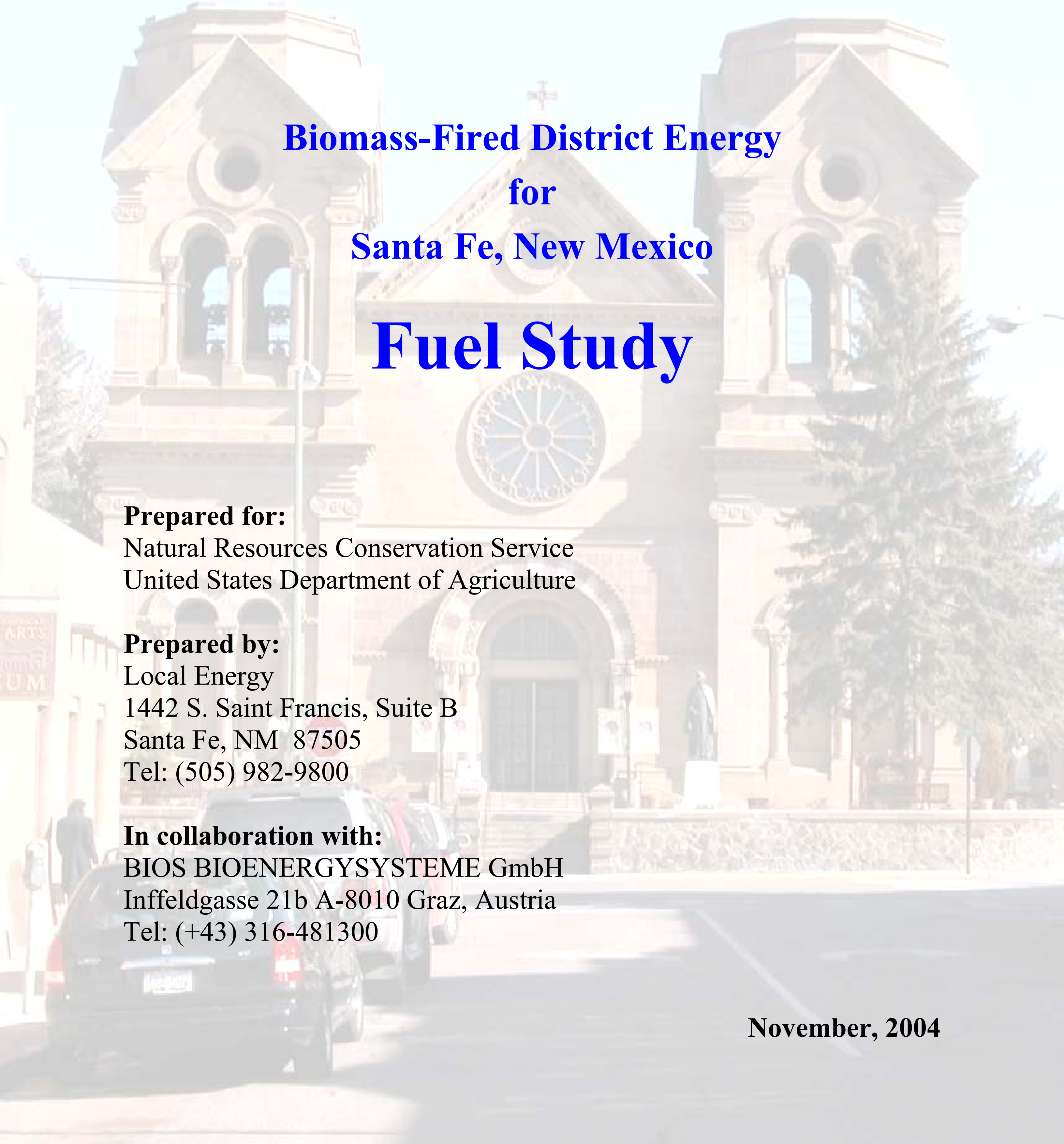


Biomass-Fired District Energy
for
Santa Fe, New Mexico

Fuel Study

Prepared for:
Natural Resources Conservation Service
United States Department of Agriculture

Prepared by:
Local Energy
1442 S. Saint Francis, Suite B
Santa Fe, NM 87505
Tel: (505) 982-9800

In collaboration with:
BIOS BIOENERGYSYSTEME GmbH
Inffeldgasse 21b A-8010 Graz, Austria
Tel: (+43) 316-481300

November, 2004

Acknowledgements

This study was made possible by a grant from the United States Department of Agriculture under the Biomass Research and Development Initiative, a program that it co-manages with the United States Department of Energy.

The authors would like to acknowledge a number of people who helped make this study possible. First, for their joint resolution in support of our effort, we would like to thank Santa Fe City Councilors Patti Bushee, Miguel Chavez, David Coss, Karen Heldmeyer, Matthew Ortiz, David Pfeffer, Carol Robertson-Lopez, and Rebecca Wurzburger, and Santa Fe County Commissioners Mike Anaya, Paul Campos, Paul Duran, Harry Montoya, and Jack Sullivan. Additional thanks goes to Bill DeGrande, Richard Fiedler, Craig Fiels, Robert Gallegos, Mike Lujan, and Lawrence Ortiz from the City of Santa Fe; Rudy Garcia, Ish Lovato, Vincent Ojinaga, and Shawn Thornton of Santa Fe County; Jill Holbert and Justin Stockdale from the Santa Fe Solid Waste Management Agency. For their time and patience providing detailed biomass data to us, we are indebted to New Mexico State Forestry Fuels Specialist James T. Johnston, USDA NRCS Soil Scientist Aaron J. Miller, USDA Forest Service Regional Measurement Specialist Steve Marsh, Regional Mensurationist Jeff Hog, Forest Fuel Specialist Chris Nap, Biomass Specialist Jerry Payne, and a number of Fire Management Officers.

Credits

Program Officer:	Dr. Glenn Carpenter – NRCS
Bioenergy Specialist:	Jerry Payne – USDA Forest Service
Project Director:	Mark Sardella, PE – Local Energy
Technical Specialist:	Prof. Dr. Ingwald Obernberger – BIOS BIOENERGIESYSTEME GmbH
Project Managers:	Boaz Soifer, Charles Lamson – Local Energy
Senior Engineer:	Alfred Hammerschmid M.S. – BIOS BIOENERGIESYSTEME GmbH
Senior Engineer:	Klaus Supancic M.S. – BIOS BIOENERGIESYSTEME GmbH
Junior Engineer:	Thomas Baernthaler M.S. – BIOS BIOENERGIESYSTEME GmbH
Junior Engineer:	Heath Blount – Local Energy
Report Authors:	Thomas Baernthaler, Charles Lamson, Mark Sardella, Boaz Soifer, Klaus Supancic, Ingwald Obernberger

Disclaimer

Cover Photo

Saint Francis Cathedral, as seen from the Plaza in Santa Fe, New Mexico. Photo by Klaus Supancic.

Table of Contents

List of Figures

List of Tables

Abbreviations and notation

(in alphabetical order)

BTU	British thermal unit
cm	Centimeter (= 0.39 inches)
d.b.	Dry base
GCV	Gross caloric value
kW	Kilowatt
kWh	Kilowatt-hour
MMBTU	1 Million British thermal units (= 293.07 kWh)
mm	Millimeter (= 0.039 inches)
NCV	Net calorific value
w.b.	Wet base
WUI	Wildland Urban Interface
(w/w)	Percent by Weight
Al	Aluminum
Ca	Calcium
Cd	Cadmium
Cu	Copper
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
O	Oxygen
P	Phosphorus
Pb	Lead
S	Sulfur
Si	Silicon
Zn	Zinc

Abstract

This report documents the methodology, results, and conclusions for a fuel study within a 50-mile radius of Santa Fe. The fuel study is part of the "Biomass-Fired District Energy for Santa Fe" project funded through the U.S. Department of Agriculture, which is an assessment of the feasibility and benefits of developing biomass district energy in Santa Fe. The fuel study informs the project of fuel availability, quality, and cost, and provides input parameters for economic optimization of the system as well as calculations regarding the biomass boiler and combustion zone, fuel storage and handling facilities, and emissions rates. The study includes identification of potential fuel resources, chemical analyses of samples from these resources, and investigation of both current and potential long-term fuel availability and cost. The study is further informed by data from European biomass energy applications, including chemical composition, cost, storage, and handling methods.

The investigation of fuel availability reveals four categories of biomass sources: wood residues from forest-thinning projects, municipal green waste from landfills and waste transfer stations, commercial green waste from wood processing companies, and products of state-funded forest-thinning projects on private land. This last resource is not investigated in this study due to its likely overlap with the municipal green waste supply. The fuel categories each have different characteristics with respect to quantity, availability, cost, and quality. A chemical analysis of biomass samples collected from 10 different sources representing the three investigated fuel-source categories is conducted, revealing that the quality of available biomass varies considerably from one source category to the next.

An analysis of current costs, including transportation of biomass fuel to Santa Fe, reveals great differences in current costs between the different source categories.

The wide variety of available biomass sources of varying qualities necessitates development of appropriate fuel processing systems and logistics to ensure optimal fuel quality. Moreover, appropriate design of heating-plant components is needed to allow fuel flexibility, reliable operation, and efficient thermal utilization of the biomass fuel.

Possible means of ash utilization are investigated in order to achieve optimal sustainability of biomass utilization. The application of ash to soil as a fertilizer on farmland and in forests appears to be a promising way to close the mineral cycle if only natural biomass fuels are used.

The results of this study indicate sufficient fuel availability for the district energy systems under investigation for Santa Fe. Furthermore, the relatively low cost of biomass fuel from commercial and municipal green-waste sources suggests that cost-effective utilization system is possible. The collaboration of forest agencies and fuel buyers will be necessary to reduce costs and achieve competitive fuel prices for biomass from forest thinnings. The analysis of fuel quality reveals that while some sources are inferior, particularly regarding ash content, significant improvements could most likely be achieved by improving handling and storage methods to reduce contamination of the fuel. All of these results bode well for construction of biomass-fired district energy systems in Santa Fe.

Kurzfassung

Der vorliegende Bericht fasst die Ergebnisse und Schlussfolgerungen aus der Evaluierung der vorhandenen Biomassebrennstoffressourcen im Umkreis von 50 Meilen um Santa Fe zusammen. Diese Studie ist Teil des vom U.S. Department of Agriculture geförderten Projekts “Biomass-Fired District Energy for Santa Fe”, das die Erstellung einer Machbarkeitsstudie für ein Biomassefernheizwerk in Santa Fe zum Ziel hat. Die Brennstoffevaluierung gibt Aufschluss über Brennstoffqualität, Kosten und Verfügbarkeit der Biomasse und bildet eine der Grundlagen für die Auslegung von Biomassefeuerung und Kessel sowie für Brennstofflager, Brennstoffbeschickung und Rauchgasreinigung. Die Studie beschäftigt sich mit der Erhebung von potenziellen Brennstoffressourcen, der chemischen Analyse von repräsentativen Brennstoffproben von diesen Ressourcen sowie mit der Evaluierung der derzeit und langfristig verfügbaren Brennstoffmengen und deren Kosten. Die erhaltenen Ergebnisse werden mit vorhandenen Daten und Erfahrungen hinsichtlich Qualität, Kosten sowie Brennstofflagerung und -handling aus Europa verglichen und bewertet.

Die Erhebung von potenziellen Brennstoffressourcen ergibt vier verschiedene Kategorien: Waldhackgut aus Durchforstungsprojekten, unbehandelte Holzabfälle von öffentlichen Deponien, Nebenprodukte aus der holzverarbeitenden Industrie sowie Hackgut aus staatlich geförderten Durchforstungsprojekten auf privaten Ländereien. Die letzte Kategorie wird in diesem Bericht nicht näher behandelt, da anzunehmen ist, dass ein Großteil der Biomasse aus diesen Projekten ohnehin auf die erhobenen Deponien gebracht wird. Die verschiedenen Brennstoffressourcen variieren hinsichtlich Menge, Qualität, Verfügbarkeit und Kosten.

Eine chemische Analyse von 10 repräsentativen Proben zeigte teilweise beachtliche Unterschiede in der chemischen Zusammensetzung und Qualität der Brennstoffe.

Die Erhebung der Brennstoffkosten inklusive Transport zu einem Heizwerk in Santa Fe sind ebenfalls von der gewählten Ressource abhängig und variieren teilweise beträchtlich.

Die große Anzahl potentieller Biomasselieferanten sowie die unterschiedlichen Qualitäten der vorhandenen Biomassebrennstoffe stellen große Anforderungen an die Logistik und Qualitätssicherung der Biomassebrennstoffe sowie an die korrekte Auslegung des Heizwerkes, um eine kostengünstige und verlässliche Brennstoffversorgung sowie einen effizienten Brennstoffeinsatz zu ermöglichen.

Weiters werden Verwertungsmöglichkeiten der anfallenden Asche bewertet, um eine möglichst nachhaltige Nutzung der Biomasse zu erreichen. Die Verwendung von Asche als Dünger für landwirtschaftliche Flächen und Wälder erscheint als vielversprechendste Möglichkeit, den Nährstoffkreislauf so weit wie möglich zu schließen.

Die im Rahmen der Studie ermittelte, nachhaltig verfügbare Menge an Biomasse ist für die Brennstoffversorgung eines Fernwärmesystems in Santa Fe ausreichend. Die Brennstoffkosten für Biomasse von holzverarbeitenden Betrieben und öffentlichen Deponien liegen auf niedrigem Niveau, so dass eine wirtschaftliche Nutzung dieser Ressourcen möglich ist. Die enge Zusammenarbeit von Forstbehörden und Brennstofflieferanten wird notwendig sein, um die

Kosten für Waldhackgut zu reduzieren und wettbewerbsfähige Preise zu erreichen. Eine deutliche Verbesserung der Brennstoffqualität, insbesondere eine Reduzierung des Aschegehalts durch die Vermeidung von Verunreinigungen durch anorganisches Material, erscheint durch die Verbesserung der Brennstoffverarbeitung und -lagerung möglich Generell sprechen die erhaltenen Ergebnisse der Brennstoffstudie für die Errichtung eines Fernwärmesystems in Santa Fe.

1 Introduction

This fuel study report is a component of the project entitled “Biomass-Fired District Heating for Santa Fe” funded by the United States Department of Agriculture. The removal of biomass fuel from the forests of New Mexico, and specifically in those forests within a 50-mile radius of Santa Fe, can serve a dual function. In addition to providing fuel for district energy, thinning forests is needed to reduce the widely publicized fire danger that the overburden presents.

The urgent need to thin forests in New Mexico is complicated by a difficult economic situation. Thinning projects in the forests can cost upwards of $1,400 per acre according to the State Land Office, and one of the forest-thinning projects investigated in this study is even more costly. The high cost of thinning slows the pace below what is needed to effectively restore forest safety and health. New Mexico’s difficult economic situation is exacerbated by recent increases in energy costs. Meanwhile, wholesale natural gas prices continue to climb on news of record low storage levels, poor drilling results, and high depletion rates in the most productive basins. Everyone suffers from higher energy costs, but New Mexicans are especially vulnerable to energy price hikes because they already spend well above the national average, as a percentage of their income, to meet their energy needs [1].

From the intersection of these two crises – dangerously overgrown forests too expensive to thin and rising energy costs threatening New Mexico’s economy – comes the impetus for this project. By structuring biomass energy projects in New Mexico as tools of economic development, the safety and health of New Mexico forests can be quickly improved while fostering rapid growth of a stable, secure, and sustainable energy industry. This project seeks to further the understanding of that process, and to put it into practice locally.

This report summarizes the investigations of biomass fuel availability surrounding Santa Fe. A sustainable, reliable, and cost-effective supply of high-quality fuel is required for economically and environmentally beneficial operation of biomass-fired energy systems. The work described in this report is prerequisite for further engineering design of optimized fuel handling, combustion and flue gas cleaning, ash handling, and ash utilization systems. The results of the inquiry will also be used to determine the economic feasibility and environmental benefits of both centralized and decentralized approaches to biomass energy supply.

Research for this study was conducted collaboratively with representatives of the Forest Service, the City of Santa Fe, and a host of commercial businesses. It will be important to continue this collaboration once biomass energy systems begin to be constructed and operated in Santa Fe.

Objectives

The purpose of this study is to gather and analyze information and data on biomass fuel availability around Santa Fe, and to assess the adequacy of that biomass as a fuel source for biomass-fired district energy systems in Santa Fe, New Mexico. The results of this fuel study, including the quantity and quality of the available biomass fuels, expected fuel costs, recommendations for appropriate fuel storage, handling, combustion, and ash utilization, are important input parameters for subsequent design and economic calculations.

The fuel study addressed the following objectives:

- ***Identification of available biomass sources in the Santa Fe area:*** The study sought to identify the available biomass resources within a 50-mile (80 km) radius of Santa Fe. The identification focused on forest-thinning projects, municipal waste streams, and commercial fuel sources.

- ***Determination of the sustainable yield of biomass from these sources:*** The study sought to assess the quantity of biomass that could be harvested sustainably from the identified sources. The information was gathered by interviewing forest specialists, recycling coordinators, and managers or owners of wood processing facilities.

- ***Investigation of the biomass fuel costs:*** The study sought to determine the total cost to obtain fuel from the identified sources, including material and transport costs. The information was gathered by interviewing forest specialists, recycling coordinators, and managers or owners of wood processing facilities, as well as by studying the data and trend of biomass fuel prices in Europe.

- ***Determination of the quality of the available biomass fuels:*** The study sought to determine the physical characteristics (moisture content, particle size) and chemical characteristics (ash content, net calorific value, composition) of the available biomass, and to use these data to evaluate the quality of the available biomass. This was done by performing chemical analysis tests on 10 biomass samples representing the variety of available biomass sources, and by interviewing forest specialists, recycling coordinators, and managers or owners of wood processing facilities.

- ***Characterization of the ashes produced from biomass combustion and evaluation of their utilization potential:*** The study sought to calculate the chemical composition of the ashes that would be produced from combustion of the biomass, and to evaluate the possibilities for environmentally sound utilization of the ash. This was done using the results of the chemical analysis tests and also by interviewing soil scientists, and by studying the utilization of ash from biomass combustion in Europe.

- ***Formulation of recommendations regarding fuel preparation, logistics, and storage in order to secure an acceptable fuel quality at reasonable prices:*** The study sought to develop recommendations for ensuring appropriate levels of fuel reliability and quality at a reasonable fuel price. These recommendations were based on the results of the quality and quantity surveys, including the assessments of potential fuel sources, interviews with forest specialists and recycling coordinators, and discussions with managers or owners of wood processing facilities.

- ***Formulation of recommendations for appropriate thermal conversion of the biomass fuels:*** The study sought to determine the requirements for the components and systems needed to ensure efficient thermal utilization, acceptable availability of the combustion plant, and good fuel flexibility. This included specification of the fuel feeding system, the furnace and boiler technologies, the flue gas cleaning system, and the ash handling system.

2 Methodology

2.1 Determination of the Project Area

Primary consideration for this report is given to potential biomass resources within a 50-mile (80 km) radius of the city of Santa Fe. This includes several areas of national forest land, several municipal landfills and transfer stations, as well as an array of private businesses whose waste products could be relevant as a fuel supply. Since biomass has a relatively low energy density, it is essential that ample fuel be available nearby a biomass facility. Furthermore, as fossil fuel costs increase so will the cost of transporting biomass fuel, and the transportation distance must therefore be kept to a minimum. If results of this initial study reveal an inadequate supply of biomass within the prescribed radius, a study of a wider area will be undertaken.

2.2 Identification of Potential Biomass Sources

Biomass sources within the prescribed radius were categorized into three groups: forest-thinning projects, municipal waste, and private businesses.

Forest thinning projects were identified through interviews with State Forestry Fuels Specialist, James T. Johnston.

Municipal waste sources were identified through interviews with Justin Stockdale, recycling coordinator at Caja del Rio Landfill in Santa Fe, and from Santa Fe County's website [2].

Private businesses were identified by a search of the Yellow Pages for sawmills, lumber mills, wood furniture manufacturers, woodcarvers, woodturners, and other wood-processing companies. The search focused on the more proximal sources, primarily in the areas of Santa Fe, Pecos, Espanola, and Los Alamos.

An additional source of biomass fuel is available through state-funded thinning projects on private land. This resource likely overlaps the municipal green-waste supply, however, since biomass removed from private land is often disposed of at municipal landfills. Because of this overlap, this source was not investigated in this study. Intercepting this source prior to disposal, thereby reducing its cost and gaining better control over its quality, will be considered at a later date.

2.3 Data Collection

2.3.1 Type of Source

Several sources of biomass fuels were identified in the Santa Fe area, including forest-thinning projects, municipal green-waste collection and processing, and private commercial green waste.

Forest Thinning Projects

Forest Thinning Projects are being conducted in the Wildland Urban Interface (WUI) areas of three ranger districts within the prescribed radius: the Espanola Ranger District, the Jemez Ranger District, and the Pecos Ranger District. Representatives of these ranger districts were interviewed regarding the quantity, quality, and cost of available biomass fuel in the areas currently being thinned as well as in areas where thinning is planned in the near future.

Municipal Green Waste Sources

Justin Stockdale, Recycling Coordinator at the Caja del Rio Landfill, was interviewed regarding the quantity, quality and cost of the green waste currently being delivered to the landfill from private individuals and from other nearby transfer stations.

Commercial Green Waste Sources

Managers and owners of private wood-processing businesses were interviewed to determine the quantity, quality and cost of the available green waste currently being produced as a byproduct of their work. Most of the businesses interviewed were timber processing facilities.

2.3.2 Location

The locations of the current forest-thinning projects as well as the municipal and private green waste sources within the prescribed radius were researched and identified. Distances to Santa Fe were measured or estimated. This information will be used to estimate and optimize the economic performance of the biomass district-heating system’s fuel supply, and to ensure long-term fuel stability.

2.3.3 Type and Quality of Available Biomass

Within each category of fuel source, the following parameters were researched: tree species, particle size when processed, moisture content, and harvesting, processing, and storage methods. Research on storage conditions focused primarily on whether sites were paved or unpaved, and used roofed or exposed (outside) storage areas.

Additionally, chemical analyses of 10 representative biomass fuel samples were carried out by BIOS BIOENERGIESYSTEME GmbH in Austria in order to obtain detailed information about their relevant specific combustion parameters. See Section 2.5.

The research on biomass type and quality will be used to ascertain the long-term viability of the available biomass resource, and to foresee any logistical challenges in reliably delivering processed fuel of usable quality to a biomass-fired district energy system.

2.3.4 Quantity of Available Biomass

The available quantity of biomass fuel from all sources within the study area were converted to units of short tons per year, and summed. Due to the present intensity of forest thinning initiatives and the simultaneous piñon die-off, current fuel availability is very high. Efforts were made to estimate fuel availability over a 10- to 15-year period. In the case of forest thinnings, this required the application of rules-of-thumb to estimate future fuel availability. An important rule-of-thumb was used to estimate the long-term fuel availability from a given thinning project based on the volume thinned in the first pass. These rules-of-thumb were compiled from interviews with Forest Service professionals [3], and yielded the conversion factors and methods referred to later in this section.

In many forest-thinning projects both merchantable wood and slash is removed. The sale of merchantable wood is sometimes used to subsidize the treatment of smaller diameter timber or "slash". Any timber with a diameter less than 4-inch (10 cm) is considered slash, and is not generally suitable for sale. Slash is typically piled on-site and burned in open air, creating a significant environmental concern since open-air burning releases notable quantities of harmful emissions as well as greenhouse gases. Merchantable material is typically sold through existing lumber distribution networks, and its value as a product exceeds its value as a fuel by enough that it is not considered available for use in a biomass heating system.

The conversion factors shown below are intended only as rules-of-thumb, since many variables including tree height, density, and moisture content affect the accuracy of estimates obtained by using them.

Conversions used to standardize the quantities reported from forest-thinning projects [3]:

- *Board-feet to cubic feet:*

  5 board feet = 1 cubic foot (0.28 cubic meters)
- *Cubic feet of slash to slash per ton:*

  100 cubic feet (2.8 m^3) of slash = 1 ton (0.91 metric tons)
- *Board-feet per ton:*

  500 board-feet = 1 ton (0.91 metric ton)
- *Average Board Feet per Acre:*

  1,500-2,400 board-feet per 1 acre (0.4 per hectare)
- *Basal area to number of trees:*

  1 square foot of basal area represents 1-4 trees

Additional conversions factors used to calculate available green waste from commercial and municipal sources:

Bark/woodchips:	1 yard (27 cubic feet/0.76 cubic meters) = 0.25 ton (0.23 metric tons)
Sawdust:	1 yard (27 cubic feet) = 0.125 tons (0.11 metric tons)

These conversions were provided by Justin Stockdale [4] and were confirmed by a number of owners and managers of commercial sources of green waste. The conversions assume a moisture content of 30 to 45 percent (w/w; w.b.) for bark and woodchips, and 20 to 25 percent (w/w; w.b.) for sawdust, depending on the tree species and particle size. Based on the experience of BIOS BIOENERGIESYSTEME GmbH, these values are plausible. However, the actual moisture content of the biomass can fluctuate significantly depending on processing technology, the term of the storage period, and the source of the biomass.

