NC DENR, 2010a). As a result, yard wastes must be disposed of in DENR permitted composting or land clearing and inert debris treatment and processing (LCID T&P) facilities.

All publicly and privately run facilities greater than 2 acres in size and processing or storing more than 6,000 cubic yards of yard wastes per financial quarter must apply for a DENR permit and comply with the standards of the permit (NC DENR, 2010b).

All publicly and privately run facilities less than 2 acres in size and processing or storing less than 6,000 cubic yards of wastes per financial quarter must apply for a DENR notification and comply with the standards of the notification. (NC DENR, 2010b).

For a list of operational LCID T&P facilities in your county visit:

<http://www.wastenotnc.org/swhome/lcidlst.pdf>.

### 1. Mulch

Mulch is a useful strategy for utilizing nonmerchantable timber, such as line clearing debris that has been chipped by a tag along chipper. When properly applied, mulch is generally good for maintaining moisture content in soils. Although it is not primarily intended as a soil amendment it does decompose and contributes to soil health. Communities that have NC DENR permitted mulch facilities can sell their product to landscapers or residents to offset mulch production costs, and potentially generate profits. Leaves, decaying wood, roots and other wood wastes with otherwise limited uses can be mulched, however the market price of the finished product is dependent upon quality. ‘Cleaner’ mulches that have less decay, even color and consistent size bring higher prices.

In Raleigh, wood chips are generated from utility line clearings some of those wood chips are applied as “raw-mulch” (meaning it hasn’t gone through the mulching process) in parks. In the fall, leaves are collected and applied as a ‘mulch’ in Raleigh city parks as a soil amendment. Proper application of raw mulches is a good alternative to communities that lack mulching facilities.

### 2. Compost

Compost is a good strategy for wastes including leaves, roots, decaying materials, and wood from utility line clearings that has been chipped by a tag-along chipper. Compost is a soil amendment and an excellent natural alternative to chemical fertilizers to establish and maintain healthy urban forests. Compost can be used in place of more expensive chemical fertilizers to reduce the costs associated with fertilizer purchase.

Communities that have NC DENR permitted composting facilities sell compost to

landscapers or residents to offset operating costs, or in some cases even generate profits. In Raleigh, most wood is chipped by tag-along chippers that are attached to dump trucks and taken directly to the city yard-wastes composting center

(<http://www.raleighnc.gov/environment/content/SolidWaste/Articles/YWProductsForSale.html>). Materials that have been stained or pressure treated are not appropriate for composting because the chemicals in the material will leach into the finished product, creating environmental and human health risks.

### 3. Hog Fuel

Hog fuel is a common term used to describe wood that is chipped and burned in a boiler to generate electricity. Specific boilers are built to burn only hog fuel, but hog fuel can be co-fired with coal in standard coal boilers (U.S. DOE EERE, 2004). Hog fuel emits about half as much CO<sub>2</sub> as coal for any given amount of electricity production (Briggs, 1994; Hong and Slatick, 1994). Therefore replacing coal with hog fuel both reduces reliance on fossil fuels and cuts CO<sub>2</sub> emissions in half.

Using hog fuel to create electricity does present several challenges. Communities must have or secure access to hog fuel burning boilers, or coal boilers into which they can add the hog fuel. Sale to outside businesses with boilers is possible, but mulch is currently more valuable than hog fuel (Lawler, 2011). Burning solid wastes also requires permitting from NC DENR, Finally, burning a community’s urban yard wastes typically can produce less than 2% of the electricity they need. The amount of electricity potentially produced from the hog fuel should be calculated to determine if and how hog fuel can contribute to the urban and community forestry program. For example, wastes may be useful to power businesses

such as a college or hospital campus or for electricity generation in municipal buildings such as the town hall or community center.

## CONCLUDING CONSIDERATIONS

Ultimately, each community must determine the most appropriate utilization strategies for specific circumstances. A diversified approach including leaving wood wastes on site when possible and mulch production would be a good starting point for most communities. Compost production and burning hog fuel are logistically more difficult but may prove beneficial for some communities.

Communities that consider the types and quantities of wastes before selecting management strategies will achieve the greatest financial efficiency in their programs. Communities that consider the full life cycle of their wood wastes will increase the efficiency of urban and community forestry programs, offset program operating costs, reduce CO<sub>2</sub> emissions associated with urban forests, and assist in the creation of resilient urban forest ecosystems. All management strategies should be considered as part of a larger urban forestry effort, which considers holistic approaches to sustained urban forest health. An adaptive urban forestry program that utilizes its waste in all aspects of management can be more efficient and more environmentally sustainable.

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## **Conclusion**

This research evaluated the feasibility of utilizing municipal biomass residues (MBR) for energy production. Results suggest that the strategy is not socially feasible at this time because residents prefer other utilization strategies above burning to generate electricity. Lack of economic incentives and poor communication between MBR managers and state agents further inhibit MBR utilization. Finally, it is unlikely that significant reductions in CO<sub>2</sub> emissions would be realized through management of MBR only.