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Front Range Forest Health Partnership Phase I Feasibility Study

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MASTER

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Executive Summary

The Front Range Forest Health Partnership (FRFHP) is an alliance of individuals, citizen groups, federal, state, private, and nonprofit organizations that formed to promote forest health restoration and reduce fire risks on Colorado's Front Range. The partnership promotes selective thinning to restore forest health and supports economically feasible end uses for wood waste materials. The Phase I study was initiated by FRFHP members to determine the environmental and economical feasibility of using wood wastes from forested and urban areas for the production of fuel-grade ethanol.

During the past century, fire suppression, urban growth, and a lack of market for small diameter trees in Colorado's Front Range area have caused major ecological changes to the forested environment. The widely spaced mature trees that once dominated the landscape and averaged 27 in. in diameter have largely been replaced by thick, crowded stands of small-diameter trees that average 5-11 in. in diameter. These stands contain a large number of unhealthy stressed trees that are susceptible to insects, diseases, and catastrophic fires that threaten to destroy important natural resources and watersheds, endanger people and private property, pollute the air, and sterilize soils.

The U.S. Forest Service (USFS) database information revealed that in the Arapahoe/Roosevelt and Pike/San Isabel National Forests and state and private lands approximately 1.9 million acres of forest are at risk to catastrophic fire, and approximately 70% of this resource based is state and private lands where many structures and people are located. Various management tools are used to reduce the risk of fire and restore forest health. Prescribed burning is widely used but there are many drawbacks to implementing this tool on a large scale. For example, public support for prescribed burning on a large scale may be low because it could degrade air quality. Selective thinning of trees in combination with prescribed fire restores forest health, reduces the risk of fire, and creates a focused wood products industry for the Front Range area.

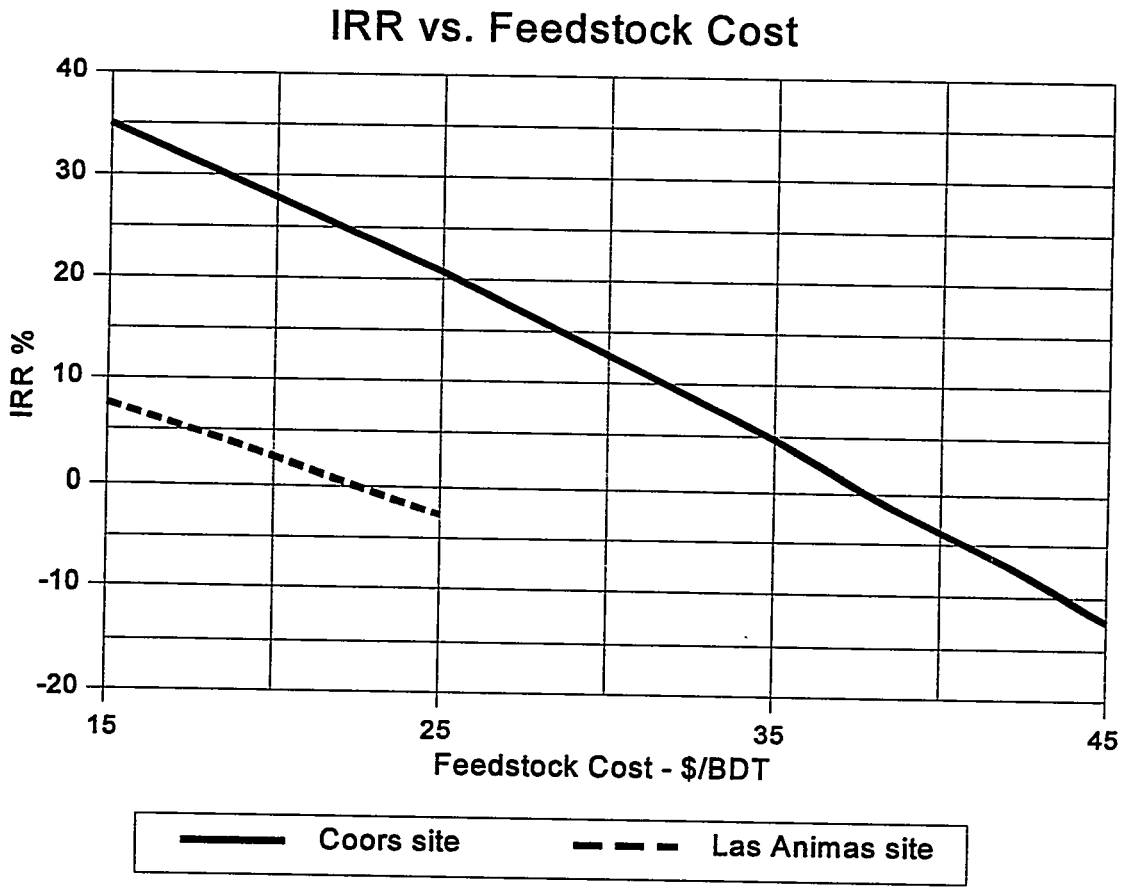
Based on the biomass supply study data, 16.6 million bone dry tons (bdt) may be available along the Front Range area (Boulder, Clear Creek, Douglas, Gilpin, Jefferson, Teller, El Paso, and Park Counties). Within the core Front Range counties of this area (Boulder, Clear Creek, Douglas, Gilpin, Jefferson, Teller, El Paso, and Park) over 7.3 million bdt (520,000 bdt per year) are available. Urban areas along the Front Range generate large quantities of wood wastes, much of which is land filled. Additionally, current wood waste product markets (compost, mulch, dyed mulch, and animal bedding) are not large enough to use all the wood waste generated along the Front Range. An additional 110,000 bdt/yr from urban tree residue (UTR) and primary and secondary processors are available for an ethanol facility.