Methodology used to estimate sustainable fuel yield from forest-thinning projects:

Estimations of the long-term potential biomass yield from forest-thinning projects relied heavily on a single rule-of-thumb provided by James T. Johnston, State Forestry Fuels Specialist [5]:

The amount thinned in the first pass to restore the forest to its approximate natural condition is equal to 3 times the amount that would need to be thinned to achieve the same result in 5 years. The annual sustainable fuel resource from a forest thinning project can therefore be estimated by the amount thinned in the first year divided by 3 and then divided by 5. This means that the sustainable yield from a forest is about one-fifteenth of the amount removed during the first pass.

Example: 2 tons (1.8 metric tons) per acre are available in year one, therefore 0.67 tons per acre (0.24 metric tons per hectare) are available in year 5, and every fifth year thereafter. On an annual basis this amounts to 0.133 tons per acre (0.5 metric tons per hectare) per year, not including the initial thinning.

Note that this formula gives an approximate annual amortization of fuel, while in actuality the fuel is not made available annually. It is estimated by Jerry Payne of the USDA Forest Service [6] that return thinning will instead be done approximately every twenty years.

2.3.5 Actual Biomass Fuel Costs

An effort was made to quantify the costs associated with bringing biomass from each of the three source categories to a biomass energy plant in Santa Fe. The current state of availability of the fuel was considered, and estimates were made from this point forward regarding the cost of further processing, transport, and delivery to Santa Fe.

Methodology for determination or estimation of fuel costs:

Commercial green waste currently has an established economic outlet and a stable cost in that sawdust and woodchips are commonly used as mulch and to prevent erosion. The actual costs for biomass from commercial sources were determined by interviewing the owners and managers of commercial sources of green waste.

No such cost structure or market exists for municipal green waste or forest thinnings. Estimations therefore had to be made based on extrapolations of known costs and from interviews with forest specialists and with Justin Stockdale, Recycling Coordinator at the Caja del Rio Landfill.

The estimated fuel costs were checked for plausibility by comparing them with actual fuel cost data from European countries.

Methodology for estimation of transportation costs:

Transportation costs were estimated based on interviews with several trucking and hauling companies in Santa Fe, with Justin Stockdale (who manages the transport of other recyclable materials and is therefore familiar with such costs), and with Bill Althouse of Althouse Inc., who has informally conducted studies of this nature.

Estimations of transport costs included consideration of the distance from the biomass source to Santa Fe and the amount of biomass that can be transported per trip.

2.4 Collection Of Biomass Fuel Samples

At least three biomass samples from each of the three different source categories (forest-thinning projects, municipal and commercial green waste sources) were collected to obtain representative information from all available biomass sources. A description of all collected biomass samples is outlined in Section 4.5.

For each sample, biomass from two to three different locations within a pile was collected and mixed to minimize the influence of inhomogeneity of moisture, species, and particle size within the pile. Biomass from the surface of piles was not collected because the moisture content of the surface layer of a pile does not generally represent the average moisture within the pile. The weight of each sample was 1-4 lbs (0.5-1.8 kg).

It is very important that the collection of samples adequately represents the potential fuel sources available, because the chemical analysis of these samples, discussed below, is a critical part of this fuel study.

2.5 Chemical Analysis Of Biomass Fuels

The chemical analysis of the representative fuel samples is necessary to acquire detailed information about all relevant combustion parameters of the available biomass. Such parameters include moisture content, ash content, gross and net calorific value, and chemical composition.

The chemical analyses were performed by BIOS BIOENERGIESYSTEME GmbH in Austria using state-of-the art methods specifically developed for biomass fuels and designed to ensure correct and complete detection of the elements investigated.

The results of the analyses were compared with average values obtained during tests of similar types of biomass from central Europe. The average values are derived from numerous chemical analyses performed by BIOS BIOENERGIESYSTEME GmbH over the past eight years, archived in BIOS' internal biomass fuel database. The averages and standard deviations calculated using the database represent typical values for woodchips and bark throughout central Europe. See Section 4.6.2.

2.5.1 Description of Analysis Methods

The analysis of biomass fuels includes two steps: sample preparation, and the analysis procedure itself. These steps are described below.

2.5.1.1 Sample Preparation

The following steps were undertaken to prepare the samples for analysis:

- Milling of the whole sample (as delivered) in a cutting mill (resulting particle size < 4 mm).
- Sample division: Each complete milled sample (about 400 g each) was formed into a cone-shaped pile. Each pile was then divided into four sub-samples. The sub-samples located opposite from one another, each representing a quarter of the original material, were mixed and a new pile was formed of this material. The resulting conical pile was also divided into four sub-samples and the opposite quarters were again mixed. The resulting mass of the final sub-sample was about 100 grams. See Figure 1.

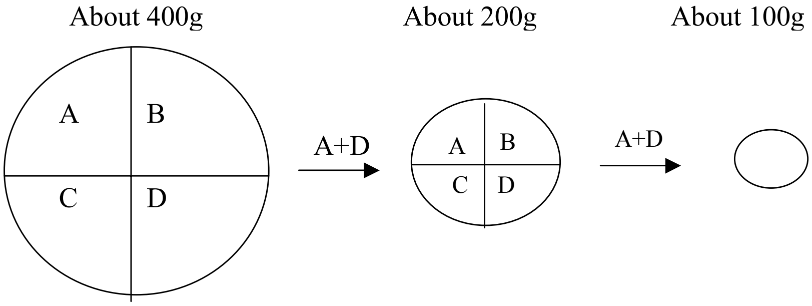


Figure 1: Sample Division

- Milling in an ultra-centrifugal mill equipped with titanium rotor and screen (resulting particle size < 0.2 mm).

2.5.1.2 Analysis Procedures

2.5.1.2.1 Determination of the Moisture Content

Moisture content (by weight) was determined for each sample using the Austrian Standard ÖNORM G 1074. Per this standard, each complete (as-delivered) sample was weighed before and after drying at 221°F (105°C).

2.5.1.2.2 Determination of Al, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Si, and Zn Content

Determinations of the content of these elements within the samples were made using multi-step pressurized digestion with HNO_3 (65 percent) /HF/ H_3BO_3 as follows:

- Graphite furnace atomic absorption spectroscopy (GFAAS) was used to measure the Cd, Cu, Ni, Pb in the sample. *Analyzer: GBC GF 3000 AVANTA S.*
- Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used to measure the Al, Ca, Fe, K, Mg, Mn, Na, P, S, Si, and Zn in the sample. *Analyzer: VARIAN VISTA-MAX.*

2.5.1.2.3 Determination of Cl Content

Determination of Cl content in the samples were made as follows:

Digestion: Bomb Combustion in Oxygen; Absorption in NaOH (0.05 molar)

Measurement: Ion Chromatography

Analyzer: DIONEX IC-90

2.5.1.2.4 Determination of C, H and N Content

Determination of the C, H, and N contents in the samples were made as follows:

Measurement: Elemental Analysis

Analyzer: CARLO ERBA EA 1108

2.5.1.2.5 Determination of the Ash Content

The ash content of each sample was measured according to SS 187171: Determination of the loss of ignition at 550°C.

2.5.1.2.6 Calculation of the O Content

Calculation of the oxygen content in the samples were made by assuming that oxygen makes up remaining unaccounted-for weight of the samples, as follows (Equation 1):

$$\text{O\% (w/w; d.b.)} = 100 - (\text{\% sum of all other elements analyzed}) \text{ (w/w; d.b.)} \quad \textbf{\textit{(Equation 1)}}$$

2.5.1.2.7 Measurements, Plausibility Check, and Quality Assurance

The digestion procedure was conducted twice for each of the analyzed samples. In addition, two control samples were analyzed. One control sample, called a blank sample, was known to not contain any of the compounds to be measured. The other, a reference material (NCS DC73348 (GBW07602), was known to contain specific quantities of these compounds. These controls were analyzed in parallel with the subject material. The data resulting from analysis of the controls were compared to their known values to verify the calibration of the equipment and to verify that the analysis process was free of contamination. The sum of the oxides of all analyzed ash-forming elements (Al, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Si, Zn) was compared to the measured ash content of each sample.

2.5.1.2.8 Calculation of Gross and Net Calorific Value

Based on the results of the chemical analyses performed, the gross calorific value (GCV) and the net calorific value (NCV) of the samples were calculated. The equations used for this calculation are listed below:

Empirical Equation for the Calculation of the Gross Calorific Value (GCV)[7]:

$$GCV = 0.3491{*}X_C + 1.1783{*}X_H + 0.1005{*}X_S - 0.0151{*}X_N - 1.034{*}X_O - 0.000211{*}X_{ash} \quad \text{[MJ/kg (d.b.)]}$$

(Equation 2)

Where: X_x = content of carbon (C), hydrogen (H), sulfur (S), nitrogen (N), oxygen (O) and ash. All values in (w/w; d.b.)

Equation for the calculation of the net calorific value (NCV):

$$\mathrm{NCV} = \mathrm{GCV} \cdot \left(1 - \frac{w}{100}\right) - 2.447 \cdot \frac{w}{100} - 2.447 \cdot \frac{h}{100} \cdot 9.01 \cdot \left(1 - \frac{w}{100}\right) \quad [\mathrm{MJ/kg\,(w.b.)}]$$

(Equation 3)

Where: NCV = Net Calorific Value in MJ/kg fuel w.b.
GCV= Gross Calorific Value in MJ/kg fuel d.b.
w = Moisture Content of the Fuel in percent (w/w; w.b.)
h = Hydrogen Content of the fuel in percent (w/w; d.b.)

2.5.1.2.9 Calculation of Ash Composition

The chemical composition of the ash content of each sample was calculated using the results of the chemical analysis. This calculation is based on the assumption that all of the ash-forming elements will be present in the ash after combustion takes place. This is true for most ash forming elements, although some of the sulfur and chlorine can exit in gaseous form with the flue gases. The calculated ash composition accurately represents the total ash, however, including the bottom ash and all fly-ash fractions. The enrichment or depletion of certain elements in the different ash fractions, which occur due to the different volatilities of ash-forming elements and also due to different precipitation temperatures of different ash fractions, cannot be accounted for in the calculation performed here.

The composition of the total ash of each biomass fuel sample can be calculated as follows for every element analyzed in each biomass fuel sample:

$\mathrm{Content}\ (X)_{ash} = \mathrm{Content}\ (X)_{biomass}\ /\ \mathrm{Ash\ Content}$

(Equation 4)

Where: $\mathrm{Content}\ (X)_{ash}$ = content of the element X in the ash of the sample (w/w; d.b.)
$\mathrm{Content}\ (X)_{biomass}$ = content of the element X in the raw biomass sample (w/w; d.b.)
Ash Content = ash content of the biomass sample (w/w; d.b.)

2.6 Evaluation of Fuel Quality

The quality of the biomass samples was evaluated by comparing the results of the chemical analyses with mean values collected from central European samples of wood chips and bark. The influence of each analyzed parameter on the combustion behavior of the biomass was considered in this comparison.

The results of the evaluation of the analyzed biomass samples are discussed in Section 4.6.3.

2.7 Identification of Ash Utilization Possibilities

Considering that the maximum estimated substitutable heat demand for customers within the target area of the planned district heating system in Santa Fe is roughly 215,000 MMBTU (63,000 MWh) per year, a considerable amount of biomass has to be utilized to provide heat for all connected customers. (See Reference [8], Main Grid, Option 1, Waste Transfer Station, Heat Only. Also see Section 4.3.5.)

The ash content of biomass fuels typically ranges from 0.5 percent (w/w; d.b.) for soft wood to 4-8 percent (w/w; d.b.) for bark and most herbaceous biomass fuels. Table 1 shows that the amount of ash in a biomass fuel is strongly influenced by bark content. This is a result of the higher ash content of bark as well as the greater prevalence of mineral impurities such as sand, earth, and stones in the bark.

Different types of biomass also have different levels of ash content. Straw, cereals and other herbaceous biomass fuels have ash contents that are higher than wood due to their greater intake of nutrients during their growing periods. Waste wood contains high amounts of mineral and metallic impurities as well as contaminants from its original manufacture and use.

Table 1: Fuel-Specific Ash Content of Various Biomass Fuels

Biomass fuel used	Ash content [%]
Bark	5.0 - 8.0
Wood chips with bark (forest)	1.0 - 2.5
Wood chips without bark (industrial)	0.8 - 1.4
Sawdust	0.5 - 1.1
Waste wood	3.0 - 12.0
Straw and cereals	4.0 - 12.0
Miscanthus	2.0 - 8.0

Notes: The ash content is given in percent (w/w, d.b.). The ash content measurement was carried out according to ISO 1171-1981 at 1,022°F (550°C); Source: [9], [10]

The ash content of the fuel is an important input parameter for designing the biomass plant's ash-removal and transportation system, and the ash storage facilities. Moreover, the ash content influences the selection of combustion, boiler, and dust precipitation technologies. From a technical point of view, fuels with lower ash content are more desirable because they result in less ash residue, allowing a simple ash-removal system and reducing costs for storage and disposal of the ash. Higher ash fuels not only result more ash residue per unit of energy produced, they also increase ash-related problems such as deposit formation, slagging, and dust emissions.

The volume and chemical composition of the ash determine its possible utilization. For sustainable biomass utilization it is essential to try to close the material fluxes and to reintegrate the biomass ashes to natural cycles. The utilization of ash as a fertilizer on farmland and in forests is an example of this reintegration. The stages of this cycle include: minerals – soil/nutrients – root/plant – combustion – ash – soil. Ash utilization on soils is only possible when untreated biomass fuels are utilized. A high concentration of elements with fertilizing and liming effects, specifically Ca, K, Mg, and P, is necessary for effective utilization of ash residues on soils.

Attempts to close the natural cycle of minerals within the process of energy production from biomass can be frustrated by heavy metals from environmental pollution being deposited in the forest ecosystem. The result is that in most cases it is not possible to recycle all of the ashes produced during the combustion process, but by separating a side-stream rich in heavy metals it is usually possible to recycle most of the ashes produced. See references [9] and [10].

Before ash from biomass combustion can be used as fertilizer, the chemical compositions of the ash and soil where the ash will be applied must be evaluated. Ash from biomass combustion usually has a high pH-value, and using it on soils with high pH-value is not generally recommended. Furthermore, if the ash contains heavy metals it cannot be used on soils already containing high concentrations of heavy metals.

3 Specific Requirements of Biomass Fuels Concerning Storage, Feeding, Combustion Technology and Flue Gas Cleaning

The specific physical and chemical characteristics of the available biomass fuels determine the selection of appropriate storage, fuel handling, and fuel feeding systems in a biomass combustion plant. They furthermore influence the selection of the combustion and flue gas cleaning technologies. Additionally, appropriate fuel storage methods and proper fuel preparation prior to delivery to the heating plant is necessary to maintain high quality standards. The following sections give a brief overview of the effect of biomass fuel characteristics on the design of a biomass-fired heating plant.

3.1 Recommendations Regarding Appropriate Biomass Fuel Handling, Processing, and Storage Prior to Delivery of Fuel to the Heating Plant

The methods used for fuel handling, processing, and storage prior to delivery to the heating plant have a significant influence on the quality of the resultant biomass fuel.

The most important factor for ensuring that the fuel delivered to the biomass plant is of the highest possible quality is prevention of contamination of the biomass by mineral matter. Such contamination leads to increased ash content, which results in a decrease in the gross calorific and net calorific value of the biomass and leads to ash-related problems. (See Section 2.5.1.2.8.) Contamination of the biomass can be avoided by storing the biomass in designated paved areas. All handling and processing equipment should also be free of any mineral matter.

Another important parameter that influences fuel quality is moisture content. Since an increase in moisture content correlates to a reduction of the net calorific value, any contact of the biomass with water should be avoided during handling, processing and storage. Depending on the climate, indoor handling, processing, and storage may be necessary. In dry weather conditions, outdoor storage of biomass can be cost-effective for drying the material and increasing its net calorific value.

Particle size is also an important quality-related criterion. Each combustion technology is associated with a maximum particle size that can be used. Additionally, the range of particle sizes should be as small as possible to encourage stable combustion conditions in the furnace. (See Section 3.4.) The particle size is determined by the grinding or chipping method used in fuel preparation. Every chipper and grinder should be equipped with a screen to control the maximum particle size of the processed material, and oversized material should be recycled back into the process.

3.2 Storage of Biomass at the Heating Plant

From an economic point of view the fuel storage area should be designed for just-in-time operation, with the storage area capacity sized for less than 10 percent of the annual fuel consumption of the plant. Long-term storage of biomass is necessary, however, if there is a time lapse between fuel production and utilization. Maintaining a larger inventory of fuel can also protect the heating plant from fluctuations in fuel costs. A larger fuel inventory furthermore facilitates reliable operation. Since biofuels generally have a relatively low energy content by volume compared with fossil fuels, correct sizing of fuel-storage facilities is important in order to reduce fuel costs.

In addition to long-term storage, a short-term storage facility with an automatic discharge system is needed to feed fuel into the combustion plant.

Biomass is commonly stored in piles, with a front loader used for manipulation of the fuel. The selection of indoor or outdoor fuel storage depends on the characteristics of the biomass and the climate conditions. Indoor storage has the advantage of consistent storage conditions (no climatic influences such as rain and wind), but storage costs are significantly higher compared to outdoor storage. Most biomass fuel is therefore stored outdoors, and indoor storage is generally used only for certain types of biomass (small-grained) or where climatic conditions do not allow for outdoor storage (i.e. too much rain or strong winds).

When woodchips or bark with moisture content over 30-percent (w/w, w.b.) are stored in a pile for a long period of time, biological and biochemical degradation must be considered. Biological and biochemical degradation result in heat generation, which under certain conditions can cause self-ignition. Other factors to consider include dry-matter losses, changes in moisture content, and health risks due to growth of fungi and bacteria.

The effects described above are complex and depend mainly on particle size (whole shoots, chunk wood, chips, or sawdust), the type of material (bark or wood), the moisture content, the storage method (outdoor, outdoor but covered with a sheet, indoor), and the method of ventilation of the pile (airtight storage, unventilated, or active ventilation with ambient air or pre-heated air). See Reference [9].

Table 2 depicts the influence of the biomass characteristics on dry-matter loss during storage.

Table 2: Influence of the Characteristics of Biomass on Dry-Matter Loss During Storage

Parameter	Influence
moisture content	higher moisture content increases dry-matter loss
type and age of crops	young crops (e.g. short-rotation coppice) show higher dry-matter losses than woodchips from forest residues
particle size	smaller particles have higher specific surface per unit volume, resulting in higher dry-matter loss

Source: Reference [9]

Small-grained biomass, such as sawdust and fine wood waste, is best stored in closed silos or bunkers to avoid dust emissions. Silos used for this purpose are up to 49-feet (15 m) in diameter and up to 131-feet (40 m) tall. Inclined screws (with an agitator) or rotating screws are used to automatically discharge fuel from these silos. When this type of storage is used, the bridging behavior of the material must be considered. Bridging can be avoided by proper design of the bunker and discharge system.

Table 3 gives an overview of preferred storage types for different types of biomass.

Table 3: Preferred Storage Types For Different Types of Biomass

Biomass	Preferred Type of Storage	Remarks
fresh wood chips and bark	outdoor storage, piled	- temperature in the core of the pile normally rises up to 140°F (60°C) within the first days - no temperature increase occurs when the particle size is larger than 8 in (20cm) - dry matter losses can amount up to 5% per month - risk of self ignition (especially relevant for bark) when stored in piles over 26 ft (8 m) height and for a time period of over 4 months
dry biomass	indoor storage, piled	- to avoid dampening by rainfall - if indoor storage is too expensive, the biomass should at least be covered
fresh biomass	indoor storage, piled	- moisture content can be reduced if natural convection is possible - natural convection also reduces the risk of spontaneous ignition
sawdust	indoor storage, silo	- indoor storage recommended due to dust emissions (outdoor storage not possible in populated areas) - appropriate design of the silo and the discharge system is necessary to avoid bridging

Source: [9]

Short-term biomass storage units are directly connected with the feeding system of the combustion plant. For short-term storage of bulk materials such as bark or wood chips, bunkers with sliding bar conveyors have very robust construction and are well suited to such fuel types.

In contrast to sliding bar conveyors, walking floors move the stored material as a whole. Walking floors are suitable for automatic fuel discharge from long-term storage facilities without additional devices. The disadvantage of this approach is that in order to achieve a certain storage height, the biomass must be fed onto the walking floors from above.

If no walking-floor system is used, moving the biomass from the long-term storage area to the bunker is done with front loaders or crane systems. Depending on the material and the discharge technology used, the storage height can be up to 33-feet (10 m) and the cross-section of the bunker can be 33 x 81 feet (10 x 25 m), resulting in a storage volume of up to 3,270 cubic yards (2,500 cubic meters) per unit.

3.3 Fuel-Feeding and Handling Systems

Fuel-feeding and handling systems are necessary to transport the fuel from the point of delivery or from the short-term storage area to the combustion system. Due to its direct influence on the downtime and performance of the combustion system, the fuel feeding needs to be designed carefully and has to be adjusted to the combustion technology used.

A great variety of biomass fuels are utilized, and appropriate designs for the fuel handling and transport systems are required. The designs must consider the following:

- Characteristics of the fuel (particle form, size and distribution, moisture content)
- Distance of transport
- Height difference to be managed from fuel storage area to combustion zone
- Noise emissions
- Risk of dust explosions and fire
- Fuel feeding capacity
- Investment, operation, and maintenance costs
- Reliability of the feeding and handling systems

Table 4 gives an overview of suitable fuel-feeding and combustion technologies for different biomass fuel types and sizes.

Table 4: Suitable Fuel-Feeding and Combustion Technologies Based On Shape and Particle Size of the Biomass Fuel

Form	Maximum Particle Size	Appropriate Delivery System	Appropriate Combustion Technology
Bulk material	< 5 mm	Direct injection, pneumatic conveyors	Directly fired furnaces, cyclone burners, CFB
Bulk material	< 50 mm	Screw conveyors	Underfeed stokers, grate furnaces, BFB, CFB
Bulk material	< 100 mm	Vibro-conveyors, chain trough conveyors, hydraulic piston feeders	Grate furnaces, BFB
Bulk material	< 500 mm	Sliding bar conveyors, chain trough conveyors	Grate furnaces, BFB
Shredded or cut bales	< 50 mm	Cutters, shredders followed by pneumatic conveyors or screw conveyors	Directly fired furnaces, grate furnaces, BFB, CFB
Bales, sliced bales	whole bales	Cranes, hydraulic piston conveyors	Grate furnaces, cigar burners
Pellets	< 30 mm	Screw conveyors	Underfeed stokers, grate furnaces, BFB, CFB
Briquettes	< 120 mm	Sliding bar conveyors, chain trough conveyors	Grate furnaces, BFB

Source: [9];

Notes: "CFB" is a circulating fluidized bed, "BFB" is a bubbling fluidized bed. For a description of the combustion technologies mentioned in this table, see Section 3.4.

3.4 Combustion Technologies

Combustion systems exceeding 100 kW are generally equipped with mechanical or pneumatic systems for fuel-feeding and process control that support fully automatic operation. In principle, the following combustion technologies can be distinguished [10]:

- Fixed bed combustion
- Fluidized bed combustion
- Dust combustion

Table 5 gives an overview of the suitability of different biomass combustion technologies based on the application and the biofuel properties.

Table 5: Advantages and Disadvantages of Various Biomass Combustion Technologies in Relation to Application and Fuel Properties

Advantages	Disadvantages
underfeed stokers	
+ simple and good load control due to continuos fuel feeding + low emissions at partial load operation due to good fuel dosing	- suitable only for biofuels with low ash content and high ash-melting point (wood fuels) - low flexibility regarding particle size (< 50 mm)
grate furnaces	
+ less sensitive to slagging than fluidized bed furnaces	- no mixing of wood fuels and herbaceous fuels possible
dust combustion	
+ mixing of wood fuels and herbaceous fuels possible if cyclone or vortex burners are used + very good load control and fast alternation of load possible	- particle size of biofuel is limited (< 10-20 mm) - water content of biofuel is limited (< 20% w.b.)
BFB furnaces	
+ high flexibility concerning moisture content and kind of biomass fuels used	- low flexibility with regard to particle size (< 80 mm) - loss of bed material with the ash
CFB furnaces	
+ high flexibility concerning moisture content and kind of biomass fuels used	- low flexibility with regard to particle size (< 40 mm) - loss of bed material with the ash

Source: [9], [10]

Fixed-bed combustion systems include grate furnaces and underfeed stokers. With these technologies, primary air passes through a fixed bed in which drying, gasification, and charcoal combustion take place. The combustible gases produced are burned after secondary air addition has taken place, usually in a combustion zone separated from the fuel bed.

Within a fluidized-bed furnace, biomass fuel is burned in a self-mixing suspension of gas and solid bed material into which combustion air enters from below. Depending on the fluidization velocity, bubbling fluidized bed (BFB) or circulating fluidized bed (CFB) combustion can be selected.

Dust combustion is suitable for fuels that are available as small particles with an average diameter smaller than 20 mm. With this technology, a mixture of fuel and primary combustion air is injected into the combustion chamber. Combustion takes place while the fuel is in suspension, and gas burnout is achieved after secondary air addition.

Several variations of each of these technologies are available.