The FRFHP members support the use of small-diameter woods and urban wood wastes for ethanol production because of Colorado's strong ethanol market. In 1996, approximately 28 million gallons of ethanol were added to gasoline during the winter months as part of the mandated oxygenated fuels program to improve air quality. Because Colorado's fuel ethanol production averages 1.7 million gal/yr (about 0.1% of the total ethanol production) and imports are over 26 million gallons per year, the market for in-state ethanol production is open.

As part of this feasibility study, a siting study was conducted to identify potential sites for an ethanol plant in the Front Range area. Of the twelve sites evaluated, the study ranked a biomass to ethanol plant located at Coors Brewing Company in Golden to be the most viable, if the feedstock cost can be kept below $25/bdt (see table on following page). Feedstock costs range from $15/bdt for urban wood wastes to $67/bdt for forest wood wastes.

The ethanol facility design presented here used technology available from HFTA, a California corporation. HFTA's dilute nitric acid process for converting wood to fuel ethanol was developed at the University of

California's Forest Products laboratory in Richmond, California. The internal rate of return (IRR) for a 14.8 million gal/yr ethanol facility that used the dilute nitric acid process for the Coors and Las Animas site versus the average feedstock cost is shown in the figure below. Calculations of the average feedstock cost assumes one-third urban wood waste is combined with two-thirds forest thinnings to produce 300,000 bdt of feedstock annually. The technology evaluated for this study is only one of many possible technologies available. Other technologies available in the marketplace may produce higher ethanol yields per bdt of wood waste material.



An ethanol facility in the Front Range could help solve many forest health, urban wood waste, air quality, and forest product industry problems. The benefits identified as a result of this study include reduced greenhouse gas emissions, improved air quality, wood waste diversion, fire prevention (which results in reduced costs to fight fires and to prevent loss of life and property), restored ecosystems, improved local economies, sustained water quality (and the potential for higher water yields), and a decreased dependence on foreign oil.

Although the preliminary findings look promising, FRFHP members have identified these challenges:

- Securing a steady supply of wood materials from forested lands is difficult.
- Many mountain home owners deny fire risks and do not take the necessary steps to thin vegetation around their homes.

- Changing and uncertain government roles, subsidies, and incentives.

- Lack of capital and investor confidence, need for new types of contractor arrangements and risk sharing.

- Forest feedstock supplier profit requirements and ethanol price realities do not match.

Based on the results of this study, an ethanol facility that uses wood wastes is feasible. At this time, the FRFHP members should proceed to Phase II objectives, which include:

- Secure commitments for steady wood supplier
- Participate in public information and outreach activities
- Identify equity partners
- Support forest ecosystem sustainability pilot projects
- Collaborate with other groups that support the FRFHP mission
- Collect additional economic pro-forma information
- Evaluate other ethanol technologies

Introduction

Background Resource Base

The forests in Colorado provide a wide array of benefits and significant revenue to the state, including timber sales and wood products. Citizens and visitors enjoy water resources, recreation, tourist activities, and magnificent scenery. Many Colorado forests are managed by government agencies, including the U.S. Forest Service (USFS), which manages 16.8 million acres; the National Park Service, which manages 649,000 acres; the Bureau of Land Management, which manages 8.3 million acres; and others who manage 500,000 acres of private and state lands (for example, CSU)—a total of 26.24 million acres[1]. See Figure 1: Front Range Land Ownership with Disturbance Probability.