3.5 Flue Gas Cleaning

Emissions from biomass combustion can in general be separated into two types: emissions that are mainly influenced by the combustion technology and process conditions (all products of incomplete combustion such as carbon monoxide, total organic compounds, and polynuclear aromatic hydrocarbons) and emissions that are mainly influenced by fuel properties. Table 6 shows emissions influenced by fuel properties.

Flue gas emissions can be reduced by primary and secondary measures. Primary measures focus on avoiding the formation of emissions within the combustion chamber, whereas secondary measures focus on removing them from the flue gas after the combustion.

Several primary measures are possible ([9], [10]) including:

- Modification of the fuel composition
- Modification of the moisture content of the fuel
- Modification of the particle size of the fuel
- Selection of the type of combustion equipment to correspond with fuel type and other parameters
- Optimization of combustion process control
- Staged-air combustion
- Staged fuel combustion and re-burning

Table 6: Emissions of Pollutants Primarily Influenced by Fuel Properties

Pollutant	Fuel Type	Typical Emissions at 11% O_2
NO_X	Native wood (soft wood)	100 - 200 mg/m^3_0
	Native wood (hard wood)	150 - 250 mg/m^3_0
	Straw, grass, miscanthus, chip boards	300 - 800 mg/m^3_0
	Waste wood	400 - 600 mg/m^3_0
HCl	Native wood	< 5 mg/m^3_0
	Waste wood, straw, grass, miscanthus	raw grass: 100 - 1000 mg/m^3_0
	chip boards (NH_4Cl)	with HCL absorption: < 20 mg/m^3_0
Particulates	Native wood	after cyclone: 50 - 100 mg/m^3_0
	Straw, grass, miscanthus, chip boards	after cyclone: 150 - 1000 mg/m^3_0
	Waste wood	after bag or electrostatic filter: < 10 mg/m^3_0
S, Pb, Zn, Cd, Cu	Native wood	< 1 mg/m^3_0
	Waste wood	raw grass: 20 - 100 mg/m^3_0
		after bag- or electrostatic filter: < 5 mg/m^3_0
PCDD/F	Native wood	typical: < 0.1 ng TE/m^3_0
		range: 0.01 - 0.5 ng TE/m^3_0
	Waste wood	typical: 2 ng TE/m^3_0
		range: 0.1 - 20 ng TE/m^3_0

Source: [9]

Notes: "NO_X" is nitrogen oxides (both monoxides and dioxides), "HCl" is hydrochloric acid, "PCDD/F" is polychlorinated p-dibenzo dioxins/furans. The volume unit "m^3_0" refers to a temperature of 77°F (25°C). "TE" represents the toxic equivalents.

The primary measures for reducing emissions related to fuel characteristics are discussed below.

Modification of the Fuel Composition:

Decreasing the amounts of certain precursor elements in the fuel, including S, Cl, N, and ash forming elements, all of which contribute to harmful emissions or operational problems, can be achieved with some types of biomass. A good example is the reduction of chlorine and potassium contained in straw by washing – either by exposure to rain or through controlled washing. Lower emissions can also be achieved by appropriate fuel mixing (e.g. a mixture of wood fuels and herbaceous fuels).

Modification of the Moisture Content in the Fuel:

The moisture content in biomass can vary from 10 percent (w/w, w.b.) (wood residues from industry where drying was applied) up to 60 percent (w/w, w.b.) (fresh cut wood and bark). A high moisture content in the fuel makes it more difficult to achieve a sufficiently high temperature in the combustion chamber, which leads to incomplete combustion and therefore to higher emission levels. For example, a temperature above 1,560°F (850°C) is necessary to ensure a low level of CO, and the presence of excessive moisture inhibits the heating plant's ability to achieve such a high temperature.

Depending on local constraints, a variety of drying methods can be applied. If available, waste heat from other processes can be used for artificial drying of the biomass at a low cost. In dry climatic conditions a moderate decrease of moisture content can also be achieved during storage. This option seems particularly relevant for Santa Fe.

Pre-heating the combustion air and using a well-insulated combustion chamber also improves the combustion quality and makes it possible to utilize fuels with high moisture content, although a subsequent reduction in boiler efficiency must be accepted. The amount of flue gas also increases due to increased water evaporation, which leads to energy losses. Energy lost via the flue gases can be partly recovered by using a flue gas condensation system.

Modification of the Fuel Particle Size:

The fuel particle size is an important consideration in selection of the combustion technology. As mentioned in Table 5, some furnaces are limited to a certain particle size. If the particle size of the utilized fuel exceeds the maximum specified size for the combustion technology, unstable combustion conditions can occur, resulting in higher emissions due to incomplete combustion. Moreover, small-grained biomass fuels increase dust emissions from the combustion process. Specification of the minimum and maximum accepted particle size is therefore an important part of every fuel delivery contract.

Secondary measures focus on the removal of emissions from the flue gas once it has left the boiler. The most important task of flue gas cleaning technologies for wood combustion is the removal of particulate emissions. Table 7 gives an overview of commonly used particle control technologies.

Table 7: Overview of Available Particle Control Technologies and Typical Sizes of Particles Removed.

Particle Control Technology	Particle Size [µm]	Effectiveness [%]
Settling chambers	>50	<50
Cyclones	>5	<50
Multicyclones	>5	<90
Electrostatic filters	<1	>99
Bag filters	<1	>99
Spray chambers	>10	<80
Impingement scrubbers	>3	<80
Cyclone spray chambers	>3	<80
Venturi scrubbers	>0.5	<99

Source: [9]

Multicyclones are the most commonly used dust removal devices because they are inexpensive and operate reliably. However, the rather low particle-removal effectiveness of multicyclones is usually insufficient for larger biomass-fired heating plants with more stringent emission limits, so additional dust removal devices such as bag or electrostatic filters are required.

Secondary measures to reduce gaseous emissions in the flue gas are also available, including selective catalytic reduction [SCR] and selective non-catalytic reduction [SNCR] for NO_x. Absorption processes in combination with bag filters may also be used for the removal of HCl, SO_x, PCDD/F and heavy metals. As shown in Table 6, these additional secondary measures are usually not necessary when untreated woody biomass (including residues from forest thinnings or green waste) is utilized, but they must be used if waste wood or herbaceous biomass fuels are used as a fuel.

4 Results

4.1 Identified Sources and their Location

Forest thinning projects, municipal green waste sources, and commercial green waste sources of biomass fuels were identified within the target area. State Forestry efforts to thin overgrowth on private land were also identified, but this fuel source was not researched in depth at this time because it is believed to overlap with municipal green waste, since much of the wood thinned on private land is disposed of at the landfill.

4.1.1 Thinning Projects

There are three Forest Ranger Districts within the study area: Espanola Ranger District, Jemez Ranger District, and Pecos Ranger District. The borders and locations of these districts can be seen graphically in Figure A1 of the Appendix.

The most prominent fuels-management challenge in the Santa Fe Wildland Urban Interface (WUI), the first half-mile surrounding municipal land, is the abundance of over-stocked forest stands with an unnaturally high percentage of small diameter stems. The State Forestry Ranger Districts have begun treating municipal and state forest-land in many areas within a 50-mile (80 km) radius of Santa Fe. Three different processes are applied depending on the needs of a particular area: thinning, fuel break, and ladder fuel removal. Fuel-break methods consist of clearing an area of land entirely to prevent the spread of fire to inhabited areas. Ladder-fuel removal consists of removing only brush and slash. Thinning consists of removal of both small and large-diameter timber in an attempt to achieve conditions similar to those that existed before fire suppression methods were consistently applied. Each of these processes is also associated with a different cost, as discussed in Section 4.4.1.

In 2002, 2003, and 2004, more than 6,100 acres (2,470 hectares) were thinned in the study area. The thinning projects on which this report focused are identified in Table 8 below. These projects are expected to be completed in the next two years.

Table 8: Identified Forest Thinning Projects Currently Underway Within 50 Miles of Santa Fe

Thinning Project	Ranger District	Thinned Area		Distance to downtown Santa Fe	
		[acres]	[hectares]	[miles]	[km]
Santa Fe Watershed	Espanola	1,100	445	20	32
Los Alamos County	Espanola	1,100	445	20	32
Cochiti Mesa	Jemez	150	61	30	48
Monument Canyon	Jemez	220	89	20	32
Glorieta/ La Cueva/ Apache Canyon	Pecos	8,000	3,238	35	56

Although thinning projects beyond those identified in Table 8 are expected, the specific details of such projects have not yet been determined. There is a general agreement that thinning needs to occur for fire prevention, primarily in the WUI. According to James Johnston [5] it is estimated that thinning in WUI areas within the study radius would occur at a continually increasing pace over the next 13 years, and that the rate of this increase would be 1,000-2,000 additional acres (405-910 hectares) thinned per year (i.e. an increase of 1,000 acre in year one, 2,000 in year two, an so on). This means that after four years, an additional 10,000 acres (4,050 hectares) will have been thinned. Jerry Payne [6] indicated that over the next ten years, 20,000 acres per year will be thinned per forest. Each forest may include several ranger districts.

Dan Key, Fire Management Officer for the Jemez Ranger District, referred to 250,000 acres (101,200 hectares) of WUI that require thinning in his district alone. His office has requested funding to begin this effort by thinning or clearing 5,200 acres (2,104 hectares) in 2005. These 5,200 acres would correspond to the Jemez Ranger District's portion of the 20,000 acres of Santa Fe National Forest to be thinned next year, according to Mr. Payne. Neither the Pecos Ranger District nor the Espanola Ranger District was able to provide comparable information indicating its total WUI thinning requirement and plans for 2005.

The thinning projects mentioned above have not yet been funded or contracted. Therefore, for the purposes of this report, fuel availability is projected by using the intended future thinning of WUI land at a rate increasing by 1,000 acres each year as described above. If the volumes of slash in future projects are comparable to those resulting from thinning in the current projects, it can be expected that a significant additional source of biomass fuel from thinning projects will be available. Table 9 shows the potential forest-thinning projects starting in 2005.

Table 9: Potential Forest Thinning Projects, Starting in 2005, Within 50 Miles of Santa Fe

Thinning Project	Ranger District	Average Thinned Area 2005		Rate of Increase per Year		Distance to downtown Santa Fe	
		[acres]	[hectares]	[acres]	[hectares]	[miles]	[km]
WUI areas	Jemez	1,000	405	1,000	405	25	40
WUI areas	Espanola	1,000	405	1,000	405	20	32
WUI areas	Pecos	1,000	405	1,000	405	35	56

Note: According to James T. Johnston [5], the rate of increase of 1,000 acres per year is planned for the next 13 years.

4.1.2 Municipal Green Waste

There are several landfills and transfer stations within the study area, although most of them transfer their green waste to the Caja del Rio Landfill, where the waste is chipped and made available at no cost for mulch and erosion control. The two transfer stations that process their own green waste are the Jacona Transfer Station (near Pojoaque) and the El Dorado Transfer Station in El Dorado. A map showing the locations of these transfer stations is shown as Figure A1 of the Appendix. Table 10 gives an overview of the locations of identified municipal green waste sources within a 50-mile (80 km) radius of Santa Fe.

Table 10: Identified Municipal Green Waste Sources Within 50 Miles of Santa Fe

Municipal Green Waste Source	Distance to downtown Santa Fe	
	[miles]	[km]
Caja del Rio Landfill	10	16
Jacona Transfer Station	20	32
El Dorado Transfer Station	20	32

4.1.3 Commercial Green Waste

There are many businesses within the study area involved in processing wood, but many of these businesses process only small quantities, such as for production of furniture. For the purposes of this study, the 10 most productive potential suppliers were selected and evaluated. These suppliers are primarily lumber mills.

Other potential suppliers were contacted including wood-furniture manufacturers, wood carvers, and wood turners. After several brief conversations with these potential suppliers, it became clear that the volumes they represented were insignificant compared to the mills, so only the mills were surveyed more thoroughly. The less productive potential resources could be aggregated to represent a more significant supply. Table 11 gives an overview of the 10 most productive potential suppliers within a 50-mile radius of Santa Fe.

Table 11: Identified Commercial Green Waste Sources Within 50 Miles of Santa Fe

Commercial Green Waste Source	Distance to downtown Santa Fe	
	[miles]	[km]
Barela Timber	50	80
Norton Hill Wood Co	in town	
Sauter White	20	32
Hansens Lumber	10	16
WH Moore Cash Lumber	20	32
Spotted Owl Timber Inc	10	16
Alpine Builders Supply	in town	
New Mexico Vigas & Timbers	20	32
Cook's True Value	20	32
Conley Lumber Mills LLC	20	32

Notes: Only the 10 most productive potential suppliers of commercial green waste are listed in this table.

Currently the product of these sources is sold or given away for use as mulch and for erosion control, primarily to private landowners and landscape contractors. It is assumed that these products could be made available as an energy source for a district heating system, specifically because they would have more value in that application than they do currently.

A map showing the locations of these sites is presented as Figure A1 in the Appendix.

4.2 Type of Biomass and Available Quality

The biomass available from the three types of sources comes from several species of trees, and the biomass is available in several forms, including wood chips, sawdust, slash, and bark peelings. The various species are listed in Table 12.

Table 12: Common and Scientific Names of Available Tree Species Within 50 Miles of Santa Fe

Common Name	Scientific Name
Ponderosa Pine	pinus ponderosa
Salt Cedar	tamarix chinensis
Pinion (pinon)	pinus edulis
Russian Olive	eleganus augustifolia
Juniper	juniperus monosperma
White Fir	abies concolor
Aspen	populus grandidentata
Sugar Pine	pinus lambertiana
Oak (type unknown)	quercus (generic)
Douglas Fir	pseudotsuga menziesii
Engelman Spruce	picea engelmannii

4.2.1 Thinning Projects

In the thinning projects investigated in this study, several species of trees are thinned and cleared. Most forests are predominantly comprised of ponderosa pine, sometimes with spruce interspersed, while others are a mix of spruce, piñon and juniper trees. Currently the product of the thinning projects is divided between merchantable materials, which are sold to wood processing industries, and small diameter material, which is generally left on site and burned as slash.

The burning of biomass on-site should be avoided in any case, since it is very inefficient and causes significant environmental damage due to incomplete combustion.

Table 13 shows the types of biomass available from forest-thinning projects.

Table 13: Available Biomass from Current Forest Thinning Projects Within 50 Miles of Santa Fe

Thinning Project	Tree Species	Material Type
Santa Fe Watershed	Ponderosa, Spruce	Slash/Chips
Los Alamos County	Ponderosa, Spruce	Slash/Chips
Cochiti Mesa	Ponderosa	Slash/Chips
Monument Canyon	Ponderosa	Slash/Chips
Glorieta/ La Cueva/ Apache Canyon	Ponderosa, Pinon	Slash/Chips

The type of biomass available from potential forest-thinning projects mentioned in section 4.1.1 is expected to be similar to what is outlined in Table 13.

4.2.2 Municipal Green Waste

Of the biomass available from municipal waste sites, several species of trees are represented. The Caja del Rio landfill, the largest potential municipal supplier of biomass, can supply primarily piñon trees cleared from private land. The large amount of piñon trees is a result of a large-scale die-off of piñon trees caused by recent drought conditions and the subsequent bark-beetle infestation. Also available at Caja del Rio are juniper and ponderosa pine.

All green waste at Caja del Rio, Jacona, and El Dorado is chipped on site. The 3-inch chips (8 cm) are arranged in piles about ten feet high, and turned periodically to prevent combustion. The storage areas are unpaved, which has significant consequences on the ash content of the stored biomass (due to contamination with rocks and dirt) as discussed in Section 4.6.3.

The chips are currently available at no cost to the public, and are used for mulch and erosion control. The climate is dry enough in New Mexico that the piles are safely left outside. Hard rain penetrates only the first few inches of the piles. For thermal utilization in a biomass-fired boiler, the ash content of the wood chips must be reduced significantly. The storage area should therefore be paved to avoid contamination of the biomass by rocks and dirt.

Table 14 shows the types of biomass available from municipal sources of green waste.

Table 14: Available Biomass from Municipal Sources Within 50 Miles of Santa Fe

Municipal Green Waste Source	Tree Species	Material Type
Caja del Rio Landfill	Pinon, Juniper	chips
Jacona Transfer Station	Pinon, Juniper	chips
El Dorado Transfer Station	Pinon, Juniper	chips

4.2.3 Commercial Green Waste

Among the potential commercial suppliers of green waste there is significant variety in the available species and material types. This variety is presumed to be a result of the involved businesses acquiring wood from a large area of New Mexico. In addition to the species referred to above, identified species from commercial sources included oak and other hardwoods, Douglas Fir, Aspen, Sugar Pine, and several varieties of spruce.

Currently this waste product is sold as mulch and for erosion control, primarily to private individuals but also to landscape contractors. It is available as bark peelings from the production of vigas (pole beams common in New Mexico construction), sawdust as a by-product of sawmills, untreated pallets (used for shipping and materials handling), and wood scraps resulting from the production of dimensional limber.

Table 15 shows the types of biomass available from commercial sources of green waste.

Table 15: Available Biomass from Commercial Sources Within 50 Miles of Santa Fe

Commercial Green Waste Source	Tree Species	Material Type
Barela Timber	Ponderosa Pine	pole shavings (chips, sawdust, bark)
Norton Hill Wood Co	Ponderosa Pine	bark, wood, sawdust
Sauter White	Spruce, Douglas Fir, Pine	chips
Hansens Lumber	Ponderosa, Spruce, White Fir	sawdust
WH Moore Cash Lumber	Ponderosa, Fir, Engelman Spruce	bark/ wood
Spotted Owl Timber Inc	Aspen, Spruce, Ponderosa, Fir	bark/wood
Alpine Builders Supply	Sugar pine, Hardwoods(Oak)	sawdust, scrap
New Mexico Vigas & Timbers	Ponderosa, Engelman Spruce, White Fir	bark/wood
Cook's True Value	Ponderosa, Hardwoods	scrap, pallets, sawdust
Conley Lumber Mills LLC	Ponderosa Pine	bark/wood

4.3 Sustainable Quantity of Available Biomass Sources

Within each of the three target source categories of biomass (thinning, municipal waste, commercial waste), attempts were made to determine the quantity of biomass that could sustainably be supplied as fuel for biomass energy production. A variety of complicating variables arose while attempting to make such a determination, and in several cases estimates of the future available resource had to be made based on very little data. In the case of forest-thinning projects, estimates were made based on the known quantity of biomass removed from the forest during the initial thinning.

The quantifiable amount of biomass available in 2003 was identified as a point of reference for determining the sustainable biomass availability from each source category.

4.3.1 Thinning Projects

4.3.1.1 BioSum Estimation of Biomass Resource Availability

FIA BioSum is a analytical tool developed by the US Forest Service that uses FIA inventory plot data, forest simulation models, and GIS modeling of existing road networks to identify optimal locations for siting of biomass cogeneration or wood processing facilities. It furthermore assesses likely impacts of fuel treatments on wildfire hazard, estimates material removed by size class, and explores tradeoffs between costs, area treated, and treatment effectiveness. With the assistance of the USDA Forest Service personnel in Santa Fe, we will compare the data and analysis from BioSum to our existing assessments of biomass fuel availability, and use the results to improve fuel-supply reliability and to help develop fuel contracts for Santa Fe biomass projects.

4.3.1.2 Current and Future Thinning Projects in the Wildland Urban Interface

The data herein are based on rules-of-thumb provided by Mr. Johnston [5] concerning the estimation of a long-term supply of biomass based on the current yield during first-pass thinning. See also section 2.3.4. Note also that this is a resource assessment, and as such it does not consider regulatory restrictions that may prevent removal of the fuel from particular thinning projects.

The *Santa Fe Watershed* thinning project will cover 1,100 acres (445.15 hectares) and produce an average of 2,400 board feet per acre (1,808 board meters per hectare) of merchantable material. This is equivalent to roughly 4.8 tons per acre (10.76 metric tons per hectare,) or 5,280 tons (4,790 metric tons) for the entire project. Since merchantable material was the only variable for which a value was provided, we must extrapolate both the values for total material and slash from the known quantity of merchantable material.

The total material removed in the initial thinning, based on a ratio of merchantable material to slash of 5:2, can be estimated at 3,380 board feet per acre (2,546 board meters per hectare). Therefore we can expect 980 equivalent board feet per acre (738 board meters per hectare) of this material to consist of slash, equivalent to about 2 tons per acre (4.48 metric tons per hectare.) The resulting slash production for the entire 1,100 acres (445 hectares) is roughly 2,200 tons (1,996 metric tons) during the initial thinning.

For a best-case scenario, it can be estimated that after the initial thinning, all merchantable material will have been removed, leaving only small diameter timber. In this circumstance we apply the formula defined in Section 2.3.4 to the entire amount of biomass removed in the initial thinning. Therefore, best-case sustainable fuel yield from this 1,100-acre (445 hectare) project is calculated to be 496 tons (450 metric tons) per year. (3,380 board feet per acre/ 15 = 225 sustainable annual board feet per acre / 5 = 45 cubic feet per acre / 100 = 0.45 tons per acre * 1,100 acres = **496 tons (450 metric tons) per year** for the Santa Fe Watershed thinning project.)

The worst-case scenario is that the ratio of merchantable to non-merchantable fuel holds true over time, in which case the result is roughly 29 percent of the above result, or **142 tons (129 metric tons) per year**.

The *Los Alamos County* thinning project will cover 1,100 acres (445 hectares) as well, also producing an average of 2,400 board feet per acre (1,808 board meters per hectare) of merchantable material. Again this number refers only to the estimated amount of merchantable material, and does not include slash. Based on the conversion factors provided by the State Forestry Department, the resultant volume of slash in the initial thinning is estimated at 2 tons per acre (4.48 metric tons per hectare). The result of slash production for the entire 1,100 acres is roughly 2,200 tons (1,996 metric tons) during the initial thinning.

Therefore best-case sustainable fuel yield from this 1,100-acre project is calculated to be 496 tons per year. (2,400 board feet + 980 board feet = 3,380 board feet per acre / 15 = 225 sustainable board feet per acre / 5 = 45 cubic feet per acre / 100 = 0.45 tons per acre X 1,100 acres = **496 tons (450 metric tons) per year** for the Los Alamos County thinning project).

The worst-case scenario is that the ratio of merchantable to non-merchantable fuel holds true over time, in which case the result is roughly 29 percent of the above result, or **142 tons (129 metric tons) per year**.

The *Cochiti Mesa* thinning project will cover 150 acres (61 hectares) yielding an estimate of between 1,800-2,000 board feet thinned per acre (1,356-1,506 board meters per hectare) of merchantable material. This project is estimated to result in the average removal of 3.8 tons per acre (8.5 metric tons per hectare) of merchantable material and about 1.9 tons per acre (4.3 metric tons per hectare) of slash. These numbers represent a smaller quantity of thinned material per acre, possibly due to lower basal area in this region. This is also a higher ratio of slash to merchantable material (2:4) than exists in the Santa Fe and Los Alamos projects, which is consistent with the hypothesis of lower basal area in this project. These data are based on first hand knowledge of the project, so is presumed to be correct. 855 tons (776 metric tons) of total material will be removed during the initial thinning, of which 285 tons (259 metric tons) can be expected to consist of non-merchantable material (slash). Over time, the sustainable biomass resource from this thinning project should equal roughly **18-57 tons (16-52 metric tons) per year**, using the best- and worst-case formulas as above.

The *Monument Canyon* thinning project will cover 220 acres (89 hectares) with an estimated yield of between 1,800-2,000 board feet thinned per acre (1,356-1,506 board meters per hectare) of merchantable material. This project is estimated to result in the average removal of 3.8 tons per acre (8.5 metric tons per hectare) of merchantable material and about 1.9 tons of slash per acre (4.3 metric tons per hectare). As in the Cochiti Mesa project, this is a higher ratio of slash to merchantable material (2:4) than exists in the Santa Fe and Los Alamos projects, probably due to lower basal area. The information is again based on first hand knowledge of the project, so is presumed to be correct. 1,254 tons (1,138 metric tons) of total material will be removed during the initial thinning, of which 414 tons (376 metric tons) can be expected to consist of non-merchantable material (slash). The resulting sustainable fuel estimate is **28-84 tons (25-76 metric tons) per year.**

The *Glorieta/La Cueva/Apache Canyon* thinning project will cover over 8,000 acres (3,237 hectares,) and an average of 2,000 board feet per acre (1,506 board meters per hectare) of merchantable material will be removed. This total is converted to 3-5 tons of merchantable material and 1-3 tons of slash per acre (6.7-11 metric tons per hectare merchantable and 2.2-6.7 metric tons per hectare slash.) 48,000 total tons (43,545 metric tons) will be removed during the initial thinning, of which 32,000 tons (29,030 metric tons) can be expected to be merchantable, leaving 16,000 tons (14,515 metric tons) of slash. Based on the formula defined above, the best-case sustainable resource assessment for this thinning project is **3,200 tons (2,903 metric tons) per year**, and the worst-case is **1,067 tons (968 metric tons) per year**.

It should be reiterated that the ratio of merchantable material to slash availability in the long term is unknown. Table 16 shows the 2004, best-case sustainable and worst-case sustainable fuel availability for the thinning projects discussed.

Table 16: Best-Case Sustainable and Worst-Case Sustainable Fuel Availability for the Thinning Projects Within 50 Miles of Santa Fe for the Year 2004

Thinning Project	2004 Yield Slash		Ratio Merch/Slash	Best-case sustainable		Worst case sustainable	
	[tons/yr]	[t/yr]		[tons/yr]	[t/yr]	[tons/yr]	[t/yr]
Santa Fe Watershed	2,200	1,996	5:2	496	450	142	129
Los Alamos County	2,200	1,996	5:2	496	450	142	129
Cochiti Mesa	285	259	4:2	57	52	19	17
Monument Canyon	414	376	4:2	84	76	28	25
Glorieta, La Cueva and Apache Canyon	16,000	14,515	4:2	3,200	2,903	1,067	968
Totals	**21,099**	**19,141**		**4,333**	**3,931**	**1,398**	**1,268**

Notes: The calculation of the specific values is described above. The unit "tons" represents short tons, "t" represents metric tons.

According to Table 16, the annual sustainable fuel availability from thinning projects within a 50-mile radius is estimated to be between 1,400 and 4,300 short tons (1,300 and 3,900 metric tons).

The differing ratios between merchantable material and slash given for different projects can be attributed to varying forest densities and the past presence of wildfires. For example, in an area that has been burned there is new growth, consisting of more small diameter timber. This would account for a smaller ratio of merchantable material to slash.

Based on the information gained from James T. Johnston [5], the thinning of WUI land at the rate of 1,000 acres (405 hectares) increase per year for the next 13 years (1,000 acre in year one, 2,000 in year two, 3,000 in year three, etc.) is intended for the future, starting in 2005. This would lead to a constant increase in available biomass from forest thinnings over the next 13 years. Figure 2 shows the potential development of biomass availability from forest-thinning projects applying this rate.

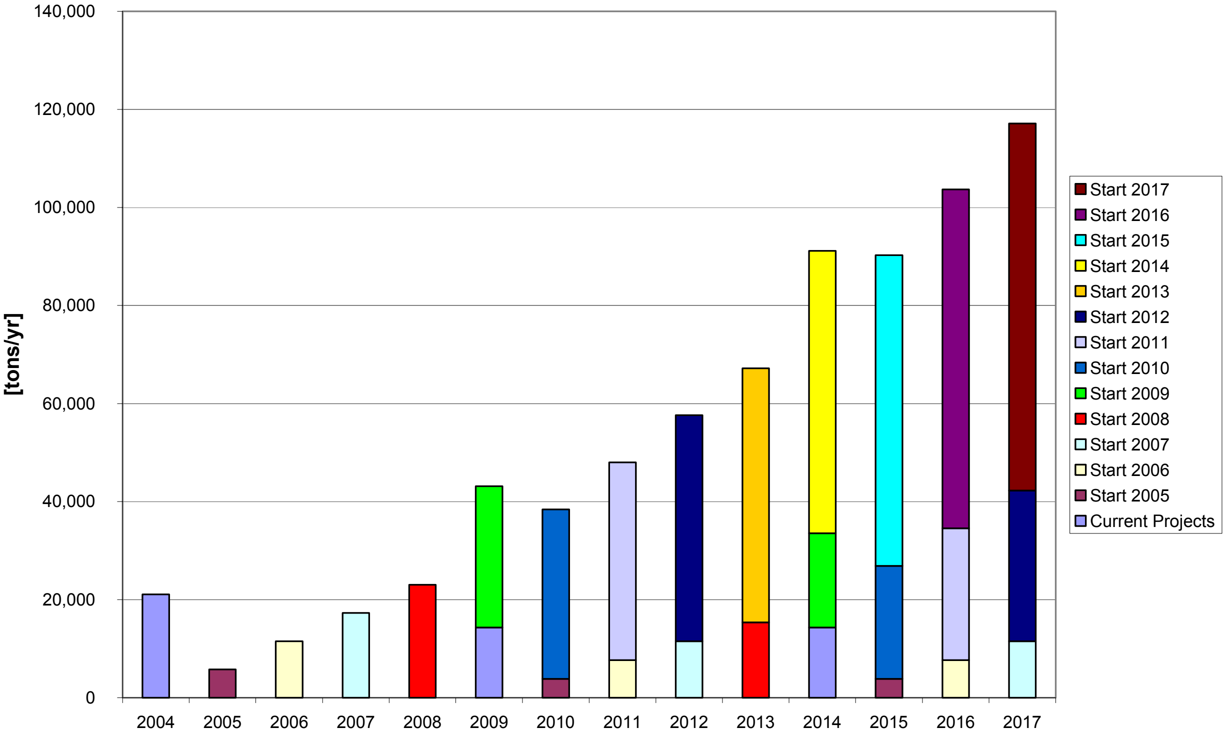


Figure 2: Sustainable Fuel Availability and Future Potential for the Thinning Projects, by Year, Within 50 Miles of Santa Fe

Notes: Fuel availability for future projects is based on the thinning rate of 1,000 acres (405 hectares) increase per year and an average yield of slash of 1.9 tons per acre (4.3 metric tons per hectare) from the initial thinning. The yield of thinning every five years after the initial thinning was based on the mean of best-case and worst-case scenario and amounts to 1.3 tons per acre (2.9 metric tons per hectare).

Starting at 5,760 tons (5,225 metric tons) in 2005, the fuel availability increases constantly and reaches 38,400 tons (34,800 metric tons) in 2010 and 117,120 tons (106,200 metric tons) in 2017.

4.3.2 Municipal Green Waste

Jacona transfer station receives an average of 350-500 tons (318-454 metric tons) of green waste material per year.

Eldorado transfer station receives an average of 350-500 tons (318-454 metric tons) of green waste material per year.

The Caja del Rio landfill processed over 14,000 tons (12,701 metric tons) of material in 2003 due to the piñon die-off. As of 2004, Justin Stockdale [4] reports a monthly average of 800 tons, with an expected spike in July or August when fire danger is higher. This is not seen as a sustainable figure, however, and records from the former City transfer station provide a more accurate long-term figure of 2,500 tons (2,268 metric tons) per year.

Combined, these municipal sources are expected to sustainably provide for 3,500 tons (3,175 metric tons) per year of green waste. See also Table 17.

Table 17: Sustainable Fuel Availability from Municipal Green Waste Sources within 50 Miles of Santa Fe

	Yield 2003		Sustainable	
Municipal Green Waste Source	**[tons/yr]**	**[t/yr]**	**[tons/yr]**	**[t/yr]**
Caja del Rio Landfill	14,108	12,799	2,500	2,268
Jacona Transfer Station	500	454	500	454
El Dorado Transfer Station	500	454	500	454
Totals	**15,108**	**13,706**	**3,500**	**3,175**

Notes: The high amount of green waste delivered to the Caja del Rio Landfill in 2003 is attributed to the piñon die-off. The unit "tons" represents short tons, while "t" represents metric tons.

It should be noted that it is uncertain at this time whether private landowners are likely to clear their dead piñon trees. If so, the trend of high green waste volume at Caja del Rio could continue for several years to come. According to Mr. Stockdale [4], the actual amount of received green waste at the Caja del Rio landfill from January to May 2004 is less than for 2003, so for the purposes of this study it was conservatively assumed that most of the clearing of dead piñon trees has already taken place.

4.3.3 Commercial Green Waste

A survey of commercial wood product businesses within the study area yielded a variety of green waste residue results. Some businesses produce much more waste than others, and each business processes their waste differently. Some chip all of their green waste, while others divide it into merchantable byproducts (sawdust, bark strips, wood chips, etc.) to increase the overall value of the waste.

Unlike the other two sources, commercial purveyors of green waste are not susceptible to wide fluctuations in volume that result from events such as the piñon die off or from the need to thin forests. Their green waste is simply a byproduct of making higher-value timber products, and this industry is established and mature. It can therefore be assumed for the purposes of this report that the figures shown for 2003 will remain relatively constant in the future.

Table 18 quantifies commercial resources by businesses, and shows their estimated production. All together these sources could provide roughly 25,000 tons (22,680 metric tons) of material annually on a sustainable basis.

Table 18: Sustainable Fuel Availability From Commercial Green Waste Sources Within 50 Miles of Santa Fe

	Yield 2003	
Commercial Green Waste Source	**[tons/yr]**	**[t/yr]**
Barela Timber	7,500	6,804
Norton Hill Wood Co	25	23
Sauter White	7,500	6,804
Hansens Lumber	50	45
WH Moore Cash Lumber	5,000	4,536
Spotted Owl Timber Inc	3,500	3,175
Alpine Builders Supply	100	91
New Mexico Vigas & Timbers	450	408
Cook's True Value	3	3
Conley Lumber Mills LLC	300	272
Totals	**24,428**	**22,161**

Note: The unit "tons" represents short tons, "t" represents metric tons.

4.3.4 Total Sustainable Quantity of Biomass from All Sources

An aggregate of the three source categories is shown in Table 19, using projected average figures from forest-thinning projects. The projected averages consider that some merchantable material will be cut in the future, and use a mean value between best-case and worst-case scenarios.

Table 19: Total Sustainable Fuel Availability From all Considered Sources Within 50 Miles of Santa Fe

	Actual Yield		Sustainable Yield		
Green Waste Source	**[tons/yr]**	**[t/yr]**	**[tons/yr]**	**[t/yr]**	**[%]**
Forest Thinning Projects	21,099	19,141	2,866	2,600	9.3%
Municipal Green Waste	15,108	13,706	3,500	3,175	11.4%
Commercial Green Waste	24,428	22,161	24,428	22,161	79.3%
Totals	**60,635**	**55,008**	**30,794**	**27,936**	**100.0%**

Notes: The actual yield was calculated using estimated yields from forest-thinning projects in 2004 (Section 4.3.1) and recorded yields from 2003 for municipal (Section 4.2.2) and commercial (Section 4.3.3) sources. The unit "tons" represents short tons, "t" represents metric tons.

The sustainable annual yield of about 30,800 tons (27,900 metric tons) will increase significantly if the intended future forest-thinning projects shown in Figure 2 are carried out at the projected rate, even if regulatory restrictions may prevent removal of the fuel from particular thinning projects.

The energy content of the sustainable fuel potential available is dependent on the expected net calorific value of the available biomass, as discussed in the next section.

4.3.5 Estimation of the Total Energy Content of the Biomass Available

The total energy content of the biomass available within a 50-mile radius of Santa Fe was estimated using an average net-calorific value from the fuels present in each of the three fuel-source categories. Net-calorific values are based on the results of chemical analyses performed on 10 representative samples (Table 30), and the total energy content is based on the estimated quantity of sustainable fuel available (Table 19). Table 20 shows the result of the calculations.

Table 20: Estimated Total Energy Content of the Biomass Available Within 50 Miles of Santa Fe

	Sustainable Yield		Net Calorific Value		Energy Content	
Green Waste Source	**[tons/yr]**	**[metric tons/yr]**	**[BTU/lb, w.b.]**	**[kWh/kg, w.b.]**	**[MMBTU]**	**[MWh]**
Forest Thinning Projects	2,866	2,600	6,129	3.96	35,134	10,297
Municipal Green Waste	3,500	3,175	4,798	3.10	33,587	9,843
Commercial Green Waste	24,428	22,161	5,381	3.48	262,886	77,044
Totals	**30,794**	**27,936**			**331,607**	**97,184**

Notes: The average net calorific values are taken from Table 30.

The results show a total energy content of the biomass fuel available on a sustainable basis of about 332,000 MMBTU (97,000 MWh) per year. Considering a realistic scenario for the main district energy system planned for Santa Fe, in which 80-percent of the substitutable heat demand in the target area actually connects to the system, the annual aggregate heat demand of the customers would amount to about 172,000 MMBTU (50,500 MWh) per year. (Option 1, Waste Transfer Station, Heat Only, see also [8].) Assuming a total efficiency of the district heating system at approximately 73 percent (including the efficiency of the plant and the heat losses of the network of pipes), and considering that the peak load is provided by a gas-fired boiler, the total required annual fuel energy input amounts to about 216,300 MMBTU (63,400 MWh).

The heating value of the currently available biomass is about 50 percent higher than the required heat input of the district heating system. This surplus of biomass fuel should allow the selection of the fuel suppliers based on quality, long-term availability, and cost.

As shown in Figure 2, a significant increase of biomass from forest-thinning projects can be expected within the next 13 years. The cost of wood chips from forest-thinning projects must be competitive, however, to allow economically reliable utilization of this fuel source.

Given the apparent available biomass resource, a biomass fuel shortage is not expected. However, appropriate storage and processing of the available biomass as well as the commitment of long-term fuel supply contracts with potential fuel suppliers is important for a secure fuel supply. Improvements to the processing and storage facilities (e.g. using paved storage areas) are highly recommended to increase and stabilize the fuel quality. Long-term fuel supply contracts encourage contractors to improve their storage and fuel-processing facilities since the payback on improvement costs is guaranteed by ongoing fuel sales. Furthermore, long-term fuel supply contracts allow for proper management of fuel-related activity for the heating plant.

4.4 Expected Costs of Different Biomass Fuel Sources

4.4.1 Thinning Projects

Biomass Costs:

The cost of biomass from thinning projects is difficult to ascertain. Projects are bid on a cost-per-acre basis, and contracted to private entities. Since some areas are much more difficult to access than others, the cost per acre of thinning can vary dramatically. Differing economies of scale are also achieved with thinning projects of different size. Presumably, the bids for thinning work vary in competitiveness as well. There is also no biomass-fuels market currently established, and many thinning projects are thus limited to non-merchantable materials. It is expected that the development of biomass-fired energy systems will create more aggressive market conditions and resultant competition that drives down the cost of biomass from thinning projects.

Based on interviews with USDA Forest Service Fire Management Officers [11], costs for thinning fall into three basic categories depending on the type of work performed. For thinning that includes removal of both small and large diameter timbers, the rule-of-thumb cost is $500 per acre ($1,236 per hectare). For ladder-fuel removal only, the cost is $250 per acre ($618 per hectare). For creation of fuel breaks, which involves clearing an area completely of all trees, the cost is $800 per acre ($1,977 per hectare). The actual cost per acre for a particular thinning project, which may include all three types of work, is an aggregate of these three costs. These data are used by Fire Management Officers to estimate budget requirements, although they recognize that for any given area these costs may vary significantly.

The cost per acre for thinning at the Los Alamos County project, at $5,800 per acre, is well above all other projects studied. Attempts to determine the reason for the unusually high costs were unsuccessful.

Time did not allow for contacting the private contractors during this preliminary study, but it is expected that those interviews will shed more on the actual costs of local forest thinning.

Information regarding the costs for thinning in the Pecos Ranger District could not be obtained because prescribed burns were being conducted in this area during the study period and the Fire Management Officers were unavailable. Since the cost per acre in Los Alamos County appears to be anomalous, costs for the other three projects are averaged to ascertain a temporary figure for the Glorieta/La Cueva/Apache Canyon Project. As this is by far the largest thinning project being researched, it is acknowledged that even a slight deviation from the estimated figure may result in dramatically different cost totals for the thinning projects combined.

Jerry Payne [6] advised that developing technology is expected to reduce thinning costs. Specifically, Mr. Payne referred to plucking trees, especially shorter juniper and pinion trees, instead of cutting them. He estimated a possible 50 percent reduction in thinning costs per acre resultant from deployment of this technology.

It is also unclear at this time what the cost of repeated thinning will be, and the costs shown here are for the initial clearing. It appears likely that thinning performed after initial thinning, if conducted regularly, would differ in cost per acre from the initial thinning due to the smaller amount of material to be cut, handled, and removed.

Table 21: Cost of Forest Thinning Projects Within 50 Miles of Santa Fe

	Area		Yield		Thinning Costs	
Thinning Project	**[Acres]**	**[hectares]**	**[tons/acre]**	**[t/hectare]**	**[US$/acre]**	**[US$/hectare]**
Santa Fe Watershed	1,100	445	4.5	10.1	$945	$2,335
Los Alamos County	1,100	445	4.5	10.1	$5,800	$14,331
Cochiti Mesa	150	61	3.5	7.8	$533	$1,317
Monument Canyon	220	89	3.7	8.3	$295	$729
Glorieta, La Cueva and Apache Canyon	8,000	3,238	3.7	8.3	$591	$1,460
Totals / Averages	**10,570**	**4,278**	**4.5**	**10.0**	**$1,163**	**$2,873**

Notes: The cost for the Glorieta thinning Project was estimated based on the average cost of the Santa Fe Watershed, Cochiti Mesa, and Monument Canyon thinning projects. The costs and yields stated in this table reflect only the volume and cost of the initial thinning of the respective areas.

Differences in the yield per unit area in Table 21 can be attributed at least in part to variation in tree density (basal area) from one thinning project to another.

The costs shown in Table 21 are based on the total costs of the thinning project. Since the main purpose of forest thinning is removal of overburden to reduce fire danger, the costs cannot be attributed to the produced biomass. Given that slash is usually piled on-site and burned in open air, it can be concluded that the current market value of slash is insufficient to pay its way out of the forest. The cost for slash as a fuel would be determined by assessing the costs for collecting the material and transporting it from the forest to the biomass plant. As no such activity is currently being conducted, these costs could not be accurately determined.

Instead, average costs for collecting and transporting the biomass in two Europeans countries were used to estimate the fuel costs domestically. In Austria the fuel cost varies from $36.50 to $73.00 per ton ($40.2 to $80.4 per metric ton) or $2.95 to $5.90 per MMBTU ($10.1 to $20.2 per MWh). (Reference [12].) The costs per unit energy are based on the measured mean moisture content of fuel from forest thinnings of 20 percent (w/w, w.b.). (See also Section 4.6.4.) The cost is dependent on the accessibility of the forest area. The lower cost is representative of easily accessible forest areas, and the higher cost represents more mountainous regions.

In Finland the fuel cost varies from $26.50 to $44.50 per ton ($29.2 to $49.1 per metric ton), or $2.14 to $3.60 per MMBTU ($7.3 to $12.3 per MWh), based on a measured mean moisture content of fuel from forest thinnings of 20 percent (w/w, w.b.). (Reference [13]). The lower costs represent slash from forest thinnings and the higher costs represent the harvesting of small trees. The lower costs in Finland compared to Austria can be correlated with higher mechanization of thinning and better accessibility of forests in Finland.

The cost for biomass from forest thinnings in Santa Fe is expected to be in the same range as the cost in Austria, since the topography of the region around Santa Fe is rather mountainous and the mechanization rate of the harvesting methods is expected to be more similar to Austria rather than to Finland.

Transport Costs:

The distance from downtown Santa Fe influences the estimation of costs as well, since transportation is a significant component of the total biomass fuel cost. Several trucking companies in Santa Fe were approached, but none gave their true costs for hauling and instead quoted only retail prices for typical hauling. These quotes neither reflect actual costs nor account for long-term contracts that would presumably result in significant discounts.

Albert Montano Trucking in Santa Fe, for example, rents out vehicles at a flat rate of $50 per hour including driver and diesel fuel for a 12-yard (9 cubic meter) truck. Four round trips per eight-hour day, hauling a mixture of bark and woodchips, with a delivery of 48 cubic yards (37 cubic meters) total would amount to 12 tons (11 metric tons) delivered for $400 or $33/ton ($37 per metric ton) or $2.68 per MMBTU ($9.15 per MWh).

Bernard Romero Trucking, also of Santa Fe, is able to haul 30 yards (23 cubic meters) per trip at a cost of $165 per trip, also for four trips per day, equaling $660 per day for a total of 30 tons (27 metric tons.) The transportation cost per ton is therefore $22 ($24 per metric ton) or $1.77 per MMBTU ($6.04 per MWh). It should be noted that Mr. Romero was willing to visit the sites at no cost to assess the sites and potential cost savings in transportation, and that he may be a good potential collaborator and long-term contractor.

Figures from Justin Stockdale regarding transportation costs for Santa Fe’s Waste Management division yield the following data, which are believed to be closer to true operating costs:

The cost for a 110-yard (84 cubic meter) truck is $60 per hour including maintenance, diesel fuel and driver. Such a truck could also make four round trips per day to the thinning projects, hauling a total of 440 yards (336 cubic meters,) or 110 tons (100 metric tons). This equates to a cost of transportation per ton of $4.36 ($4.81 per metric ton). or $0.35 per MMBTU ($1.20 per MWh). This is believed to be a more useful estimate of transportation costs for the purposes of this study.

Generally, all those interviewed regarding transportation costs concurred that costs per yard or per ton are lower when a larger truck is used. Use of a 110-yard (84 cubic meter) truck would require an aggregation of biomass fuels to one site for loading, as none of the sites are expected to produce this volume individually. It may also prove difficult to use such a large truck to collect biomass from forest-thinning projects, and further logistics may need to be explored to keep the freight costs low.

Bill Althouse of Althouse Inc. estimated the cost of transport within a 50-mile (80 km) radius at $10-20 per ton ($11-$22 per metric ton.) or $0.81-1.61 per MMBTU ($2.74-5.48 per MWh). Since it is questionable at this stage of the project whether 110-yard trucks can be efficiently used for transporting wood chips from forest thinning projects, the cost provided by Althouse Inc. was used for the estimation of aggregate transport costs for biomass from thinning projects.

Clearly these figures are rudimentary and are only intended as first-order estimates of the true costs of hauling biomass fuel to a heating plant in downtown Santa Fe. Further study will divide these figures into fuel, labor, and operating costs for a better understanding of how economic benefits can be achieved.

Total Costs:

Based on the average biomass costs from forest thinnings projects in Austria ($4.42 per MMBTU or $15.15 per MWh) and using the information obtained from Bill Althouse for the transport costs ($1.20 per MMBTU or $4.11 per MWh), the total average fuel costs for biomass from forest-thinning projects, including costs of both biomass fuel and transportation costs, can be estimated at about $6.60 per MMBTU ($19.30 per MWh). This cost is far too high to be competitive with biomass from other currently available sources surrounding Santa Fe. Significant cost reductions will be necessary to achieve a competitive price for biomass from forest thinnings. Since no economic outlet currently exists for the slash produced, it is anticipated that these costs can be reduced significantly.

4.4.2 Municipal Green Waste

Biomass Costs:

Mulch is currently free to the public from the Caja del Rio landfill. In order to guarantee prioritization of the heating plant over other outlets for green waste, and to further a partnership with the City and County of Santa Fe, a price would need to be set for the green waste available at the landfill and transfer station. This price is estimated by Justin Stockdale to be $7.50 per ton ($8.27 per metric ton) or $0.78 per MMBTU ($2.67 per MWh) using the results outlined in Section 4.6.4.

Transport Costs:

The hauling cost to bring fuel to downtown Santa Fe from the El Dorado and Jacona transfer stations is estimated using the 110-yard (84 cubic meter) truck and making 6 trips per day at a cost of $480 per day. The result is 165 tons (150 metric tons) per day or $2.90/ton ($3.20/metric ton) or $0.30 per MMBTU ($1.03 per MWh). Fuel pickups from Jacona and El Dorado together would only require 6 days of work per year. The costs incurred for the fuel storage requirements of this arrangement have not yet been researched.

The hauling cost to bring fuel to downtown Santa Fe from the Caja Del Rio transfer station is also estimated using the 110-yard (84 cubic meter) truck, but instead making 10 trips per day at a cost of $480 per day. The result is 275 tons (249 metric tons) per day or $1.75/ton ($1.93/metric ton) or $0.18 per MMBTU ($0.62 per MWh). Fuel pickups from Caja Del Rio would require about 9 days of work per year.

Total Costs:

Based on the available information, total average fuel costs for biomass from municipal green waste sources, including biomass the fuel itself and transportation costs, is estimated to be $9.25/ton ($10.20/metric ton) for the Caja del Rio landfill and $10.40/ton ($11.46/metric ton) for the Jacona and El Dorado transfer stations. The aggregate price will thus be somewhere between

$0.96 per MMBTU ($3.28 per MWh) and $1.08 per MMBTU ($3.69 per MWh). To be conservative, the higher price was used in all further calculations.

4.4.3 Commercial Green Waste

Biomass Costs:

The commercial green-waste sector is more developed than the forest-waste and municipal green-waste sectors, and accurate costs are therefore easier to estimate. As discussed above, a single commercial green-waste supplier may have several forms of green waste available, each with different associated costs.

Many commercial sources of green waste currently make their waste products available at no cost to the public. These waste products are used as mulch, scrap firewood, and for other purposes. For this study a single best-estimate price was assigned to each waste product based on an average of the actual costs for the same product at all establishments selling that product. This practice is based on the assumption that once a market exists, all waste of a given type will be sold at approximately the same price.

Table 22: Costs of Primary Waste by Product, Commercial Green Waste Sources

Commercial Green Waste Source	Green Waste Product	Yards/year	Cost/yard	Tons/year	Cost/ton
Barela Timber	Bark	29,132	$1.67	7,283	$6.68
Norton Hill Wood Co	Bark	100	$2.58	25	$10.32
Sauter White	Wood Chips	30,000	$2.58	7,500	$10.32
Hansens Lumber	Sawdust	250	$2.58	31	$20.64
WH Moore Cash Lumber	Bark/Wood Chips	20,000	$4.00	5,000	$16.00
Spotted Owl Timber Inc	Bark/Wood Chips	15,000	$2.75	3,750	$11.00
Alpine Builders Supply	Sawdust/Scrap Wood	700	$2.58	88	$20.64
New Mexico Vigas & Timbers	Bark/Wood Chips	1,800	$2.58	450	$10.32
Cook's True Value	Scrap/Sawdust/Pallets	12	$2.58	1	$20.64
Conley Lumber Mills LLC	Bark/Wood Chips	1,200	$3.33	300	$13.32
Totals / Averages		**98,194**	**$2.63**	**24,428**	**$10.59**

Note: The costs listed were obtained from the managers/owners of the respective wood processing companies.