Each forest type differs in frequency of natural disturbances (fire, insects, disease). For example, normal fire frequency for Ponderosa Pine forests varies from 2 to 30 years; spruce-fir forests may have intervals of 300—650 years[2]. There are several distinct forest types at various elevations in Colorado forests[2]: Tundra; Englemann Spruce, Subalpine Fir, Limber and Bristlecone Pine; Aspen and Lodgepole Pine; Ponderosa Pine, Douglas Fir, Mixed Conifer; Pinion Pine/Juniper; Grasslands. See Figure 2: Front Range Forest Cover Types with Disturbance Probability.

Colorado's Front Range (including Boulder, Chaffee, Clear Creek, Custer, Denver, Douglas, El Paso, Fremont, Gilpin, Grand, Huerfano, Jefferson, Lake, Larimer, Las Animas, Park, Pueblo, Saguache, and Teller Counties, and the Arapahoe, Roosevelt, San Isabel, and Pike National Forests) is an extensive area of forest and brushlands with steep topography. It is relatively dry (average annual rainfall 16 in.), and has periods of high winds and lightning.

Front Range forests are now dominated by small trees (280–390 trees/acre compared to 40-50 trees/acre before the turn of the century)[3]. Forest managers are concerned that the absence of frequent, light-intensity fires has allowed much of the area to become densely grown with combustible undergrowth and a semi-continuous tree canopy. If current trends continue, all resource values on national forest and adjoining lands are likely to suffer increased losses from insects, diseases, uncontrollable wildfires, and floods[4] (see Figure 1).

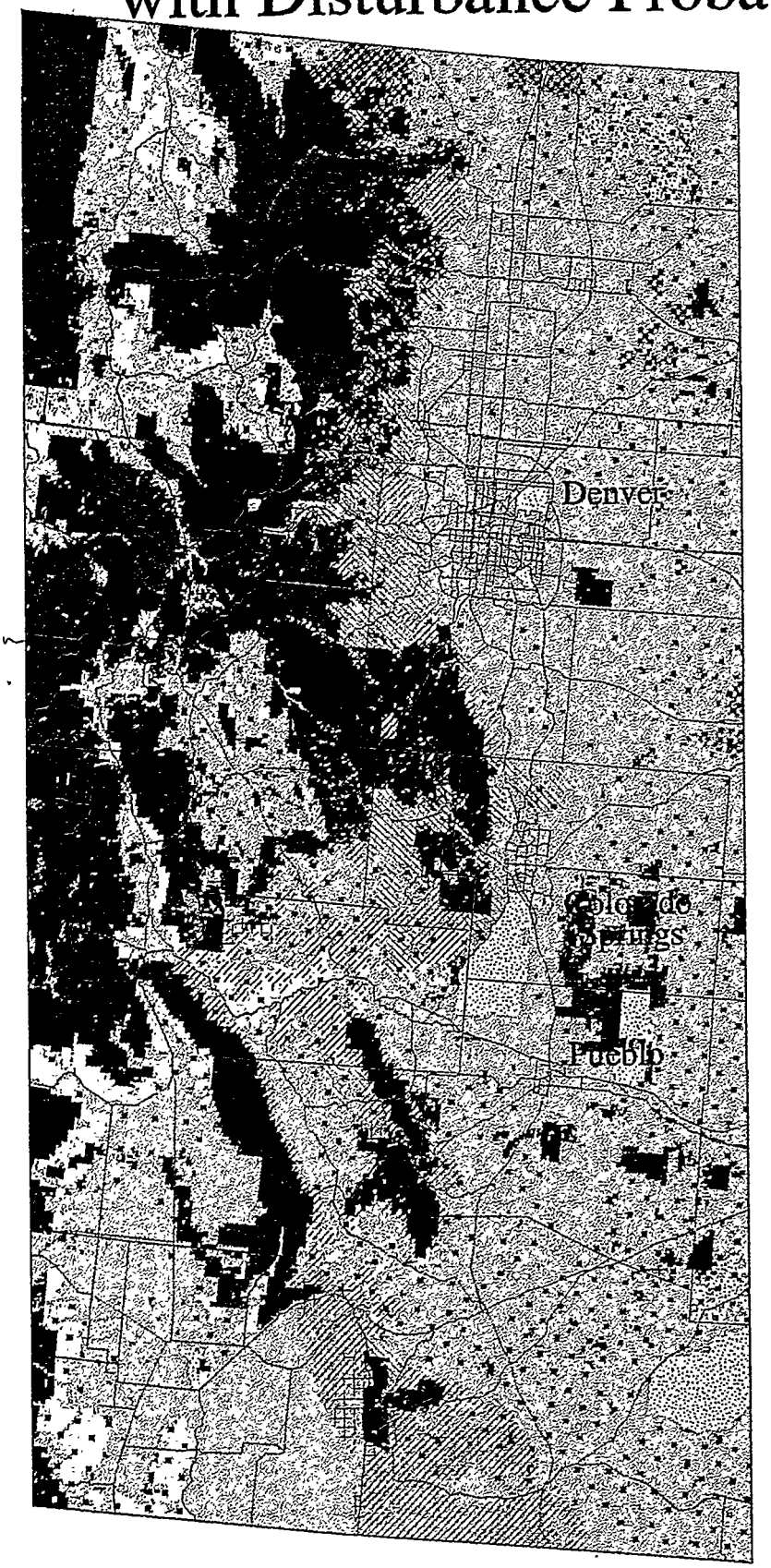
Additionally, during the past century, the average tree diameter has decreased from approximately 27 in. to 8 in.[5]. Forest managers and the forest products industry are seeking markets for small-diameter trees to redevelop the overall supply base and solve forest health problems.