Transport Costs:

Transportation costs can be estimated using the formulas given previously. A 110-yard (84 cubic meter) truck could haul a mix of chips and sawdust weighing 18.33 tons per load, and could make roughly 6 trips per day for $480. The total tonnage hauled per day would be 110 tons (100 metric tons) at a cost of $4.36/ton ($4.81 per metric ton) or $0.41 per MMBTU ($1.38 per MWh) using the calorific values determined in Section 4.6.4.

Total Costs:

The total average delivered fuel costs for biomass from commercial green waste sources, including both fuel and transport costs, can be estimated at about $15/ton ($16.5 per metric ton) or $1.39 per MMBTU ($4.74 per MWh).

Apart from wood residues from forest thinnings, the main portion of the biomass used in Austria for thermal utilization comes from the wood processing industry. A well-developed market for sawdust, wood chips, bark and other residues from lumber and timber production already exists. In Austrian markets, the cost for biomass varies depending on the type of biomass and the fuel quality, but in general the cost ranges from $20/ton ($22.10 per metric ton) or $2.90 per MMBTU ($9.80 per MWh) for bark and sawdust to around $35/ton ($38.60 per metric ton) or $5.00 per MMBTU ($17.10 per MWh) for wood chips with average moisture content of 50 percent (w/w, w.b.). The average estimated biomass fuel cost within the investigated area around Santa Fe is thus significantly lower than actual biomass costs in Europe, which will improve the economic performance of the Santa Fe project.

4.5 Sample Collection

Fourteen samples from seven different biomass sources were collected for chemical analysis using the sampling methodology discussed in Section 2.4. Table 23 shows a list of all biomass samples collected during the fuel study, including from forest thinnings, municipal and commercial green waste sources.

Since only ten of the collected samples could be sent to Austria for the chemical analysis (due to transport regulations of the Department of Agriculture in Austria), a pre-selection took place prior to shipping. The pre-selection was performed such that all three different fuel source types (thinning projects, municipal green waste, commercial green waste) were represented in the samples.

- All three samples from the Caja del Rio landfill (samples #1, 2, 3) were selected to represent municipal green waste sources.
- The three samples collected at the Spotted Owl Sawmill (samples #4, 5, 6) were selected to represent commercial green waste sources.
- One sample from each of the four forest-thinning projects (samples #7, 8, 10, 12) that were visited was selected to represent forest-thinning projects.

Table 23: Biomass Samples Collected for Chemical Analysis

Sample Number	Date Collected	Location
Sample #1	4/6/2004	Caja Del Rio Landfill, Santa Fe
Sample #2	4/6/2004	Caja Del Rio Landfill, Santa Fe
Sample #3	4/6/2004	Caja Del Rio Landfill, Santa Fe
Sample #4	3/4/2004	Spotted Owl Timber Inc., Santa Fe
Sample #5	3/4/2004	Spotted Owl Timber Inc., Santa Fe
Sample #6	3/4/2004	Spotted Owl Timber Inc., Santa Fe
Sample #7	3/16/2004	Albuquerque Area River Thinning Project
Sample #8	3/17/2004	Los Lunas Area River Thinning Project
Sample #9	3/17/2004	Los Lunas Area River Thinning Project
Sample #10	3/18/2004	East Mountain Thinning Project
Sample #11	3/22/2004	Pecos Wilderness Thinning Project
Sample #12	3/22/2004	Pecos Wilderness Thinning Project
Sample #13	3/22/2004	Pecos Wilderness Thinning Project
Sample #14	3/18/2004	East Mountain Thinning Project

Note: For further information see Table 24.

With at least three samples selected for testing from each fuel source type, a representative selection of the available fuel sources was achieved. The remaining samples (#9, 11, 13 and 14) were not sent for testing.

4.6 Chemical Analysis

4.6.1 Samples investigated

Table 24a and 24b give an overview of the samples analyzed.

Table 24a: List of Samples Analyzed

Sample Number	Sampling Date	Sampling Location	Biomass Type	Biomass Processing
Sample #1	4/6/2004	Caja Del Rio Landfill, Santa Fe	mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis); taken from a pile (facing south) between 1 and 6 months old	grinder with screen
Sample #2	4/6/2004	Caja Del Rio Landfill, Santa Fe	mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis); taken from the middle of a pile between 1 and 6 months old	grinder with screen
Sample #3	4/6/2004	Caja Del Rio Landfill, Santa Fe	mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis); taken from a pile (facing north) between 1 and 6 months old	grinder with screen
Sample #4	3/4/2004	Spotted Owl Timber Inc., Santa Fe	mixture of bark and wood from Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir, White Fir; taken from a pile between 1 and 4 weeks old	2-stage-grinder
Sample #5	3/4/2004	Spotted Owl Timber Inc., Santa Fe	mixture of bark and wood from Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir, White Fir; taken from a pile between 1 and 5 days old	grinder

Note: For pictures of the respective samples see Figure 3 and Figure 4.

Table 24b: **List of Samples Analyzed**

Sample Number	Sampling Date	Sampling Location	Biomass Type	Biomass Processing
Sample #6	3/4/2004	Spotted Owl Timber Inc., Santa Fe	mixture of sawdust from Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir, White Fir; taken from a pile between 1 and 4 weeks old (est.)	saw mill
Sample #7	3/16/2004	Albuquerque Area River Thinning Project	Salt Cedar (Tamarix spp.), Russian Olive (Elaeagnus angustifolia), Cottonwood (Populus wislizeni)	mechanical mastication
Sample #8	3/17/2004	Los Lunas Area River Thinning Project	Salt Cedar (Tamarix spp.), Russian Olive (Elaeagnus angustifolia), Cottonwood (Populus wislizeni), chipped at 03/09/2004	chipping
Sample #10	3/18/2004	East Mountain Thinning Project	mix of Pinon (Pinus edulis) and Juniper (Juniperus monosperma)	chipping
Sample #12	3/22/2004	Pecos Wilderness Thinning Project	mix of Ponderosa Pine (Pinus ponderosa) and Pinon (Pinus edulis); collected from the forest soil	grinding

Figure 3 and Figure 4 show pictures of the original samples. A visual inspection of the samples reflects significant differences between them regarding particle size. The samples from commercial green waste sources (#4, #5 and #6 from Spotted Owl) have a relatively homogenous particle size within each sample, whereas the samples from municipal green waste sources (#1, #2 and #3 from Caja del Rio Landfill) and from forest-thinning projects (#7, #8, #10 and #12) consist of wood and bark possessing a wide range of particle sizes. Generally, the particle size of the samples investigated ranges from 0.1 to 8 inches (0.25 to 20 cm).

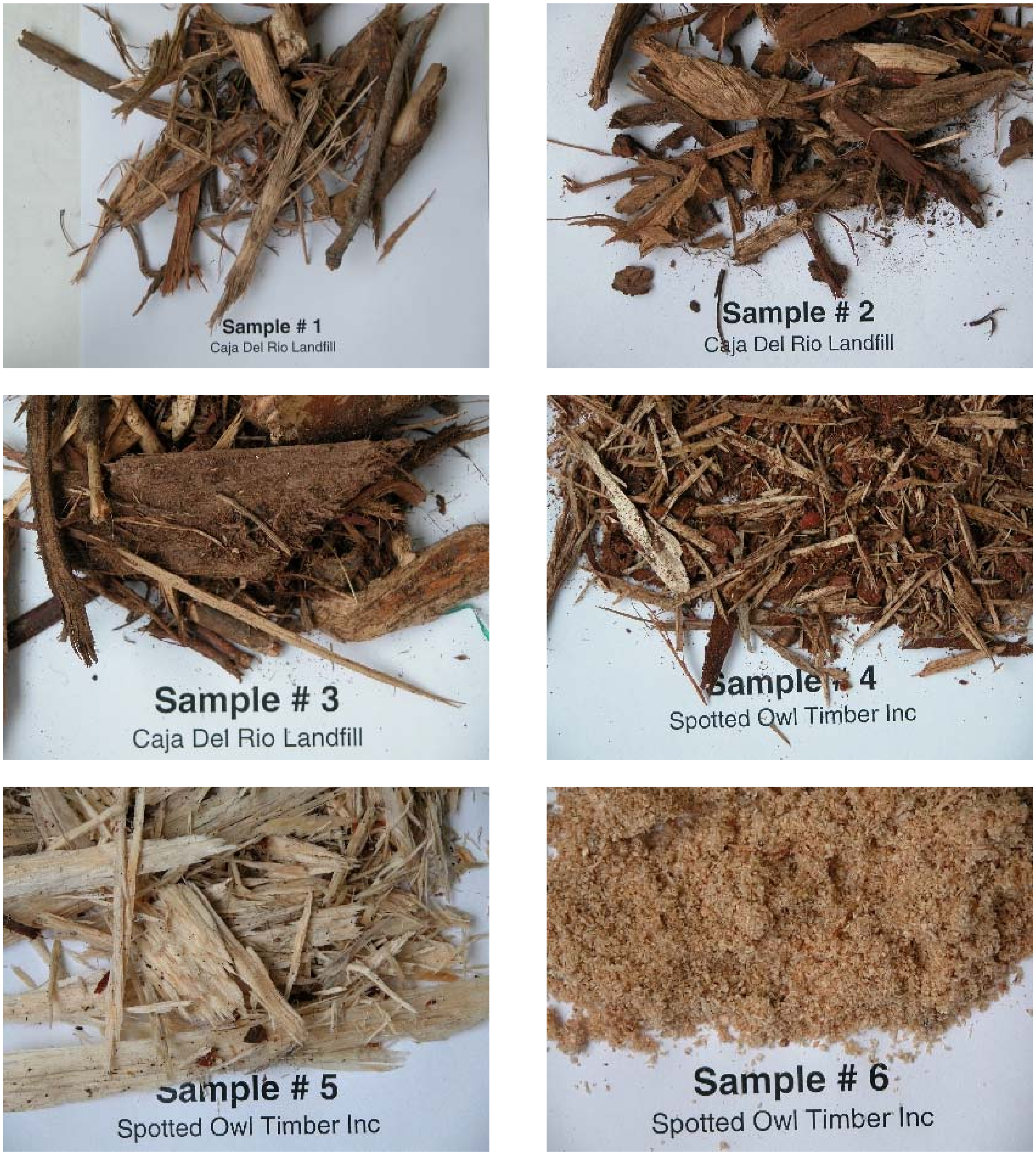


Figure 3: Images of Samples 1, 2, 3, 4, 5 and 6 Before Sample Preparation

Note: For detailed data of the samples see Table 24

Figure 4: Images of Samples 7, 8, 10 and 12 Before Sample Preparation

Note: For detailed data regarding the samples, see Table 24.

4.6.2 Results of Wet Chemical Analyses

Based on the analysis methods described in Section 2.5.1, all relevant combustion-specific parameters of the analyzed biomass samples were determined. Table 25 gives an overview of the results achieved from the wet chemical analysis. The analysis results are compared to representative values for wood chips and bark fuels from middle Europe (Austria, Germany, Switzerland, Northern Italy). These comparative values (see Table 28) have been taken from the in-house biomass fuel database from BIOS BIOENERGIESYSTEME GmbH. The values are based on 18 analyses of woodchips (mainly spruce) as well as 14 analyses of bark samples (also mainly spruce). The comparison should enable an easier assessment of the quality of the biomass fuels available to the biomass project in Santa Fe.

Table 25: Results of Wet Chemical Analyses of Biomass Fuel Samples to Determine Water, Ash, Carbon, Hydrogen, and Nitrogen Concentrations in Comparison to the Average Composition of Bark and Wood Chips from Middle-European Sources

Sample		**Sample # 1**	**Sample # 2**	**Sample # 3**	**Sample # 4**	**Sample # 5**
Int. Ref. No.		**5055**	**5056**	**5057**	**5058**	**5059**
Water Content	% (w/w w.b.)	20.37	20.04	30.11	27.94	49.35
Ash Content	% (w/w d.b.)	9.37	26.10	15.71	10.28	1.05
Carbon (C)	% (w/w d.b. naf)	46.26	38.86	42.63	46.42	48.89
Hydrogen (H)	% (w/w d.b. naf)	6.14	5.12	5.58	5.94	6.53
Nitrogen (N)	% (w/w d.b. naf)	0.41	0.42	0.39	0.19	0.12
Carbon (C)	% (w/w d.b. af)	51.04	52.58	50.58	51.74	49.41
Hydrogen (H)	% (w/w d.b. af)	6.77	6.93	6.62	6.62	6.60
Nitrogen (N)	% (w/w d.b. af)	0.45	0.57	0.46	0.21	0.12

Sample		**Sample # 6**	**Sample # 7**	**Sample # 8**	**Sample # 10**	**Sample # 12**
Int. Ref. No.		**5060**	**5061**	**5062**	**5063**	**5064**
Water Content	% (w/w w.b.)	47.00	11.80	15.88	42.83	8.79
Ash Content	% (w/w d.b.)	0.54	2.78	2.09	3.04	5.60
Carbon (C)	% (w/w d.b. naf)	49.08	47.66	48.33	50.07	47.16
Hydrogen (H)	% (w/w d.b. naf)	6.65	6.28	6.36	6.65	6.31
Nitrogen (N)	% (w/w d.b. naf)	0.10	1.57	1.07	0.38	0.21
Carbon (C)	% (w/w d.b. af)	49.35	49.02	49.36	51.64	49.96
Hydrogen (H)	% (w/w d.b. af)	6.69	6.46	6.50	6.86	6.68
Nitrogen (N)	% (w/w d.b. af)	0.10	1.61	1.09	0.40	0.22

Sample		**wood chips (database)**		**bark (database)**	
		mean	**std.dev.**	**mean**	**std.dev.**
Water Content	% (w/w w.b.)				
Ash Content	% (w/w d.b.)	0.92	0.65	3.53	0.61
Carbon (C)	% (w/w d.b. naf)	50.40	0.32	50.31	0.51
Hydrogen (H)	% (w/w d.b. naf)	5.91	0.28	5.79	0.26
Nitrogen (N)	% (w/w d.b. naf)	0.12	0.02	0.24	0.20
Carbon (C)	% (w/w d.b. af)	50.87	0.32	52.15	0.51
Hydrogen (H)	% (w/w d.b. af)	5.96	0.29	6.00	0.26
Nitrogen (N)	% (w/w d.b. af)	0.12	0.02	0.25	0.21

Notes: The data for wood chips and bark (database) were taken from the BIOS in-house biomass fuels database. "d.b" and "w.b." represent dry basis and wet basis, respectively. "naf" and "af" refer to non-ash-free and ash-free, respectively. "std. dev." refers to standard deviation.

Table 26 and Table 27 show the results from the wet chemical analyses of the analyzed biomass fuel samples. The average composition of wood chips and bark from central European sources is listed in Table 28.

Table 26: Results of Wet Chemical Analyses of Biomass Fuel Samples #1 to #5 for Ash-Forming Elements

Sample Int. Ref. No.		Sample # 1 5055	Sample # 2 5056	Sample # 3 5057	Sample # 4 5058	Sample # 5 5059
Chlorine (Cl)	mg/kg d.b.	224	324	215	122	154
Sulfur (S)	mg/kg d.b.	292	366	310	176	118
Aluminum (Al)	mg/kg d.b.	3,063	16,360	6,943	4,437	259
Cadmium (Cd)	mg/kg d.b.	0.08	0.08	0.04	0.08	0.06
Calcium (Ca)	mg/kg d.b.	9,325	10,254	11,804	7,101	1,487
Copper (Co)	mg/kg d.b.	3.96	6.57	4.32	2.76	1.50
Iron (Fe)	mg/kg d.b.	1,339	2,744	2,739	1,509	105
Lead (Pb)	mg/kg d.b.	2.54	2.02	4.29	1.44	< 0,3
Magnesium (Mg)	mg/kg d.b.	957	1,167	1,296	731	307
Manganese (Mn)	mg/kg d.b.	40.95	68.83	72.60	82.61	38.71
Nickel (Ni)	mg/kg d.b.	8.90	22.47	10.49	3.61	<1
Phosphorus (P)	mg/kg d.b.	328	469	347	245	106
Potassium (K)	mg/kg d.b.	2,605	6,140	4,194	2,708	897
Silicon (Si)	mg/kg d.b.	22,820	71,982	39,879	26,733	1,620
Sodium (Na)	mg/kg d.b.	755	4,997	1,773	1,215	92
Zinc (Zn)	mg/kg d.b.	22.94	92.61	19.71	20.28	13.04

Notes: "d.b" represents dry basis. All analysis values in mg/kg d.b. refer to non-ash-free material. The composition of wood chips and bark is listed in Table 28.

Table 27: Results From the Wet Chemical Analyses of Biomass Fuel Samples #6, #7, #8, #10 and #12 for Ash-Forming Elements

Sample		Sample # 6	Sample # 7	Sample # 8	Sample # 10	Sample # 12
Int. Ref. No.		**5060**	**5061**	**5062**	**5063**	**5064**
Chlorine (Cl)	mg/kg d.b.	142.36	246.08	480.30	161.30	143.10
Sulfur (S)	mg/kg d.b.	77.64	772.54	3,103.65	300.37	172.38
Aluminum (Al)	mg/kg d.b.	102.84	728.75	179.14	462.95	2,404.01
Cadmium (Cd)	mg/kg d.b.	0.07	0.04	0.05	0.03	0.12
Calcium (Ca)	mg/kg d.b.	908.95	4,968.36	4,162.16	8,124.31	5,370.48
Copper (Co)	mg/kg d.b.	1.21	5.93	3.61	3.05	5.60
Iron (Fe)	mg/kg d.b.	57.31	370.27	97.18	205.02	1,132.44
Lead (Pb)	mg/kg d.b.	< 0,3	0.78	< 0.3	0.70	1.11
Magnesium (Mg)	mg/kg d.b.	179.86	766.19	962.68	594.54	590.29
Manganese (Mn)	mg/kg d.b.	33.33	21.67	10.04	7.44	33.24
Nickel (Ni)	mg/kg d.b.	<1	1.07	<1	0.96	2.11
Phosphorus (P)	mg/kg d.b.	65.90	334.82	289.19	391.43	239.89
Potassium (K)	mg/kg d.b.	570.06	2,284.84	1,664.21	1,535.23	1,652.17
Silicon (Si)	mg/kg d.b.	698.20	3,587.11	884.29	1,673.45	12,703.97
Sodium (Na)	mg/kg d.b.	33.18	448.57	355.29	124.90	535.02
Zinc (Zn)	mg/kg d.b.	10.47	9.26	4.35	19.55	17.70

Notes: "d.b" represents dry basis. All analysis values in mg/kg d.b. refer to non-ash-free material. The composition of wood chips and bark is listed in Table 28.

Table 28: Average Composition of Bark and Wood Chips from Middle European Sources for Ash-Forming Elements

Sample		wood chips (database)		bark (database)	
Int. Ref. No.		mean	std.dev.	mean	std.dev.
Chlorine (Cl)	mg/kg d.b.	56.47	27.59	201.53	51.70
Sulfur (S)	mg/kg d.b.	241.87	224.52	499.14	155.76
Aluminum (Al)	mg/kg d.b.	251.81	119.71	793.03	313.76
Cadmium (Cd)	mg/kg d.b.	0.18	0.12	0.46	0.21
Calcium (Ca)	mg/kg d.b.	3,195.25	2,316.51	11,287.37	2,525.39
Copper (Co)	mg/kg d.b.	1.98	1.31	4.91	1.07
Iron (Fe)	mg/kg d.b.	224.43	98.61	627.57	222.85
Lead (Pb)	mg/kg d.b.	1.06	0.66	2.09	1.02
Magnesium (Mg)	mg/kg d.b.	395.23	256.45	1,350.87	390.61
Manganese (Mn)	mg/kg d.b.	369.26	192.59	688.00	240.72
Nickel (Ni)	mg/kg d.b.	5.42	3.69	4.45	2.98
Phosphorus (P)	mg/kg d.b.	240.97	72.28	515.94	83.91
Potassium (K)	mg/kg d.b.	907.11	376.40	2,368.41	603.27
Silicon (Si)	mg/kg d.b.	1,316.86	853.69	3,936.04	2,417.36
Sodium (Na)	mg/kg d.b.	61.47	39.98	176.29	117.17
Zinc (Zn)	mg/kg d.b.	35.38	29.42	114.72	25.66

Notes: The data for wood chips and bark (database) were taken from the BIOS in-house biomass fuel database. "d.b" represents dry basis. All analysis values in mg/kg d.b. refer to non-ash-free material.

4.6.3 Discussion of Results

Figure 5 through Figure 8 show the results of the wet chemical analysis of the fuel samples, and compares them with the mean values from European samples of wood chips and bark taken from the BIOS in-house fuel database. This comparison makes apparent the major deviations between the European biomass fuels and the fuel samples from Santa Fe.

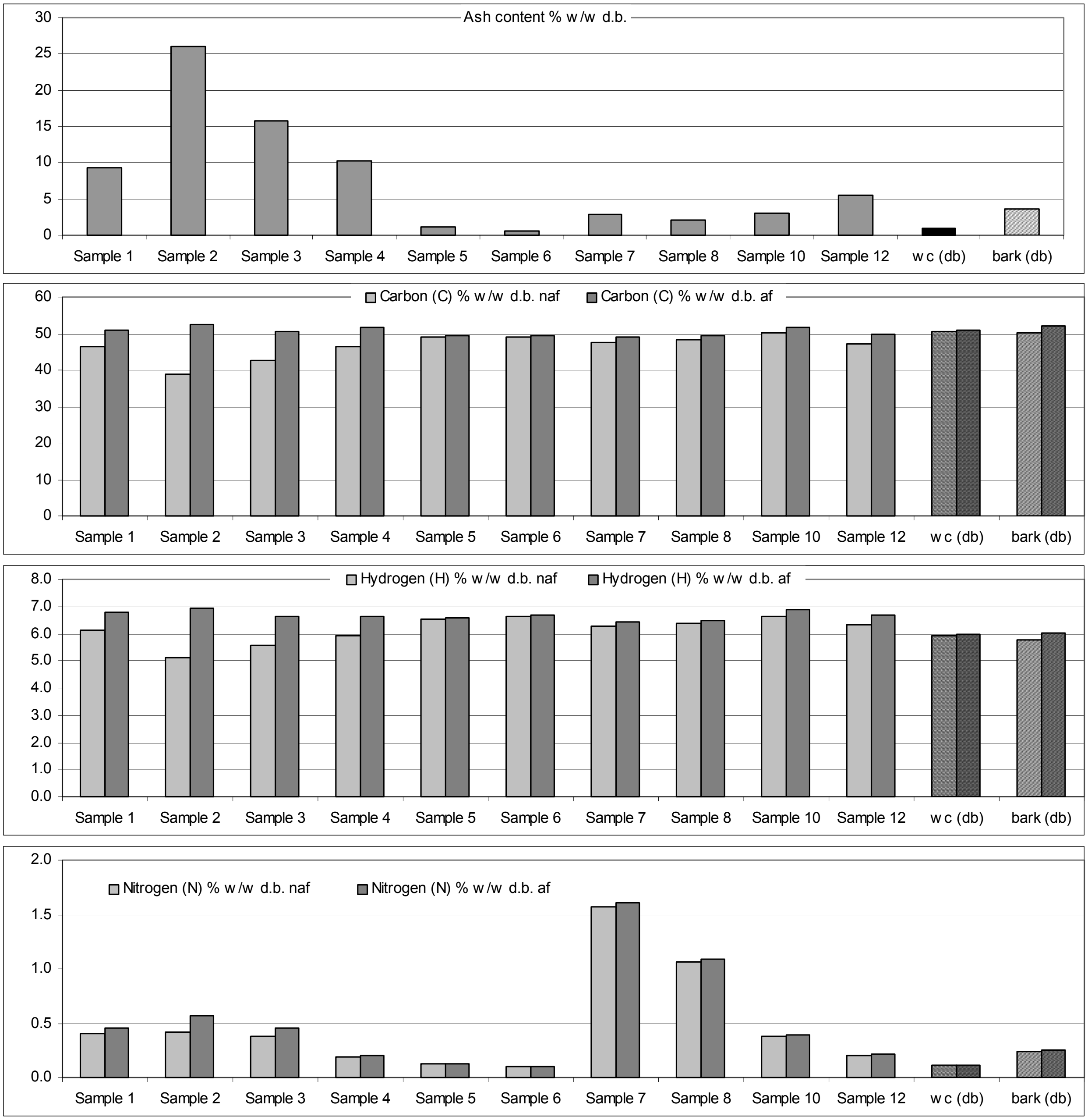


Figure 5: Results of Wet Chemical Analyses of the Samples Compared to Mean Values for European Bark and Wood Chips Samples

Notes: "d.b." represents dry basis, "wc" refers to wood chips. The data for wood chips and bark were taken from the BIOS in-house fuel database. "naf" and "af" refer to non-ash-free and ash-free, respectively.