Urban areas along the Front Range also generate excessive amounts of wood waste and have limited disposal options. According to the Environmental Protection Agency (EPA), of the tree, landscaping, and wood residues generated (45 million tons), only 8.4 million tons are currently recovered for other uses such as mulch and compost[6]. The amount of Front Range wood residues obtained from urban tree trimming, construction and demolition waste, primary and secondary wood processors, and landscaping wastes is more than 110,000 bone dry tons (bdt)/yr[7]. In 1995, Coloradans disposed of 2.3 million yd^3 of yard wastes[8].

Another seemingly unrelated problem for Colorado is air pollution. Historically, Colorado has had one of the worst carbon monoxide (CO) problems in the country. The state has worked hard to reduce these toxic emissions via an oxygenated fuels program and car inspections. Population growth threatens to erase the progress made to improve air quality during the past decade.

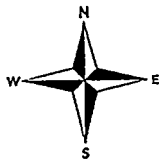
Figure 1

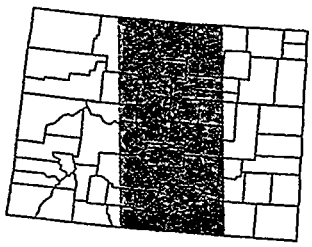
Front Range Land Ownership with Disturbance Probability



Legend

- Private lands
- State Land Board or Colorado State Forest
- US Forest Service
- Wilderness Areas
- Bureau of Land Management
- National Park Service
- Other Non-Private lands
- High Risk
- Medium Risk
- Low Risk
- County lines
- Roads





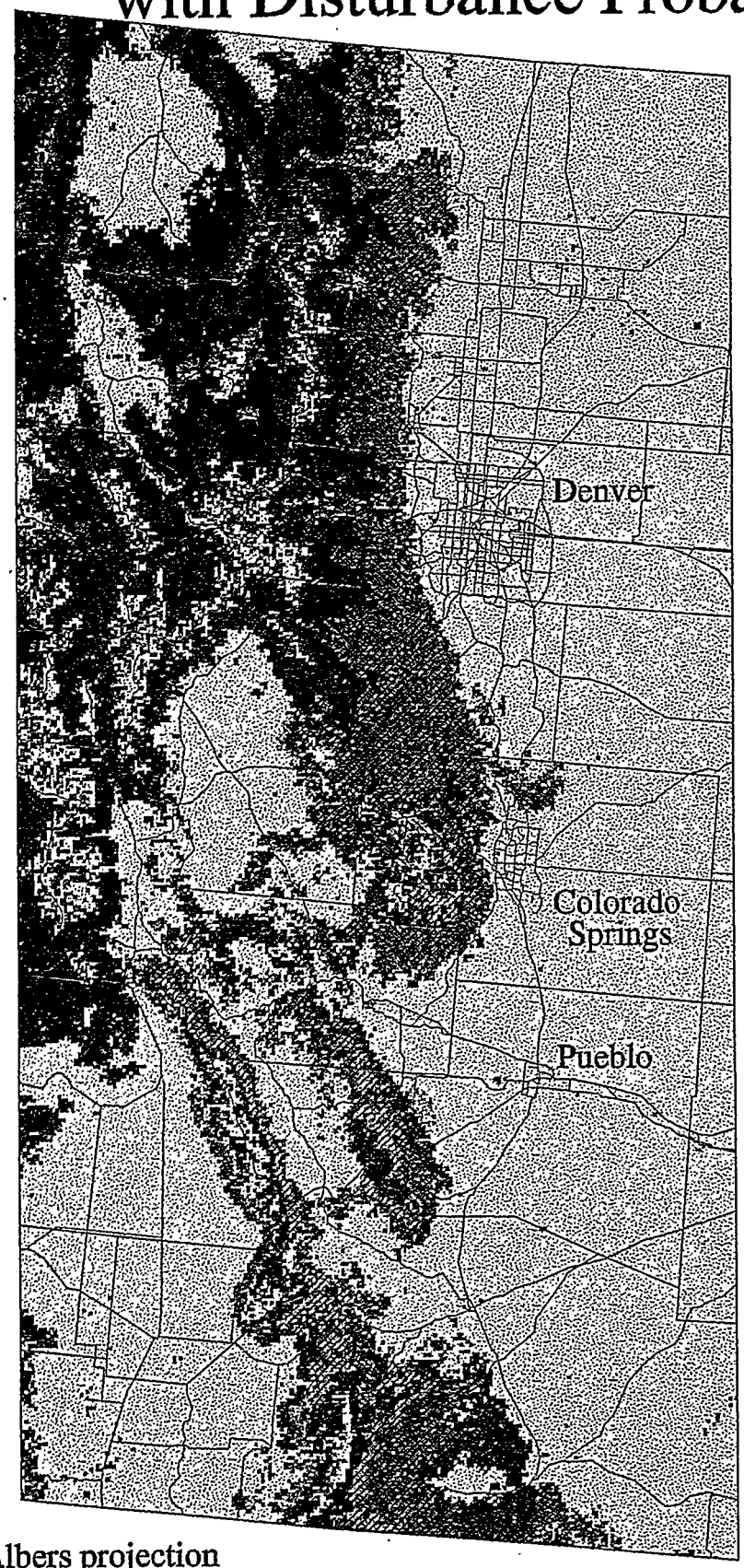
Colorado

Miles

Albers projection 0 20 40 60 80

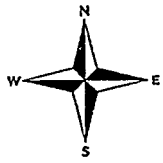
Figure 2

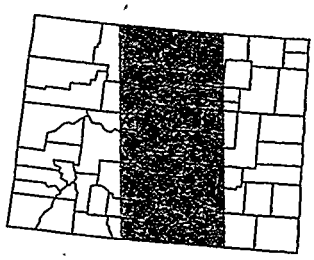
Front Range Forest Cover Types with Disturbance Probability



Legend

- Pinyon-juniper
- Ponderosa pine
- Douglas-fir
- Lodgepole pine
- Fir-spruce
- Aspen-birch
- Western Hardwoods
- Chaparral
- Elm-Ash-Cottonwood
- Oak-hickory
- Nonforest
- Water
- High Risk
- Medium Risk
- Low Risk
- County lines
- Roads





Colorado

Albers projection

Compiled from USFS AVHRR data

Miles

0 20 40 60 80

The Front Range Forest Health Partnership

The Front Range Forest Health Partnership (FRFHP) is an alliance of individuals, citizens groups, federal, state, and local government agencies, and private businesses whose mission is to promote the economically effective and efficient use and marketing of small-diameter trees and under used wood waste on Colorado's Front Range for forest health restoration, clean water, and clean air. Partners are listed below.

- National Renewable Energy Laboratory (NREL)
- Boulder County Wildfire Mitigation Group
- Coloradans for Clean Air
- Colorado State Forest Service
- Colorado Timber Industry Association
- Colorado Tree Farmers Association
- Denver Water Board
- The Front Range Urban Forestry Council
- Colorado County and City wildfire prevention, forestry, and solid waste staff
- Governor Romer's Office of Energy Conservation
- Merrick Engineering
- The USFS Forest Products Laboratory
- NEOS Corporation
- Sangre de Cristo Resource Conservation & Development Council
- U.S. Forest Service - Arapahoe/Roosevelt, Pike San Isabel, Black Hills National Forests
- Local community groups and interested citizens
- Wood product and landscaping companies

To support this mission, a Phase I Wood Waste to Ethanol Feasibility Study was initiated by FRFHP members to analyze the feasibility of using small-diameter trees and urban wood wastes to produce fuel ethanol. Benefits of converting wood waste into fuel grade ethanol are included in Net Public Benefits below.

Net Public Benefits

Environmental and economic benefits can be derived from a biomass-to-ethanol plant that uses small-diameter trees and urban wood wastes that are not directly associated with payroll or plant purchases. A description of these benefits follows.

Waste Diversion

Converting wood to biofuels will significantly decrease the amount of wood wastes sent to landfills. At present, most ethanol produced in the United States is from agricultural crops. The use of forest and urban wood wastes is a cost-effective solution to producing biofuels from resources that are typically burned or disposed of as solid waste. Coloradans disposed of 2.3 million yd^3 of wood wastes (15% of total waste) in 1995[8]. Approximately 27,000 yd^3 of wood waste goes to Denver metropolitan landfills annually. Today landfilling a ton of waste in Colorado costs \$4.05/yd^3, so landfilling wood waste costs about \$110,000.