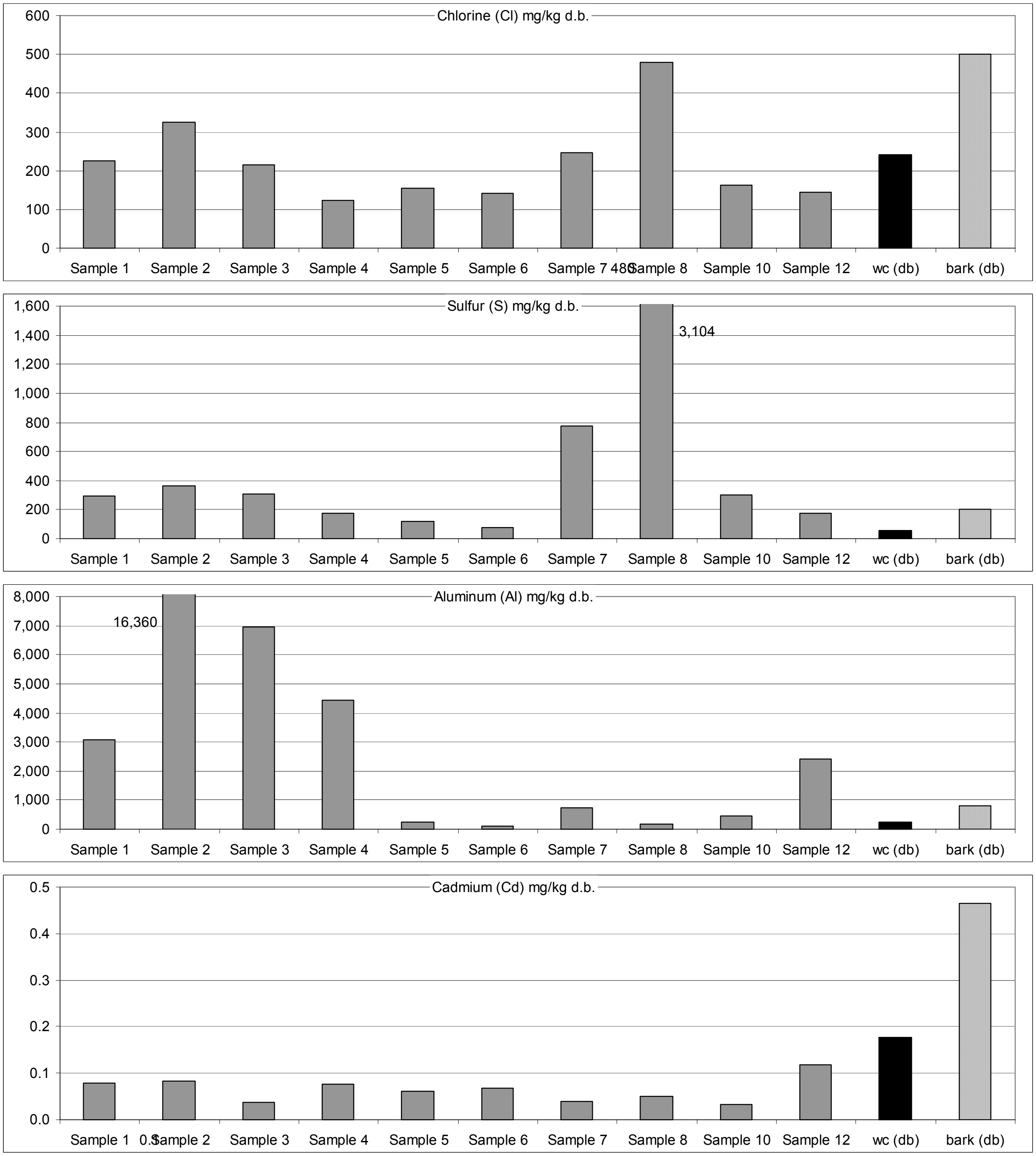


Figure 6: Results of Wet Chemical Analyses of the Samples Compared to Mean Values for European Bark and Wood Chips Samples

Notes: "d.b." represents dry basis, "wc" refers to wood chips. The data for wood chips and bark were taken from the BIOS in-house fuel database.

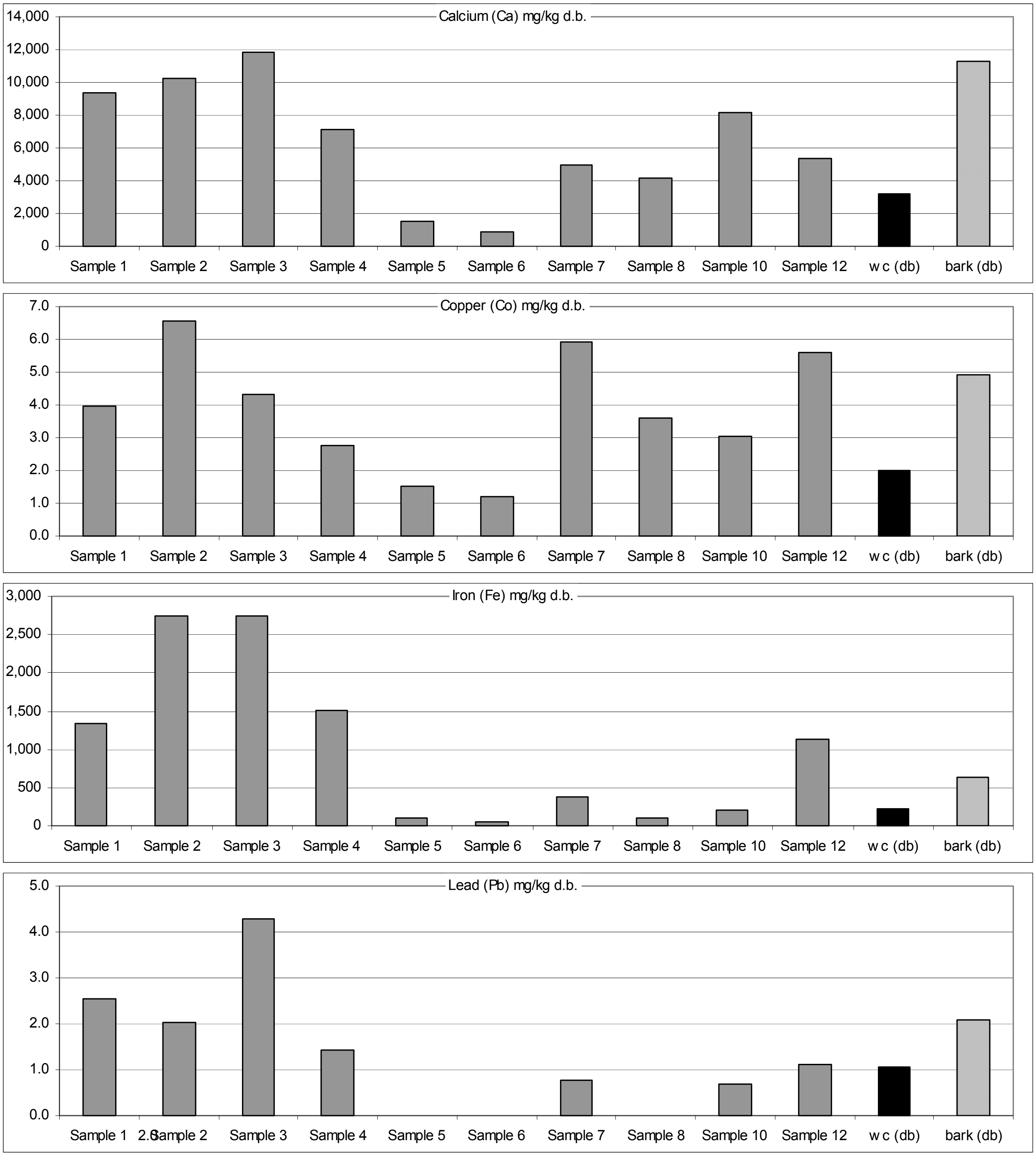


Figure 7: Results of the Wet Chemical Analyses of the Samples Compared to Mean Values for European Bark and Wood Chips Samples

Notes: "d.b." represents dry basis, "wc" refers to wood chips. The data for wood chips and bark were taken from the BIOS in-house fuel database.

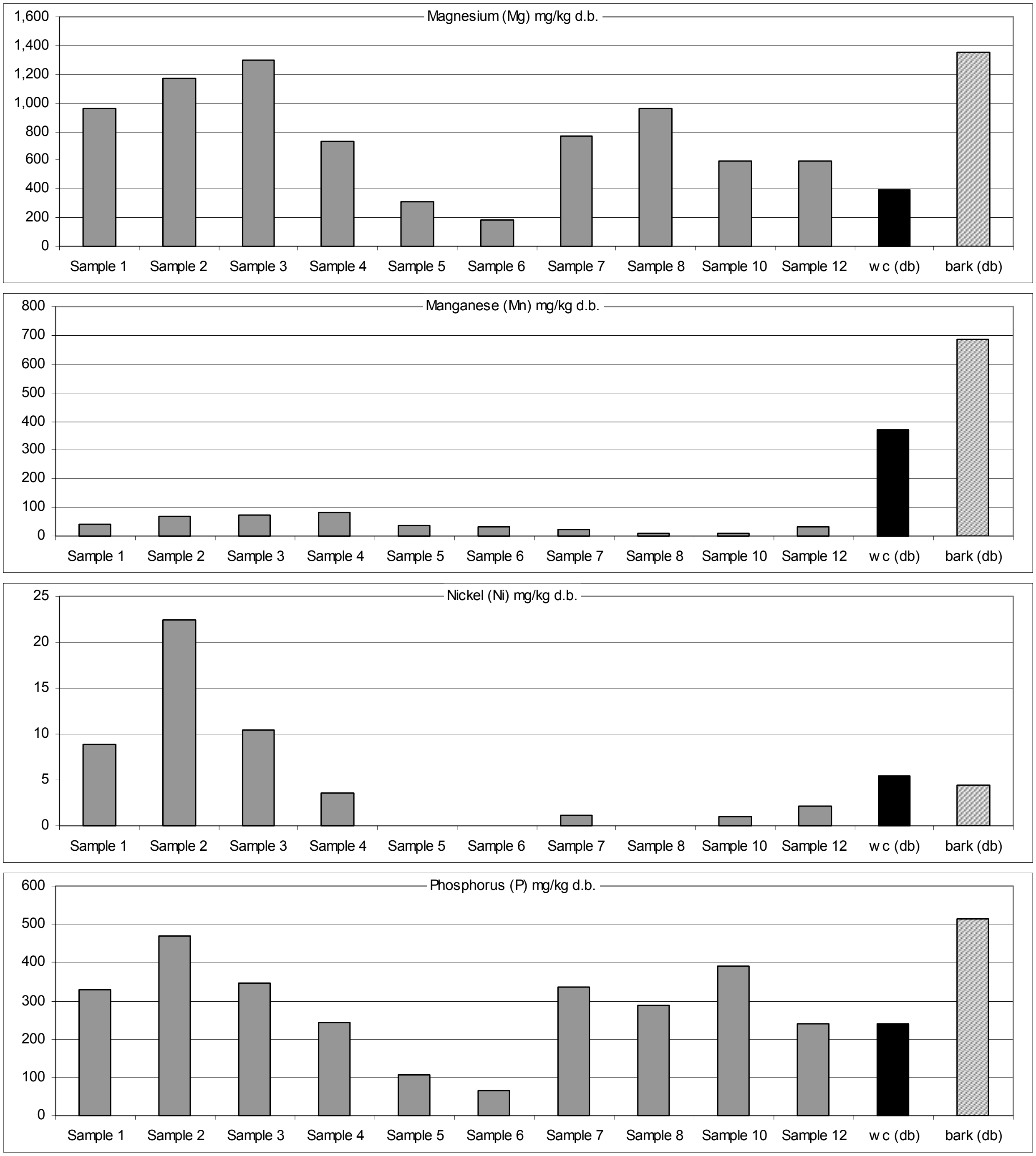


Figure 8: Results of Wet Chemical Analyses of the Samples Compared to Mean Values for European Bark and Wood Chips Samples

Notes: "d.b." represents dry basis, "wc" refers to wood chips. The data for wood chips and bark were taken from the BIOS in-house fuel database.

In the following section, the results of the wet chemical analyses are discussed.

Sample #1: Caja Del Rio Landfill, Santa Fe

This sample is a mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis) woods and was taken from a south facing wood chip pile that is one to six months old. The sample contains high ash content, due in particular to significant amounts of silicon and aluminum in the sample. The analysis results indicate that the high ash content of the sample is mainly due to contamination with mineral matter (sand, earth, and stones), which can most probably be attributed to storage and manipulation of the fuel on unpaved surfaces at the landfill site. The increased ash content also reduces the amount of organic matter per kilogram of dry substance, and therefore the gross calorific value of the fuel sample. See Section 4.6.4. Moreover, the sample contains relatively high concentrations of sodium and iron. The water content of 20.4 percent (w/w, w.b.) is rather low, probably due to the long storage time and the dry climate in Santa Fe. From a combustion point of view, the high ash content has to be carefully considered in selection of appropriate furnace, boiler, flue gas cleaning and ash handling technologies. This material can be considered a relatively dry fuel of moderate quality.

Sample #2: Caja Del Rio Landfill, Santa Fe

This material is a mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis) woods. It was taken from the middle of a pile between 1 and 6 months old. The ash content of this sample is extremely high due once again to the significant presence of silicon and aluminumThe analysis results indicate that the material is heavily contaminated with mineral matter (sand, earth, stones), which can be attributed to the storage and manipulation of the fuel on unpaved surfaces at the landfill site. Moreover, the sample contains high contents of potassium and iron as well as very high sodium levels. The amount of nickel is also higher than the mean value for European wood chips and bark. The high ash content reduces the amount of organic matter per kilogram of dry substance, and therefore the gross calorific value of the fuel sample. See Section 4.6.4. The water content of 20 percent (w/w, w.b.) is rather low and is likely due to the long storage time and the dry climate in Santa Fe. From a combustion point of view, the extremely high ash content as well as the high concentrations of K and Na make utilization of this material as a fuel difficult. This material is not recommended for combustion unless mixed with a higher quality wood fuel.

Sample #3: Caja Del Rio Landfill, Santa Fe

This sample is a mixture of Juniper (Juniperus monosperma) and Pinon (Pinus edulis) woods. It was taken from a north facing pile between 1 and 6 months old. The sample contains very high ash content, due in particular to the significant presence of silicon, aluminum and iron. The potassium and sodium contents are also high. The analysis results show that severe contamination with mineral matter has taken place (from sand, earth, and stones), which can again be attributed to storage and manipulation of the fuel on unpaved surfaces at the landfill site. The high ash content also reduces the amount of organic matter per kg dry substance and therefore the gross calorific value of the fuel sample. See Section 4.6.4. The water content of 30.1 percent (w/w, w.b.) is moderate for a biomass fuel but high compared to the other two analyzed samples from the Caja Del Rio Landfill. From a combustion point of view, the very high ash content as well as the high concentrations of K and Na make utilization of this material as a fuel difficult. This material is not recommended for combustion unless mixed with a higher quality wood fuel.

Sample #4: Spotted Owl Timber Inc., Santa Fe

This sample is a mixture of bark and wood from Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir and White Fir woods. It was taken from a large pile that is one to four weeks old. The material contains high ash content due to the significant amounts of silicon, aluminum, and iron identified. The amount of sodium in the sample is also high. The material is contaminated with mineral matter (including sand, earth, and stones), which is likely due to storage and manipulation of the fuel on unpaved surfaces. The increased ash content also reduces the amount of organic matter per kilogram of dry substance, and therefore the gross calorific value of the fuel sample. See Section 4.6.4. The water content of 27.9 percent (w/w, w.b.) is rather low, and is probably due to the long storage time of the logs prior to processing and the dry climate in Santa Fe. From a combustion point of view, the high ash content must be considered in selection of appropriate furnace, boiler, flue gas cleaning and ash handling technology. If appropriate combustion equipment is used, it can be considered a semi-dry fuel of moderate quality.

Sample #5: Spotted Owl Timber Inc., Santa Fe

This sample is a mixture of bark and wood comprised of Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir and White Fir woods taken from a small pile between 1 and 5 days old. This material is comparable to untreated woody biomass fuels (sawmill byproducts) from central Europe. The relatively high water content of 49.3 percent (w/w, w.b.) can be attributed to the freshness of the sample and to the rain that was falling during sample collection. (The pile from which the sample was taken was quite small and rain was penetrating the whole pile.) Fresh sawmill by-products in European conditions have water contents between 50 and 58 percent (w/w, w.b.). From a combustion point of view, this fuel can be utilized without restriction and can be considered a moist fuel of good quality.

Sample #6: Spotted Owl Timber Inc., Santa Fe

This material is a mixture of sawdust from Aspen, Engleman Spruce, Ponderosa Pine, Douglas Fir and White Fir woods taken from a small pile estimated to be one to four weeks old. This material is comparable to untreated woody biomass fuels (sawmill by-products) from central Europe. The relatively high water content of 47 percent (w/w, w.b.) can be attributed to the freshness of the sample and to the rain that was falling during sample collection. (The pile from which the sample was taken was quite small and rain was penetrating the whole pile.) From a combustion point of view, this fuel can be utilized without restriction and can be considered a moist fuel of good quality.

Sample #7: Albuquerque Area River Thinning Project

This sample is a mixture of Salt Cedar (Tamarix spp.), Russian Olive (Elaeagnus angustifolia) and Cottonwood (Populus wislizeni). Compared to the wood fuel compositions given in the BIOS database, this material contains a high sodium level, but the carbon content is slightly lower than that in average wood fuel samples from central Europe. The content of sulfur in the sample is high and the nitrogen content can be classified as very high compared to typical natural wood fuels. The water content of 11.8 percent (w/w, w.b.) is very low, which increases the net calorific value of the fuel per unit weight. From a combustion point of view, this fuel can be utilized as a dry and energy-rich wood fuel in furnaces suitable for ash-rich biomass. Special consideration should be taken to minimize NO_x emissions via selection and design of the combustion technology if using this biomass as fuel, due to its high nitrogen content.

Sample #8: Los Lunas Area River Thinning Project
This mixture of Salt Cedar (Tamarix spp.), Russian Olive (Elaeagnus angustifolia) and Cottonwood (Populus wislizeni) was chipped in March of 2004. It contains extremely high sulfur levels and high concentrations of nitrogen, chlorine and sodium compared to natural wood fuels from central Europe. The water content of 15.9 percent (w/w, w.b.) is very low, increasing the net calorific value of the fuel per unit weight. From a combustion point of view this fuel is dry and energy-rich, but special consideration should be taken to select a combustion technology that minimizes the formation of SO_x and NO_x. Due to its extremely high sulfur content, utilization of this material as a fuel is difficult and cannot be recommended until test runs with this fuel have been performed and evaluated. This biomass fuel is therefore not recommended for combustion unless mixed with a higher quality wood fuel.

Sample #10: East Mountain Thinning Project
This material is a mixture of Pinon (Pinus edulis) and Juniper (Juniperus monosperma) woods. Compared to other samples from thinning projects, the water content in this sample of 42.8 percent (w/w, w.b.) is relatively high. This can possibly be explained by the freshness of the material. This sample is comparable with untreated woody biomass fuels from Austria. From a combustion point of view, this fuel can be utilized in furnaces suitable for ash-rich biomass fuels. For such equipment, this sample can be considered a moist fuel of good quality.

Sample #12: Pecos Wilderness Thinning Project
This sample is a mixture of Ponderosa Pine (Pinus ponderosa) and Pinon (Pinus edulis), which was collected from the forest floor. The sample has a high ash content, due in particular to high silicon, aluminum and iron levels. This finding appears to be due to contamination of the fuel with mineral impurities such as sand, earth, and stones. Furthermore, the concentration of sodium is high in comparison to wood chips and bark fuels from central Europe. The water content of 8.8 percent (w/w, w.b.) is very low, increasing the net calorific value of the fuel per unit weight. From a combustion point of view, this fuel can be utilized in furnaces suitable for ash-rich biomass fuels. For such equipment it can be considered a dry and energy-rich fuel of medium quality.

4.6.4 Net Calorific Value of the Analyzed Samples

Based on the results of the chemical analyses and the equations outlined in Section 2.5.1.2.8, the gross calorific values and the net calorific values of the analyzed biomass fuel samples were calculated. Table 29 and Table 30 show the results of these calculations.

Table 29: Gross Calorific Values of the Analyzed Biomass Fuel Samples

	Gross Caloric Value					
Sample #	Non ash-free			Ash-free		
	[MJ/kg, (d.b.)]	[kWh/kg, (d.b.)]	[BTU/lb, (d.b.)]	[MJ/kg, (d.b.)]	[kWh/kg, (d.b.)]	[BTU/lb, (d.b.)]
Municipal Waste						
Sample #1	18.73	5.21	8,052	21.48	5.97	9,234
Sample #2	14.48	4.03	6,227	22.39	6.23	9,627
Sample #3	16.53	4.59	7,105	21.08	5.86	9,062
Average Mun.	**16.58**	**4.61**	**7,128**	**21.65**	**6.02**	**9,308**
Commercial Waste						
Sample #4	18.54	5.15	7,971	21.57	6.00	9,275
Sample #5	20.20	5.61	8,683	20.49	5.70	8,810
Sample #6	20.43	5.68	8,782	20.58	5.72	8,846
Average Com.	**19.72**	**5.48**	**8,479**	**20.88**	**5.80**	**8,977**
Forest Thinnings						
Sample #7	19.51	5.42	8,388	20.28	5.64	8,717
Sample #8	19.89	5.53	8,551	20.48	5.69	8,806
Sample #10	20.96	5.83	9,011	21.86	6.08	9,400
Sample #12	19.25	5.35	8,274	20.85	5.80	8,966
Average FT	**19.90**	**5.53**	**8,556**	**20.87**	**5.80**	**8,972**
Wood chips	20.11	5.59	8,645	20.34	5.65	8,743
Bark	20.03	5.57	8,612	20.99	5.83	9,022

Notes: "GCV" represents the gross calorific value. The data for wood chips and bark were taken from the BIOS in-house fuel database.

The gross calorific values of the samples with low and medium ash contents (Sample #5, #6, #7, #8, #10 and #12) are comparable with untreated woody biomass fuels from Europe. Samples #1, 2, 3, and 4 have lower gross calorific values, which can be attributed to the high ash content of these samples. High ash content in the sample reduces the amount of organic combustible matter per unit weight of dry substance. See also Section 4.6.3.

Apart from the gross calorific value, the water content is the most significant determinant of net calorific value. This is illustrated by the fact that the samples with the lowest water contents (Samples #7, #8, #12) display the highest net calorific values. The results of the chemical analyses reflect generally lower moisture contents compared to European samples, for which the average moisture content is between 30 to 50 percent (w/w, w.b.). Low water content in the samples thus results in higher net calorific value by weight. The relatively low moisture content in domestic samples can be generally attributed to the dry weather conditions in Santa Fe.

The actual moisture content of biomass represented by Samples #5 and #6 are expected to be lower than the measured values since it was raining when these samples were collected. The moisture content of Sample #4 seems to be more representative of this sample group. The quality of Sample #4 was not affected by the rain as the pile from which it was collected was large enough to hinder saturation. The moisture content of Sample #4 was therefore used for all three samples to estimate the expected net calorific value of biomass from commercial green waste sources.

Table 30: Net Calorific Value of the Biomass Samples Investigated

Sample #	Moisture Content	NCV non ash-free		
	[% (w/w, w.b.]	[MJ/kg, (w.b.)]	[kWh/kg, (w.b.)]	[BTU/lb, (w.b.)]
Municipal Waste				
Sample #1	20.37	13.34	3.71	5,735
Sample #2	20.04	10.19	2.83	4,380
Sample #3	30.11	9.95	2.77	4,280
Average Mun.	**23.51**	**11.16**	**3.10**	**4,798**
Commercial Waste				
Sample #4	27.94	11.73	3.26	5,045
Sample #5*	27.94	12.83	3.57	5,518
Sample #6*	27.94	12.98	3.61	5,580
Average Com.	**27.94**	**12.52**	**3.48**	**5,381**
Forest Thinnings				
Sample #7	11.80	15.70	4.36	6,749
Sample #8	15.88	15.16	4.22	6,519
Sample #10	42.83	10.10	2.81	4,340
Sample #12	8.79	16.07	4.47	6,910
Average FT	**19.82**	**14.26**	**3.96**	**6,129**

**Notes: The moisture content of Sample #4 was used to replace those of Sample #5 and Sample #6 to eliminate the influence of rain during the sample collection. "NCV" represents net calorific value.*

The average net calorific value results for each biomass source category were used to estimate the total energy content of the available biomass fuels. See Section 4.3.5.

Improving the processing and storage facilities and improve the fuel handling logistics would increase the gross and net calorific values of the available biomass by reducing mineral contamination, thus lowering the ash and the average water content.