Insurance and Property Loss Prevention

During the past 10 years approximately 70 houses have been lost to wildfire on the Front Range. Assuming that these houses are worth \$170,000 (average Denver metropolitan price) with \$40,000 in furnishings, the

actual loss per year would be approximately $1,470,000. However, larger and more expensive houses in the UWI could easily exceed this figure. Wildfire mitigation efforts would reduce the risk of catastrophic property losses[20].

Decreased Cost of Fighting Fires

During the past 10 years, the cost to fight fires in Front Range forested areas has averaged $350-$400/ acre. The cost to fight fires in the UWI areas is more difficult and the costs are higher at approximately $1,500/acre. Selective thinning efforts in these areas could reduce fire-related costs.

Carbon Emissions Reduction

Using wood wastes for ethanol production greatly reduces greenhouse gas emissions from vehicles and landfills. Wood is considered a potential substitute for fossil fuels and is one way to reduce emissions and mitigate potential increases in CO_2 and methane (CH_4) concentrations in the atmosphere[21].

In the low-oxygen environment of a landfill, approximately 50% of the organic materials such as urban tree waste is decomposed by bacteria into CH_4 and CO_2; the rest becomes heat, water vapor, and stable organic materials. Both CH_4 and CO_2 are known greenhouse gases. Methane is 24.5 times more effective at trapping heat in the atmosphere than CO_2, and 36% of the total U.S. emissions of CH_4 comes from landfills[22]. By diverting UTR's from landfills for ethanol production, about half the carbon in the wood could displace CO_2 emissions from petroleum.

The combustion of wood does not contribute to greenhouse gas production because the regrowth of trees causes the cycle of renewability. For example, a tree burned today gives up CO_2; however, a new tree can be regrown in 100 years and capture a similar amount of CO_2. Therefore, because the tree absorbs CO_2, the use and combustion of trees has no net effect on CO_2 levels, as long as trees are replanted.

Improved Air Quality - Effects of Ethanol

Since January 1, 1988, oxygenates have been added to gasoline in the Denver metropolitan area from November through February. This causes gasoline to burn more completely, which reduces CO emissions, greenhouse gases, and other harmful pollutants. The EPA has conducted extensive research and estimates that gasoline vapors and motor vehicle emissions cause 75%–90% of CO and 50% of ozone and particulates. Motor vehicles continue to be a major source of air pollution in Colorado. Pollutants from vehicles, coupled with negative air quality impacts of a growing population, threaten to offset or reverse the air quality gains made during the last decade [17].

Restored Forest Ecosystems

Well-managed forests, developed partially by removing and using small-diameter trees for fuel-grade ethanol production, will yield manifold long-term benefits. Forests would be more resistant to insects, disease, and destructive wildfires and require less effort, resources, and money to suppress fires. Additionally, endangered animals and plants would have a better survival rate.

Improved Local Economies

An ethanol plant will stimulate the creation of a new market for small-diameter trees and increase job opportunities in rural communities. For example, a small ethanol plant would create 38 full-time jobs. In

Las Animas County, where unemployment is more than 10%, the opportunity to use biomass to create jobs will be welcome[20].

Sustained Water Quality and Potentially Higher Water Yields

Restoring forest health reduces catastrophic fire risks and their aftereffects, which can be detrimental to water quality. Also, water yield studies conducted in the Fraser Experimental Forest (Grand County) show that mitigation efforts may increase water yields. This is of particular interest to the Northern Colorado Water Conservancy District (NCWCD) and the Denver Water Board. Both Denver Water and NCWCD use water from the western slope and Front Range forest watersheds [11].

Decreased Dependence on Foreign Oil

In 1996 more than 50% of the petroleum used in the United States was imported, which contributed more than $50 billion to the trade deficit (about half the total). Assuming that Colorado's population is 1.5% of the national population and 112 billion gallons of gasoline is consumed in the United States per year, Colorado's annual petroleum deficit is $750 million and 840 million gallons of gasoline is imported. If Coloradans replaced 5 million gallons of gasoline with ethanol, Colorado's portion of the trade deficit would decrease by $4.46 million. Other costs that contribute to the oil trade deficit are the military expenses to protect oil reserves in the Persian Gulf[20].