As discussed in Section 3.4, the size of the biomass-fired furnace determines the range of useable fuel quality. Larger furnaces are less sensitive to fluctuations in fuel quality, and can efficiently utilize a wide variety of fuel qualities. Small-scale furnaces require fuel with a higher quality. For this reason, two different fuel qualities were contemplated:

Fuel quality 1 represents the average of all analyzed samples, weighted by the proportion of each biomass source to the total available amount of biomass. The resultant average biomass sample has relatively high ash content and fluctuating quality. It can therefore only be used for large-scale applications such as the main district heating grid. Furthermore, a mixture of many different fuel sources is necessary to meet the high fuel demand of the heating plant of the main grid.

Fuel quality 2 represents the average of Sample #5 and Sample #6, using the moisture content of Sample #4. This fuel has a low ash content and a constant quality and is suitable for small-scale applications such as the micro-grids.

Table 31: Calculated Fuel Qualities for Large-Scale and Small-Scale Applications

Fuel Quality 1					
	Fraction of Total	**Moisture Content**	**NCV**		
Source		[% (w/w, w.b.]	[MJ/kg, (w.b.)]	[kWh/kg, (w.b.)]	[BTU/lb, (w.b.)]
Municipal	11.37%	23.51	11.16	3.10	4,798
Commercial	79.33%	27.94	12.52	3.48	5,381
Forest Thinnings	9.31%	19.82	14.26	3.96	6,129
Average		**26.68**	**12.52**	**3.48**	**5,384**
Fuel Quality 2					
		Moisture Content*	**NCV**		
Source		[% (w/w, w.b.]	[MJ/kg, (w.b.)]	[kWh/kg, (w.b.)]	[BTU/lb, (w.b.)]
Commercial		**27.94**	**12.91**	**3.59**	**5,549**

**Notes: The moisture content of Sample #4 was used to replace those of Sample #5 and Sample #6 to eliminate the influence of rain during the sample collection. "NCV" represents net calorific value.*

4.6.5 Chemical Composition of Ash in the Investigated Samples

Based on the results of the chemical analysis and the equation given in Section 2.5.1.2.9, the chemical composition of the ash contained in the investigated samples was calculated. Results are shown in Table 32.

The results represent the average chemical composition of the total ash produced in the tests. At the biomass plant the ash will be produced in various ash fractions, such as bottom ash or fly-ash, and the chemical composition of the individual ash fractions will vary from the average somewhat. (Some elements have a greater tendency to end up in the bottom ash, others in the fly ash.) The calculated chemical composition nevertheless represents a good aggregate estimate of the composition of the expected ash with respect to nutrients, liming compounds, and heavy metals. The results can therefore be used to determine the suitability of the ash for use as a fertilizing or liming agent.

Table 32: Chemical Composition of the Total Ash Contained in the Biomass Fuel Samples Investigated in Comparison to Average Values for Middle European Wood and Bark Fuels

Element	Sample #1 [mg/kg]	Sample #2 [mg/kg]	Sample #3 [mg/kg]	Sample #4 [mg/kg]	Sample #5 [mg/kg]	Sample #6 [mg/kg]
Aluminum (Al)	32,709	62,672	44,188	43,168	24,705	19,044
Cadmium (Cd)	1	0	0	1	6	13
Calcium (Ca)	99,569	39,281	75,125	69,080	141,707	168,325
Copper (Cu)	42	25	27	27	143	225
Iron (Fe)	14,295	10,511	17,434	14,678	9,998	10,614
Lead (Pb)	27	8	27	14	29	56
Magnesium (Mg)	10,219	4,471	8,245	7,108	29,222	33,308
Manganese (Mn)	437	264	462	804	3,689	6,172
Nickel (Ni)	95	86	67	35	95	185
Phosphorus (P)	3,505	1,796	2,206	2,379	10,118	12,203
Potassium (K)	27,816	23,522	26,694	26,341	85,444	105,567
Silicon (Si)	243,666	275,747	253,805	260,061	154,361	129,297
Sodium (Na)	8,058	19,142	11,284	11,825	8,721	6,144
Sulfur (S)	3,122	1,400	1,971	1,717	11,285	14,377
Zinc (Zn)	245	355	125	197	1,243	1,938
Element	**Sample #7 [mg/kg]**	**Sample #8 [mg/kg]**	**Sample #10 [mg/kg]**	**Sample #12 [mg/kg]**	**Wood [mg/kg]**	**Bark [mg/kg]**
Aluminum (Al)	26,241	8,552	15,229	42,929	28,000	22,657
Cadmium (Cd)	1	2	1	2	22	14
Calcium (Ca)	178,905	198,700	267,247	95,901	355,000	322,486
Copper (Cu)	214	173	100	100	222	140
Iron (Fe)	13,333	4,640	6,744	20,222	24,889	17,943
Lead (Pb)	28	14	23	20	122	60
Magnesium (Mg)	27,589	45,958	19,557	10,541	43,889	38,600
Manganese (Mn)	780	479	245	594	41,033	19,657
Nickel (Ni)	39	48	31	38	600	129
Phosphorus (P)	12,057	13,806	12,876	4,284	26,778	14,743
Potassium (K)	82,274	79,449	50,501	29,503	100,778	67,657
Silicon (Si)	129,168	42,216	55,048	226,857	146,333	112,457
Sodium (Na)	16,152	16,961	4,109	9,554	6,778	5,029
Sulfur (S)	27,818	148,167	9,881	3,078	26,889	14,257
Zinc (Zn)	333	208	643	316	3,933	3,277

Notes: The values represent the total ash content of a fuel sample, assuming that 100 percent of all ash forming elements excluding Cl remained in the ash after combustion. All elements calculated for will mainly be bound as oxides in the ash.

The results show great variety in the elemental composition of the different samples. Based on the results of the chemical analyses, samples #1, 2, 3, and 4 can be considered ash-rich, while samples #5, 6, 7, 8, 10, and 12 have medium or low ash content.

Ash-Rich Samples

The chemical analyses of samples #1, 2, 3, and 4 indicate a very high ash content. It is assumed that this is caused by contamination of the biomass with dirt and rocks during storage and handling on unpaved surfaces.

Compared to average values of wood chips and bark samples from central Europe, the ash-rich samples have high aluminum (Al) and silicon (Si) contents. The content of sodium (Na) is also higher than comparable values of wood chips and bark in central Europe. On the other hand, the contents of nutrients like potassium (K), magnesium (Mg) and phosphorus (P) are lower than the average values of wood chips and bark in central Europe. Furthermore, the content of calcium (Ca), which is relevant for determining the liming effect of the ash, is considerably lower than average values found in biomass samples from central Europe.

The low content of heavy metals like cadmium (Cd), lead (Pb), nickel (Ni) and zinc (Zn) in the ash indicates good potential suitability of the ash for fertilizer.

Samples with Medium or Low Ash Content

The chemical analyses of Samples #5, 6, 7, 8, 10, and 12 show a medium or low ash content.

Compared to average values found in wood chips and bark samples from central Europe, these samples have high silicon (Si) contents. The content of sodium (Na) is also higher than comparable values of wood chips and bark in central Europe. The content of nutrients is higher than in the ash-rich samples, while the content of phosphorus (P) and magnesium (Mg) is still lower than the average values of biomass samples from central Europe. Furthermore, the samples have higher calcium (Ca) contents than the ash-rich samples. The average calcium content of wood chips and bark from Central Europe is higher than in the domestic samples.

The content of heavy metals in these samples is considerably lower than average values in samples from central Europe. Low heavy-metals content improves the suitability of the ash as a fertilizer.

4.7 Ash Utilization Possibilities

As shown in Table 32, chemical analyses of the samples showed lower content of nutrients and compounds with liming effects, including oxides of potassium, calcium, magnesium and phosphorus, than are typically found in wood and bark in central Europe. On the other hand, the content of heavy metals in the domestic samples is below average values for wood and bark. See Section 4.6.5.

In general, the required properties needed to utilize the ash for fertilizer (outlined in Section 2.7) are present in the ash of the analyzed samples. A return of the ash to farmland or forestland is therefore possible.

Preliminary research was conducted into the type and acidity of soils within the study radius. Data were provided by Aaron Miller, Soil Scientist at the USDA's Natural Resources Conservation Service in Santa Fe. Acidity is a good initial indicator of the suitability of ash for fertilization in the area.

The following table shows the main soil types in the Santa Fe area and the pH levels for the first two strata below ground level.

Table 33: Main Soil Types in the Santa Fe Area and pH Levels for the First Two Strata Below Ground Level

Soil Series	Parent Material	Elevation [feet]	pH Ground Level	pH Second Level
Predawn	Alluvium/granite, gneiss, schist, loess, volcanic ash	6,500-7,300	6.8	6.8
Panky	Alluvium/granite, gneiss, schist, loess, volcanic ash	6,000-6,700	6.9	8.3
Arnor	Alluvium/granite, gneiss, schist, over residuum from granite	7,000-7,500	6.8	7.0
Altega	Eolian material, Alluvium/sandstone, shale	7,000-7,600	7.6	7.6
Tapia	Alluvium/micaceous siltstone, sandstone, mudstone	5,600-6,500	8.0	8.4
Rotado	Eolian material/residuum from rhyolitic tuff	6,900-7,600	6.6	6.6
Aliante	Alluvium/sandstone, shale	7,000-7,600	6.8	7.6
Sedillo	Eolian material and alluvium/tertiary intrusive material	5,500-6,500	8.2	8.2
Cerrillos	Eolian material and alluvium/tertiary intrusive material	5,500-6,500	8.2	8.2
Palatka	Slope alluvium or colluvium/residuum from rhyolitic tuff	6,000-6,900	6.4	6.6
Arojomil	Eolian material over relict alluvium/granite, gneiss, schist	6,000-7,000	8.2	8
Canuela	Eolian Material and slope alluvium over residuum/rhyolitic tuff	6,100-6,900	6.6	6.6

Source: [14]

Notes: All samples were taken from Santa Fe County, and are believed to be representative of the various soils within the study radius. "Ground level" represents a maximum of 5 inches (25 cm). "Second level" represents a depth of 1-12 inches (2.5-30 cm). Depths for ground level and second level vary depending on the soil series.

All the soils listed in Table 33 have a pH level of almost neutral. Ash from biomass typically has a pH level between 12 and 13. Given that investigated ashes have lower calcium (Ca) and higher silicon (Si) contents compared to average values for wood and bark ashes from central Europe, the pH level of the investigated samples is expected to be slightly lower than typical values from central Europe.

The long-term application of ash on the soils listed in Table 33 will increase the pH and nutrient levels of the soils.

In conclusion, the general requirements for an environmentally sustainable closing of mineral cycles using wood and bark ashes produced during biomass combustion are present. For a more detailed investigation of possible biomass ash utilization of as a fertilizing and liming agent in the Santa Fe region, a complete chemical analysis of the soils and a more comprehensive evaluation by a local soils expert are needed.

4.8 Specific Requirements of Biomass Fuel Concerning Storage, Feeding, Combustion Technology and Flue Gas Cleaning

4.8.1 Recommendations for Storage and Preparation of Biomass Prior to Delivery to a Heating Plant

4.8.1.1 Storage at the Fuel Sources

As discussed in Section 3.2, safety measures and other factors must be considered when storing biomass. Since most of the analyzed biomass samples have relatively low water content, the risks of spontaneous combustion can be considered low. Dry-matter losses are also not expected to be of great concern since no young crops are currently being considered for use as biofuels.

To avoid self-ignition, fresh bark should not be stored in piles higher than 26 ft (8 m). Moreover, the storage area must allow air convection from all sides.

The minimum capacity of each storage area at the fuel sources has to be designed with the capacity of the fuel-transport trucks in mind. The storage capacities should also be designed with consideration of possible aggregation of multiple biomass sources, as this practice can improve transport efficiency.

Considering the dry weather conditions in Santa Fe (average rainfall 17-inches (440 mm) per year, Reference [15]), fine material such as sawdust can be cost-effectively stored outside. A storage facility enclosed by three walls and a roof (to avoid dust emissions) will provide ample protection of fuel quality without the high cost of a complete enclosure. For the remainder of the sampled biomass fuels there is no need for a roofed storage area. Wood chips and bark can be simply piled outside. All storage areas must be paved, however, to reduce fuel contamination by mineral matter.

The lack of paved storage areas is believed to be the main reason for the high ash contents of the samples from the Caja Del Rio landfill (Samples #1, 2, and 3) and Sample #4 from Spotted Owl Lumber. Samples #5 and #6 from Spotted Owl Lumber exhibited low ash content in spite of being stored on an unpaved surface, but these samples were collected from a fresh pile that had never been turned.

Sample #12 from the Pecos Wilderness thinning project has the highest ash content of all samples from forest-thinning projects. It was collected directly from the forest floor, so contamination by mineral matter from the soil can be expected. The other samples from forest-thinning projects do not have high ash contents. Information about storage methods for these samples (Samples #7, 8, and 10) could not be obtained since they were provided by members of the Forest Service rather than being collected by our staff. However, it is believed that the samples were collected right after the chipping process, thus minimizing mineral contamination. To keep the ash content low, biomass fuels from forest-thinning projects should be collected immediately after thinning, and transported to appropriate storage areas to minimize the potential of contamination.

4.8.1.2 Fuel Preparation at the Fuel Sources

The samples from municipal green waste sources and forest thinnings (Samples #1, 2, 3, 7, 8, 10 and 12) show a wide variation in particle size, whereas the samples from commercial green waste sources have more uniform particle size.

The samples from the Caja del Rio landfill (Samples #1, 2, and 3) were ground by a mobile grinder. The particle size ranges from 0.1 inches to about 5 inches (0.25 to 12.5 cm). The mesh size of the screen on the grinder's output is about 2 inches (5 cm,) but longer pieces with diameters smaller than 2 inches (5 cm) apparently fall through the screen.

The samples from Spotted Owl lumber mill (Samples #4, 5, and 6) have a more uniform particle size. Sample #5 was processed by a mobile grinder, resulting in a particle size between 0.5 and 3 inches (1 and 7.5 cm.) The material is very thin, so feeding from plant-site storage into the heating plant by screw conveyors is possible even though some particles are larger than 2 inches (5 cm). Sample #4 is a product from a two-stage grinder. The first stage is similar to the grinder that is used for Sample #5, and the second stage is a finer grinder. The particle size therefore ranges from 0.1 to 2 inches (0.25 to 5 cm). The particle size of sawdust is determined by the method by which the source lumber is processed. Sawdust particle sizes are about 0.1 inches (0.25 cm) and do not vary considerably.

The samples from forest thinnings (Samples #7, 8, 10, and 12) have a very inconsistent particle size, ranging from 0.1 to 8 inches (0.25 to 20 cm). Detailed information regarding the processing methods could not be obtained, but based on the wide range of particle sizes it is believed that coarse chippers or grinders with large-mesh screens are used.

Large-Scale Biomass-Fired Systems

Large-scale biomass-fired systems utilizing grate furnaces as the selected combustion technology can effectively burn biomass with particle sizes up to 20 inches (50 cm). See Section 3.4 and 4.8.3. This level of fuel flexibility means that the required quality standards regarding particle size for grate furnaces (and therefore the subsequent requirements for fuel processing at the fuel source) are not stringent. Simple screens can be used to achieve the necessary particle size. All analyzed biomass samples fulfill the basic particle-size requirements for large-scale applications.

Small-Scale Biomass-Fired Systems

Small-scale biomass projects with underfeed stokers as the selected combustion technology necessitate higher demands on the particle size of the fuel. See Section 3.4 and 4.8.3. Only biomass with a particle size smaller than 2-inches (5 cm) can be used in these applications. Of the analyzed samples, only the samples from commercial green waste sources (Samples #4, 5, and 6) meet this requirement. Before other fuel sources can be considered for small-scale applications, better grinding and chipping equipment using finer screens must be used to raise the quality to the standards necessary for small-scale applications.

4.8.2 Storage, Fuel Feeding and Handling Systems at the Heating Plant

General Recommendations

Systems for assuring appropriate fuel quality and for assessing the correct dollar value to the delivered biomass fuel will need to be established at the heating plant.

At the fuel delivery point at the heating plant, a visual inspection of the biomass must be performed. Deliveries that are obviously contaminated and inappropriate deliveries containing rocks, waste or other problematic ingredients, containing particle sizes outside of the specification, or containing unspecified material (i.e. waste wood) should be rejected. If the delivery passes the visual inspection, the value assessment process would then begin.

The delivered biomass should be assessed based on its net caloric value (i.e. the delivered BTU's). A calculation of the energy content based on weight and net calorific value (NCV) is recommended. The NCV is calculated using the moisture content of the fuel delivered and the type of biomass fuel. A typical method is as follows: the weight of the load is measured at a scale house, and the moisture content of a sample from the fuel delivered is determined using a moisture meter that provides quick results. The net calorific value can then be calculated using the gross calorific value of the delivered fuel and the moisture content obtained from the measurements. The gross caloric value of each fuel source should be determined by chemical analysis prior to the first delivery. See Section 3.5. The energy content, which determines the price of the fuel delivered, is calculated by the NCV times the weight of the biomass fuel.

If a scale house is not available, an alternative assessment method depends on measurement of the delivered volume rather than the weight. The volume can be converted to weight by using the average value of the bulk density of the specific fuel source. The bulk densities of all delivered fuel sources should be determined for every fuel source prior to the first delivery to maximize the accuracy of this process.

The determined gross calorific value and bulk density of the fuel, as well as the calculation method for the net calorific value, moisture content, and fuel price should be defined in the fuel delivery contract.

Invoicing based solely on volume or weight is not recommended, since biomass fuels of fluctuating quality and from different sources will most likely be used in the heating plant.

Furthermore, random tests regarding ash content of delivered fuels should be performed. Biomass deliveries with ash content higher than that specified must be rejected. See also the discussion of large-scale and small-scale applications later in this section.

Large-Scale Biomass-Fired Systems

The requirements for long-term storage of biomass fuel at a heating plant are similar to the requirements at the fuel source as discussed in Section 4.8.1.1. Front loaders will be used for fuel manipulation between long-term storage areas and the short-term storage facilities.

Considering the large size of the planned heating plant in Santa Fe and its considerable annual fuel demand, it will not be possible to maintain high reliability with only one fuel source. A mixture of wood chips, sawdust and bark from a variety of sources will therefore be needed to achieve a reliable fuel supply.

The particle size of the analyzed samples ranges from 0.1 to 8 inches (0.25 to 20 cm). (Section 4.6.1.) Based on the fact that larger fractions of bark with an expected particle size up to 20 inches (50 cm) are also available (see Table 15), an even wider range of particle sizes within the aggregate of utilized fuel types can be expected.

The ash content of fuel utilized in the biomass-fired boiler must not exceed 10 percent (w/w, d.b.) for large-scale applications. Generally, fuels of lower quality (having high ash, moisture, nitrogen or sulfur contents, for example) should be mixed with fuels of higher quality (low ash, moisture, etc.) to achieve constant conditions in the furnace and to allow a wider selection of fuel sources, qualities, and costs for the heating plant.

The appropriate storage and fuel-feeding systems for the expected particle size consist of short-term storage in bunkers with sliding bar conveyors. Sawdust must be mixed with large-sized fuels to maintain continuous fuel feeding. If additional fuel feeding systems are required to transport the fuel from the storage bunker to the biomass-fired boiler, additional sliding-bar conveyors or chain-trough conveyors can be used. See also Section 3.3.

Small-Scale Biomass-Fired Systems

The requirements of long-term storage at the heating plant are similar to the requirements at the fuel source (Section 4.8.1.1). For small-scale plants however, just-in-time fuel storage solutions are possible if reliable fuel deliveries can be guaranteed. In this case, only a storage bunker with a sliding bar conveyor is needed. The bunker can be directly filled from a truck, eliminating the need for additional fuel handling.

Due to the relatively low fuel demand of the smaller boilers in micro-grid applications, such systems can rely on a single fuel source. Buying fuel from a single source is helpful for maintaining relatively constant fuel quality. If the fuel supply is constantly high-quality and as long as biomass with particle sizes below 2 inches (5 cm) is utilized (sawdust, small wood chips), then screw conveyors can be used for fuel-feeding. The screw conveyors are generally installed after the sliding-bar conveyor in the storage bunker to move fuel from the storage bunker to the biomass-fired boiler.

The ash content of the fuel utilized in the small-scale biomass-fired boiler must not exceed 5 percent (w/w, d.b.) and, if possible, the ash content should be even lower. The use of bark should therefore be avoided since it has a relatively high ash content. See Table 1. Furthermore, the moisture content of the utilized biomass should not exceed 40 percent (w/w, w.b.). If different fuel sources are used, fuels of lower quality (having high ash, moisture, nitrogen, or sulfur content) should be mixed with fuels of higher quality (lower in ash, moisture, etc.) to achieve constant conditions in the furnace.

An appropriate quality-assurance system must be used to ensure that all delivered fuels meet the requirements regarding particle size, ash content, fuel type, and moisture content.

4.8.3 Combustion Technologies

Large-Scale Biomass-Fired Systems

As mentioned in Section 4.6.4, the heating plant for the main district heating system in Santa Fe will require a diversity of biomass sources in order to maintain security of the fuel supply.

Since the aggregation of multiple fuel sources will result in fluctuating fuel quality, grate furnaces are the best available technology. (See Section 3.4.) Grate furnaces are very flexible in their tolerance of variations in moisture content, ash content, and particle size. Since no herbaceous fuels are available within the study target area, the poor performance of grate furnaces on a mixture of wood fuels and herbaceous fuels is not relevant within the study parameters.

As some of the biomass samples contain high ash contents, underfeed stokers are not a suitable combustion technology for the main district heating system plant.

Although bubbling and circulating fluidized-bed combustion systems (BFB, CFB) are tolerant of wide variations in moisture content and fuel type, these systems have limited flexibility with regard to particle size. Fuel particles smaller than 3 inches (8 cm) for BFB and smaller than 1.5 inches (4 cm) for CFB are generally required, and based on the available fuel types, this will necessitate additional fuel preparation at the heating plant. Moreover, these combustion technologies cannot operate at partial load, and therefore are not suitable for applications with significant heat-load variation throughout a year.

Small-Scale Biomass-Fired Systems

The annual heat demand and resultant annual fuel demand of the micro-grid options considered in Santa Fe are significantly lower than those of the main district heating system. This allows tighter limits to be placed on the specifications of fuel quality and consistency. As a result, technologies with more stringent tolerances and lower investment costs can be selected.

Underfeed stokers represent a proven technology for small-scale applications due to their simple load control and fuel dosing systems. As long as consistent fuel quality is maintained regarding ash content and particle size, such systems have a proven track record of excellent performance.

4.8.4 Flue Gas Cleaning

Considering the type of available biomass (only untreated wood chips, bark and sawdust), no emissions other than dust are expected to reach levels that require secondary emission reduction measures. (Note: The nitrogen content in Samples #7 and #8 was above average, and biomass from these sources, if utilized, should be mixed with material from other sources prior to combustion. Otherwise, additional devices for NO_X reduction may need to be installed to prevent excess NO_X emission levels.

Since all samples have less than 50 percent (w/w, w.b.) moisture content and the average moisture content is less than 30 percent (w/w, w.b.), no negative effects on the combustion conditions which would increase emissions are expected.

Some samples have a relatively high ash content, which leads to higher amounts of fly ash and dust emissions, however. If it is not possible to reduce the ash content by avoiding contamination of the biomass with mineral matter (e.g. using paved storage areas), the high ash content must be considered in the design of both the de-dusting devices and the boiler – possibly necessitating automatic boiler cleaning. Depending on the requirements set for fuel quality and the limits set for dust emissions, a multi-cyclone seems to be an appropriate solution for small-scale applications and the combination of a multi-cyclone and an electrostatic precipitator (ESP) should suffice for large-scale applications.

5 Summary, Conclusions, and Recommendations

5.1 Summary and Conclusions

Total Sustainable Fuel Availability, Expected Costs and Expected Energy Potential

The investigation of possible fuel sources identified four different categories of biomass sources within a 50-mile radius of Santa Fe: wood residues from forest-thinning projects, municipal green waste from landfills and waste transfer stations, commercial green waste from wood processing companies, and state-funded thinning projects on private land. This last resource was not investigated at this time due to its likely overlap with the municipal green-waste supply.

Commercial green waste accounts for the largest portion of the available biomass. Biomass from current forest-thinning projects and municipal green waste facilities make up a smaller proportion of the total but are less stable, as the available quantities may change from year to year. The values shown in Table 34 are based on the sustainable annual yield of currently available green waste sources. Many additional forest-thinning projects that will likely start in the coming years are not included in the table because these projects are not yet funded.

If the intended thinning projects on WUI land within a 50-mile (80 km) radius of Santa Fe increase at the rate of 1,000 acres (405 hectares) per year for the next 13 years (1,000 acre in year one, 2,000 in year two, 3,000 in year three, etc.), a constant increase in available biomass from forest thinnings over the next 13 years, and thus a significant increase in the total available energy potential, can be expected.

Table 34: Total Sustainable Fuel Availability, Expected Costs and Expected Energy Potential

	Sustainable Yield		Exp. Del. Costs		Exp. Energy Potential	
Green Waste Source	**[tons/yr]**	**[metric tons/yr]**	**[$/MMBTU]**	**[$/MWh]**	**[MMBTU]**	**[MWh]**
Forest Thinning Projects	2,866	2,600	7	19	35,134	10,297
Municipal Green Waste	3,500	3,175	1	4	33,587	9,844
Commercial Green Waste	24,428	22,161	1	5	262,886	77,045
Totals	**30,794**	**27,936**			**331,607**	**97,186**

Notes: Sustainable yield is based on currently available sources. Expected delivery costs are based on biomass costs and transport costs obtained from comparable average European costs (forest-thinning projects), and interviews with recycling coordinators (municipal green waste) and managers and owners of wood processing industries (commercial green waste). The costs of municipal green waste are based on transport costs from the Jacona and El Dorado waste transfer stations. "Expected Energy Potential" is calculated using the average net calorific value of each green waste source.

The results show a total energy content of the biomass fuel available on a sustainable basis valued at about 332,000 MMBTU (97,000 MWh) per year. Considering a realistic scenario for the main grid with a connection rate of 80 percent of the potential heat demand, the annual heat demand of the customers would amount to about 172,000 MMBTU (50,500 MWh) per year within the target area of the planned district heating plant in Santa Fe. Assuming a total efficiency of the district heating system of approximately 73 percent including the efficiency of the plant and the heat losses of the network of pipes, and considering that the peak load is provided by a gas-fired boiler, the total required annual fuel energy input amounts to about 216,300 MMBTU (63,400 MWh).

The heating value of the currently available biomass is thus about 50 percent higher than the required heat input. This surplus of biomass fuel should allow the selection of the fuel suppliers based on quality, long-term availability and cost.

If the intended forest-thinning projects on WUI land are carried out, a significant increase of biomass from forest-thinning projects can be expected within the next 13 years. The cost of wood chips from forest-thinning projects must be competitive with costs from the other source categories to allow economically viable use of this fuel source.

Municipal green waste from landfills and transfer stations, and green waste from wood processing industries (commercial green waste) are available at considerably lower costs than biomass fuel in Europe. (Table 34). A market price for biomass from forest-thinning projects could not be determined because the fuel is usually left on site and burned. Based on the assumption that fuel from forest thinning in New Mexico will have a cost similar to that in Austria, where accessibility of forests is comparable, the cost of wood chips from forest thinning is significantly higher than the costs of green waste from municipal or commercial sources. Since no economic outlet currently exists for the slash product of these projects, it is anticipated that these costs can be reduced significantly through market competition.

The fuel costs are based on an efficient fuel logistic system that avoids partial loading of trucks and provides a reliable fuel supply throughout the year. Considering the diversity of fuel sources and their various locations, the establishment of such a system requires the close collaboration of the heating plant operator with fuel suppliers and transportation companies. The establishment of a biomass fuel supply business could allow for third party management and coordination of the fuel supply chain to ensure reliability of fuel cost and quality.

Chemical Analyses of Representative Samples and Available Fuel Quality

The quality of the biomass available varies considerably from source to source. Several types of biomass (sawdust, wood chips, bark or mixtures) in a range of particle sizes from 0.1 to 20 inches (0.25 to 50 cm) are available.

Based on the results of the chemical analyses of 10 representative biomass samples collected from all three fuel sources categories (forest thinnings, municipal green waste, commercial green waste), the fuel samples can be classified into ash-rich samples and samples with low or medium ash content.

Ash-rich samples have an ash content between 10 and 26 percent (w/w, d.b.). It is assumed that this is caused by contamination of the biomass with dirt and rocks during storage and handling on an unpaved surface. Compared to averages from samples of wood chips and bark from central Europe, the samples showed high concentrations of aluminum (Al), silicon (Si), and sodium (Na). On the other hand, the concentrations of elements with fertilizing and liming effects, such as potassium (K), magnesium (Mg), phosphorus (P), and calcium (Ca), were lower than the average concentrations of these elements in wood chips and bark from central Europe. The low concentration of heavy metals like cadmium (Cd), lead (Pb), nickel (Ni) and zinc (Zn) in the ash bodes well for the possibility of utilizing the ash for fertilizer.

Samples with low or medium ash contents have concentrations between 0.5 and 5.6 percent (w/w, d.b.). Compared to averages from samples of wood chips and bark from central Europe, the domestic samples have high silicon (Si) and sodium (Na) contents. The concentrations of elements with fertilizing and liming effects is higher than that of the ash-rich samples, but the content of phosphorus (P), magnesium (Mg), and calcium (Ca) is lower those found on average in biomass samples from central Europe. The content of heavy metals is considerably lower compared to average values of samples from central Europe. Low concentrations of heavy metals increase the suitability of the ash as a fertilizer.

Two out of four samples from forest thinnings have higher nitrogen (N) concentrations and very high sulfur (S) concentrations compared to averages from samples of wood chips and bark from central Europe. Exclusive use of these biomass fuels is not recommended, although they could be utilized when mixed with a higher quality wood fuel.

Ash Characterization and Possibilities of Ash Utilization

The concentrations of nutrients and compounds with liming effects (oxides of potassium, calcium, magnesium and phosphorus) in the ashes of the analyzed samples are lower than the average concentrations of these same nutrients in wood and bark from Central Europe. On the other hand, the heavy metal content in domestic samples is lower than the average content in central European wood and bark.

Ash from biomass combustion usually has a high pH-value, and its use on soils with an already high pH-value is not recommended. Based on the data obtained from the USDA’s Natural Resources Conservation Service in Santa Fe, the long-term application of ash on local soils will increase their pH level as well as their nutrient levels.

Based on the analysis herein, the general requirements for an environmentally sustainable closing of some mineral cycles using ashes produced during biomass combustion are present. However, a complete chemical analysis of the soils and a more comprehensive evaluation by a local soil expert are needed for a more detailed investigation of the utilization potential of biomass ashes for fertilizing and liming in the Santa Fe region.

Recommendations Regarding Fuel Preparation, Fuel Logistics and Fuel Storage

The high ash content of some samples can be attributed to improper handling and storage on unpaved storage areas, leading to contamination of the biomass fuel with mineral matter (sand, dirt, and stones) thus increasing the ash content. To maintain low ash content, improved handling and storage at the fuel sources is essential.

All storage areas at the fuel sources and the heating plant should be paved to avoid contamination of the biomass fuel with mineral matter. Biomass fuels from forest-thinning projects should be collected immediately after thinning and transported to appropriate processing and storage areas to minimize their contamination. Small-grained biomass should be stored in outdoor bunkers enclosed on three sides and covered by a roof to avoid dust emissions. Considering the dry weather conditions in Santa Fe, wood chips and bark can be piled outdoors uncovered.

The large amount of available biomass sources and the wide variation in fuel quality call for the development of a fuel-quality assurance system to maintain constant quality of delivered fuels. Negotiating long-term fuel supply contracts with potential fuel suppliers, in which fuel specifications including particle size, water content and type of fuel are clearly defined, is the most important step for developing consistent fuel quality. Visual inspections of delivered biomass at the heating plant will also be necessary to maintain the specified fuel quality.

The value of the delivered biomass should be assessed based on its net calorific value (delivered BTU). The calculation of net calorific value based on the weight and moisture content of delivered biomass is recommended. The net calorific value and the price for delivery can then be calculated using these values and the gross calorific value, which should be determined by chemical analysis prior to the first delivery. If a scale house is not available, the value of the fuel delivery is measured by volume by converting volume to weight using the average bulk density value of the specific fuel source. The bulk densities of each delivered fuel source should be determined prior to the first delivery.

The determined gross calorific value, bulk density, and calculation method of net calorific value should all be defined in the fuel delivery contract.

Recommendations Concerning Appropriate Thermal Conversion of Biomass Fuels (Including Fuel Feeding, Combustion, and Flue Gas Cleaning)

In addition to the development of a reliable fuel supply system and a means of utilizing the produced ash, the appropriate design of the heating plant components to achieve efficient utilization of biomass is essential. Depending on the size of the heating plant, different technologies were selected:

Large-Scale Biomass-Fired Systems

Considering the large size of the planned heating plant in Santa Fe and its high annual fuel demand, it will not be possible to rely on only one fuel source while maintaining fail-safe operation. Therefore, a mixture of wood chips, sawdust, and bark, with particle sizes ranging from 0.1 to 20 inches (0.25 and 50 cm) should be used to achieve a reliable fuel supply.

The ash content of the fuel utilized in the biomass-fired boiler must not exceed 10 percent (w/w, d.b.) for large-scale applications. Generally, fuels of lower quality should be mixed with fuels of higher quality to achieve constant conditions in the furnace and to allow a wider variety of cost and quality in fuel sources for the heating plant.

Front loaders will be used for fuel manipulation between the long-term storage areas and the short-term storage facilities.

Short-term storage in bunkers with sliding bar conveyors is the appropriate fuel feeding system for the expected particle size. If additional fuel feeding systems are required to transport the fuel from the storage bunker to the biomass-fired boiler, sliding bar conveyors or chain trough conveyors can be used.

Considering the variety of fuel quality and the range of particle size, grate furnaces are the best available technology. Grate furnaces are highly tolerant of varying moisture content, ash content and particle size, and can operate at partial load conditions.

Other available combustion systems such as bubbling and circulating fluidized bed combustion systems (BFB, CFB) are not recommended, since these systems are limited in their acceptable particle size range. Generally these systems require particles smaller than 3 inches (8 cm) for BFB and smaller than 1.5 in (4 cm) for CFB. Moreover they can only operate at full load or conditions close to full load. They are therefore not suitable for application in a district heating system such as Santa Fe's, which must accommodate significant changes in heat load throughout a given year.

Considering the type of available biomass, which consists only of untreated wood chips, bark and sawdust, no emissions other than dust are expected to reach levels that require secondary emission reduction measures. To ensure this, the biomass with high nitrogen and sulfur concentrations (Samples #7 and #8) must be mixed with biomass of higher quality.

Since all samples have moisture contents below 50 percent (w/w, w.b.) and average moisture contents less than 30 percent (w/w, w.b.), no negative effects of high moisture content on the combustion conditions, which can increase emissions, are expected.

Some samples have relatively high ash concentrations, however, which leads to increased formation of fly ash and dust emissions. If it is not possible to reduce the ash content by avoiding contamination of the biomass with mineral matter, the high ash content must be considered in the design of both de-dusting devices and the boiler itself. The boiler design may need to include automatic boiler cleaning. Based on fuel quality and the limiting target value of dust emissions, the combination of a multi-cyclone and an electrostatic precipitator (ESP) seem to be an appropriate solution.

Small-Scale Biomass-Fired Systems

Due to their considerably lower fuel demand compared to the large district heating system, smaller boilers for micro-grids may rely on fuel from a single source, resulting in relatively constant fuel quality.

The ash content of the fuel utilized in a small biomass-fired boiler must not exceed 5 percent (w/w, d.b.) with the goal of further reducing fuel ash content if possible. The use of bark should be avoided due to its relatively high ash content. Furthermore, the moisture content of the utilized biomass should not exceed 40 percent (w/w, w.b.). If different fuel sources are used, fuels of lower quality should be mixed with fuels of higher quality to achieve constant conditions in the furnace.

Just-in-time fuel logistics seem possible if a secure fuel supply can be guaranteed. In this case, the only required component for fuel handling is a storage bunker with a sliding bar conveyor. If the bunker can be directly filled from a truck, no additional fuel handling is necessary.

If the fuel supply is constantly high-quality and as long as biomass with particle sizes below 2 inches (5 cm) is utilized (sawdust, small wood chips), then screw conveyors can be used for fuel-feeding. The screw conveyors are generally installed after the sliding-bar conveyor in the storage bunker to move fuel from the storage bunker to the biomass-fired boiler.

Considering the potential for using fuels that are consistently high quality, underfeed stokers appear to be the best technology choice for the small-scale applications. Underfeed stokers feature simple and effective load control and fuel dosing systems, which consistently perform well provided the fuel supply quality stays high with regard to ash content, water content, and particle size.

An appropriate quality assurance system must be implemented to assure that delivered fuels meet all requirements regarding particle size, ash content, fuel type, and moisture content. Considering the type of available biomass (only untreated wood chips, bark and sawdust) no emissions other than dust are expected to reach levels that require secondary emission reduction measures. The selection of the fuel sources and the quality assurance system should guarantee that no fuels with high nitrogen or sulfur contents are used. Based on the fuel quality and the low target value for dust emissions, a multicyclone dust removal device seems to be an appropriate solution for the micro-grids.

5.2 Recommendations

Based on the results outlined in this report the following recommendations can be made:

- Since the expected energy potential of the available biomass within a 50-mile (80 km) radius of Santa Fe exceeds the expected fuel demand of the main district heating system by approximately 50 percent, fuel sources closest to Santa Fe should be considered first as potential fuel suppliers in order to minimize fuel transportation costs.
- Additional information about forest-thinning projects regarding sustainable fuel quantity, future thinning projects, and costs for slash should be obtained to verify or adjust the assumptions of biomass quality and cost from forest-thinning projects.
- To realize the greatest economic benefit from the utilization of forest-thinning products, all of the different products generated by the thinning process should be commercially utilized. Each thinning product, including each of the various grades of merchantable material and slash, should be utilized in the most valuable manner. Realizing the greatest value may require aggregation of multiple fuel buyers.
- An efficient fuel-logistics system should be established to minimize transportation costs. Close collaboration between the heating plant operator and the fuel suppliers and transportation companies will be necessary.
- To achieve reliable fuel quality, it is important to negotiate long-term fuel supply contracts with potential fuel suppliers. Basic requirements for processing, handling and storage of the fuel at the biomass source, all relevant fuel specifications, and the parameters required for invoicing should be defined in the supply contracts. Several large fuel suppliers should be contracted to guarantee a secure fuel supply and to stimulate competition.

- A centralized facility for storing fuel for small-scale systems (micro-grids) should be established to allow just-in-time storage solutions at the micro-grid sites.
- A quality assurance system should be developed to guarantee the specified fuel qualities.
- The selection of fuel feeding, combustion, and flue-gas cleaning technologies should be made with consideration for the available fuel qualities and the required heating capacity of the heating plant. A distinction in fuel types between large-scale and small-scale applications is recommended.
- Since utilization of ashes on agricultural or forests soils seems possible, contacting local soil experts for a more detailed evaluation of the effect of a biomass ash utilization on local soils is recommended. Based on this evaluation, guidelines for the utilization of biomass ash should be developed and possible consumers of the ash identified.

6 References

1 New Mexico Energy, Minerals and Natural Resources Department, 2002: New Mexico's Natural Resources 2002, Data and Statistics for 2001. New Mexico Energy, Minerals and Natural Resources Department, New Mexico, USA

2 Website of the Santa Fe Solid Waste Department, http://www.co.santa-fe.nm.us/departments/solidwaste/solidwste.html

3 Based on interviews with the following experts: James T. Johnston, State Forestry Fuels Specialist, Steve Marsh, Regional Measurement Specialist, Jeff Hog, Regional Mensurationist, Chris Nap, Forest Fuel Specialist, in March, April and May 2004.

4 Interview with Justin Stockdale, Recycling Coordinator at the Caja del Rio landfill, April and June 2004

5 Interview with James T. Johnston, State Forestry Fuels Specialist, April 2004

6 Meeting with Jerry Payne, Biomass Specialist of the USDA Forest Service, June 2004

7 Gaur, S. Reed, T.B., 1995: Atlas of Thermal Data for Biomass and other fuels National Renewable Energy Laboratory (NREL), USA

8 Local Energy, 2004: Biomass-Fired District Energy for Santa Fe – Preliminary Design of the Network of Pipes and the Heating Plant, Report to be published, Santa Fe, NM, USA

9 van Loo, S, and Koppejan, J., (eds.), 2002: Handbook of Biomass Combustion and Co-Firing, ISBN 9036517737, Twente University Press, Enschede, the Netherlands

10 Obernberger, I., 1998: Nutzung fester Biomasse in Verbrennungsanlagen unter besonderer Berücksichtigung des Verhaltens aschebildender Elemente, Schriftenreihe „Thermische Biomassenutzung“, Band 1, ISBN 3-7041-0244-X, dbv-Verlag für die Technische Universität Graz, Austria

11 Interviews with USDA Forest Service Fire Management Officers, April 2004

12 Rohrmoser, “Bereitstelung von Waldhackgut”, talk at the conference of the Styrian Chamber of Agriculture “Waldhackgut, efffizient und komfortabel bereitstellen”, December 5th, 2003, Graz, Austria

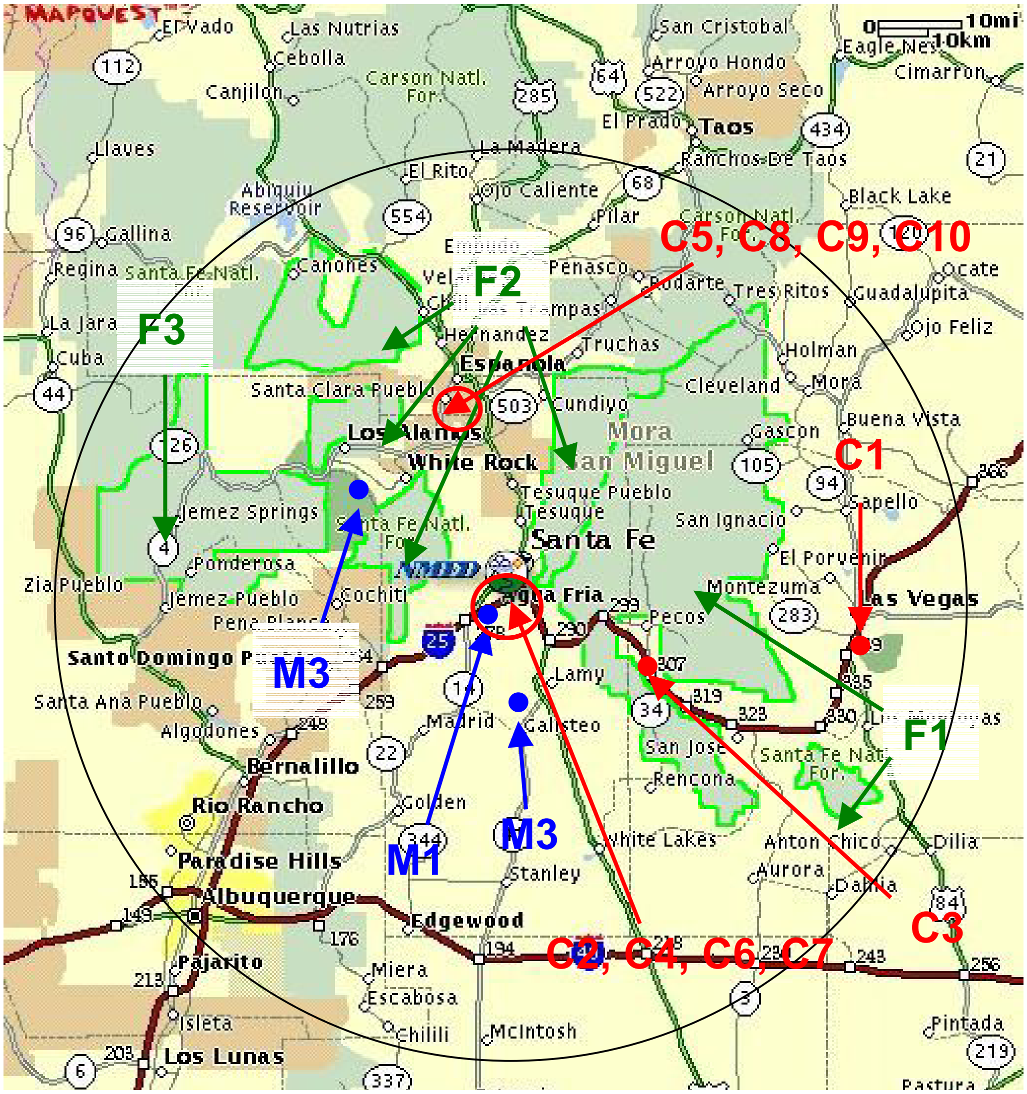
13 Hakkila, P.; 2003: Developing Technology for large-scale production of Forest Chips – Wood Energy Technology Programme 1999-2003, Interim Report, National Technology Agency, Helsinki, Finland, 2003

14 Interview with Aaron J. Miller, Soil Scientist at the USDA Natural Resources Conservation Service, Santa Fe, May 2004

15 http://search.weather.yahoo.com/climo/USNM0292_f.html

APPENDIX

Figure A1: Biomass Sources Investigated within a 50-mile Radius of Santa Fe



	Ranger Districts
F1	Pecos Ranger District
F2	Espanola Ranger District
F3	Jemez Ranger District

	Municipal Green Waste Sites
M1	Caja del Rio Landfill
M2	Jacona Transfer Station
M3	El Dorado Transfer Station

	Commercial Green Waste Sites
C1	Barela Timber
C2	Norton Hill Wood Co
C3	Sauter White
C4	Hansens Lumber
C5	WH Moore Cash Lumber
C6	Spotted Owl Timber Inc
C7	Alpine Builders Supply
C8	New Mexico Vigas & Timbers
C9	Cook's True Value

Table A1: Wood Waste Suppliers Near Santa Fe

Supplier	Phone #	Address	City
Forestry Projects			
Santa Fe Natiional Forest			
City of Santa Fe			
Landfill/Transfer Station/Urban Waste			
Caja del Rio	424-1850, 780-0628	Caja del Rio	Santa Fe
Lumbermills/Sawmills			
Conley Lumber Mills LLC	753-7746	30 Wheat Street	Espanola
Spotted Owl Timber Inc	474-5326		Santa Fe
Hansens Lumber	471-8280		Santa Fe
Alpine Builders Supply	982-2543	493 W Water	Santa Fe
Empire Builders Supply	982-2646	1802 Cerrillos	Santa Fe
Frontier Wood	474-9663	4523 Hwy 14	Santa Fe
Hope Lumber	471-7474	1137 Siler	Santa Fe
Lumber Inc	474-4773	#8 Crouch Ct	Santa Fe
New Mexico Vigas & Timbers	753-6189		Espanola
Rio Grande Forest Products	753-2832		Espanola
Regalos de La Tierra	757-6444		Pecos
Blue Sky Timber	450-7902		Santa Fe
Norton Hill Wood Co	471-2456	701 Airport Rd	Santa Fe
Timberline Wood Products	387-5030	1-877-287-5030	Santa Fe
El Ranchito Lumber Company	757-6331	PO Box 68	Pecos
Wood Furniture Manufacturers			
Creative Woods by Fred Romero	753-6270	PO Box 155	Santa Cruz
Southwestern Spanish Craftsmen	982-1767	328 S Guadalupe	Santa Fe
Taos Furniture	988-1229	219 Galisteo	Santa Fe
Wood Furniture Custom Builders			
Chandler Chair Co	982-2588	1808 2nd St.	Santa Fe
Comfortzone Southwest Furniture	473-0965	3258 Cerrillos Rd	Santa Fe
Concepts in Cabinetry	757-3444	Rt 2 Box 57B	Pecos
Doolings'	471-5956	525 Airport Road	Santa Fe
Ernst Scott Custom Woodworks	757-2786		Pecos
Fulton Woodworks	473-2818	Rt 6 Box 3-A	Santa Fe
Galisteo Home Furnishings	992-3300	132 E. Marcy St.	Santa Fe
Heart & Soul Custom Furniture	316-0784		Santa Fe
Old Santa Fe Furniture	983-6556	1542 Cerrillos Rd	Santa Fe
Santa Fe Collection	473-7995	2913 Rufina Ct.	Santa Fe
Santa Fe Country Furniture	984-1478	1708 Cerrillos Rd	Santa Fe
Santa Fe Studio Furniture	471-0534	1544 B Center Dr	Santa Fe
Santa Fe Woodworks	473-3159	2260 Calle de Arce	Santa Fe
Jeff Smith Woodworking	982-8450	1414 2d Street	Santa Fe
Szantho Wood Works	474-4836	2823 Industrial Rd	Santa Fe
Taylor Made	757-6594		Glorieta
Tony's Cabinets & Custom Woodworks	757-8783		Pecos
Wood Design	438-0200	1242 Siler Rd	Santa Fe
The Wood Joint	474-4124	3B Otto Rd	Santa Fe
Woodworkers Guild Gallery	424-9117	8380 Cerrillos Rd #404	Santa Fe
Wood Carving			
Alchemy Woodcarving	471-1712	1364 Rufina Cir	Santa Fe
Go With the Grain	989-1123		Santa Fe
Micheal Kluck	473-7111	PO Box 202	Cerillos
Wood Turning			
Santa Fe Fine Finishing	438-4850	17 Ceramic Ct	Santa Fe
Tesuque Design	988-5395		Santa Fe
Wood Working			
Baglione Custom Woodworks	988-7326	1701 Lena	Santa Fe
Heartwoods	474-6577	1241 Siler Rd	Santa Fe
Jackson George Woodworks	473-2690	1364 Rufina Cir #9	Santa Fe
Jones Woodworking	471-6955	#5 Willow	Santa Fe
Nyquist-Woodworks.com	992-8642		Santa Fe
Pierpoint Cabinets & Woodworking	473-2690	#9 Rufina Cir	Santa Fe
Way Out West Woodwork	438-2639	2921 Rufina Crt	Santa Fe
Wolfswinkel Enterprises	473-2050	3812 Oliver Rd	Santa Fe
Woody Rick	424-6380	223 N Guadalupe	Santa Fe