Colorado's Front Range Forests and Urban/Wildland Environment

Forest Health Issues

Forest ecosystems consist of trees, watersheds, insects, fungi, soils, a variety of plant species, aquatic and land animals, and birds. Before Europeans settled in the western United States, this area's forest ecosystems adapted to frequent, low-intensity fires that thinned natural regrowth and decreased combustible organic materials. Since the early 1900s, fire exclusion policies have resulted in unhealthy forest ecosystems, shifts in understory plant species and forest fuel buildup, an increase in the number of trees, and less forest diversity. Forest ecosystem scientists point to pre-European settlement as a model that present-day forest ecosystems should resemble[3]. However, many debate whether this time period should be the model for forest health restoration. The forest management tools used to mimic nature and restore today's forests have also been controversial issues.

Today, fire suppression and an oversupply of small-diameter trees have created forest health problems in Colorado forests. A description of these problems follows.

- **Colorado forests are outside the range of normal forest conditions.** Large areas of Colorado forests are dominated by shade-tolerant understory species. In a normal forest, these species would be much less frequent.

- **Colorado forests lack the diversity of age classes and successional stages over large areas.** Ponderosa Pine forests in the Front Range lack the healthy diversity of age classes and stages.

- **Colorado's forests lack a diversity of plant and animal species.** Colorado Ponderosa Pine forests lack a diversity of plants and animals that are typical of this forest type.

- **Fire suppression has caused Colorado's Front Range forests to accumulate large quantities of trees and dead woody debris.** Forest density has caused excessive buildups of pine needles and tree limbs on forest floors. Trees, grasses, and wild flowers grow poorly and are at high risk of attacks by insects, disease, uncontrollable fires, and exotic pests/noxious weeds.

- **Colorado Front Range forests stand to lose water yields.** According to a recent study conducted in the Ponderosa Pine forests of Arizona, tree density causes intensified competition for moisture by reducing the amount of water that reaches the forest floors.

The Urban/Wildland Interface and Wildfire Risk Issues

Colorado's Front Range forested environment is rapidly changing because of increases in population growth that have created an urban/wildland interface (UWI), a forested area where people build structures and communities (cabins, condominiums, ski resorts, summer homes, subdivisions, etc.). However, on the Front Range these lands are where fire has historically been a natural aspect of the ecosystem, its vitality, and its survival. As more people move into these areas, the risk of catastrophic fire increases dramatically. Colorado's UWI is a result of mixed land ownership caused by random early settlement, increased attraction to rural living, needed rural economic growth, and scattered home development over large tracts of land.

As more people move to UWI areas, vacation, and enjoy outdoor activities in forested areas where natural fires are excluded, the threat of catastrophic fires increases dramatically. Fires in forested and UWI areas can start in a variety of ways (lightning strikes, downed power lines), but most are caused by human

carelessness and negligence—unattended campfires, house fires, and debris burning. Of 3,158 fires on Colorado's nonfederal lands in 1994, 2,671 (85%) were caused by people. These fires killed firefighters, burned homes and thousands of acres of land, and cost millions of dollars in fire fighting and damages to natural resources[9].

The USFS and Colorado State Forest Service (CSFS) recently created a map using Geographical Information Systems technology to assess the probability of catastrophic fires along the Front Range. This assessment indicates that more than 10,600 square miles are at risk of fire[10]. See Figure 3: Probability of Catastrophic Disturbance Events.

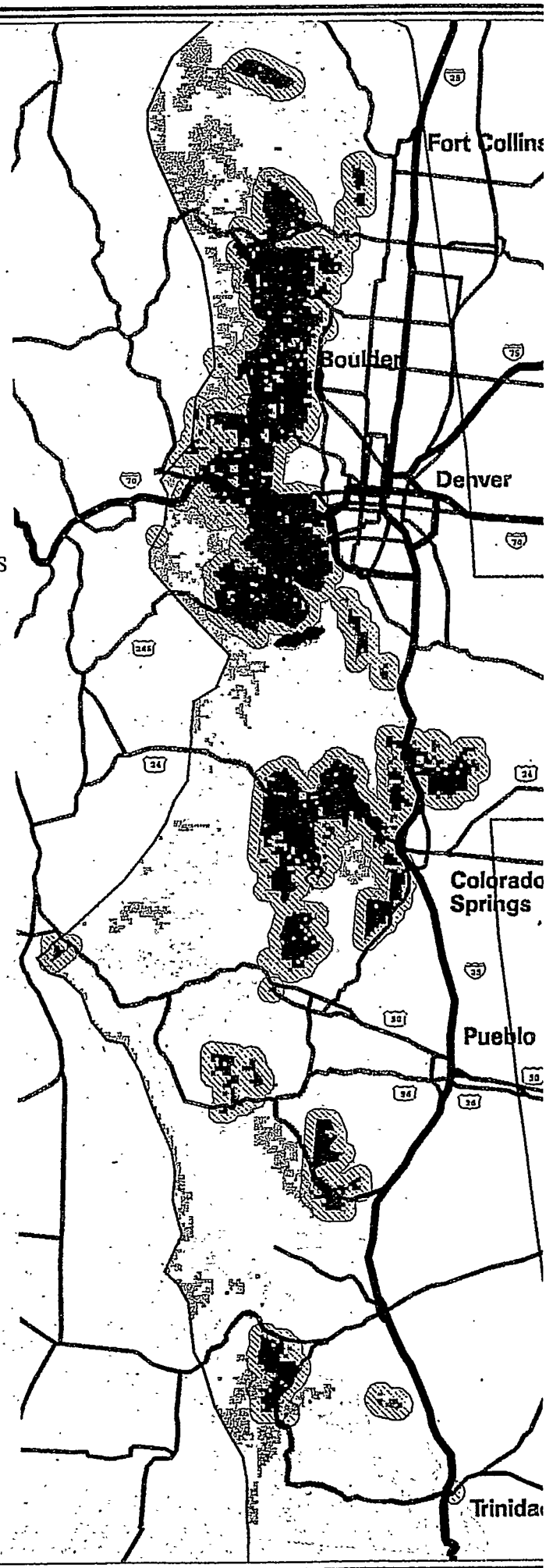
The most recent catastrophic fire (Buffalo Creek Fire) in the Front Range area occurred in rural Jefferson County in May 1996 and was caused by a neglected campfire. A general description of the Buffalo Creek wildfire aftereffects follows[11].

- **Loss of life and property.** Although firefighting efforts saved the Town of Buffalo Creek and the Spring Creek subdivision, the fire burned 12,000 acres in 5 hours and 12 structures were destroyed.

- **Soil sterilization.** The fire damaged the area's protective cover of vegetation and the sterilized soil could not absorb water.

- **Flooding damages.** After the fire, flash floods destroyed Buffalo Creek's private water system, costing residents $200,000 in damages. Additionally, state highways, county roads, forest roads, and bridges were severely damaged. Heavy water flows (10 times the normal rate) deposited massive amounts of mud and silt into the Platte River, damaging fish habitat and stream bank vegetation. Two lives were lost in the flood. The Denver Water Department is currently evaluating alternatives to either trap sediments, or dredge and remove sediments from Strontia Springs Reservoir. Initially, capitol construction costs could approach 6 million dollars, with ongoing annual operating costs of as much as $500,000 per year. The natural and structured reforestation could take as long as 50 years. During this time, the amount of erosion and degradation of water quality will continue to severely affect the utility's ability to operate its reservoirs and water treatment plants[11] .

Figure 3 Probability of Catastrophic Disturbance Events



- High –1528.45 sq miles
- Medium –4412.94 sq miles
- Low –883.96 sq miles
- High Area Buffers –3735.09 sq miles
- Buffalo Creek Fire –18.75 sq miles

The probability of catastrophic distubance events is a result of the combination of disturbance regime and housing density. Short interval (high) or medium interval (medium) disturbance regimes when combined with high or medium housing density result in a probability factor of high. Short or medium interval disturbance regimes with low housing density result in medium probability, as do high and medium housing density with long interval (low) disturbance. Low disturbance and low housing result in a low probablity factor. The high area buffers are the high probability areas buffered by two miles.

This GIS product was compiled from various sources and may be corrected, updated, modified, or replaced at any time.

September 11, 1996

Forest Land Management for Forest Health Improvement

To be sustainable, forest ecosystems must be managed with techniques that are ecologically sound, socially acceptable, and economically feasible[12] . Management options can be used to improve forest health conditions and reduce the risks of wildfires, insects, and disease outbreaks:

A. Options

Option 1: No Management Tools. If no management tools are used, biomass will continue to build up and, as recent history suggests, these stands will eventually be lost to catastrophic wildfire, insect attacks, and disease.

Option 2: Prescribed Fire: Prescribed fire attempts to closely mimic natural fires and can fireproof an area for 15 to 30 years in a highly controlled manner. Experienced fire managers ignite and manage fires to reduce the presence of unwanted plant species, encourage regeneration of other species, and to reduce excessive buildup in forests. There are many concerns about using this tool. First, the task of restoring health forests in the Front Range will require the use of prescribed fire on a scale never before attempted. Prescribed fire is not without risk and escaped fires can be quite costly[2]. Second, significant increases in prescribed fire may conflict with Clean Air Act requirements and state regulations, especially as they apply to fine (less than 2.5 micron) particles that are increasingly identified with public health concerns[12]. Thus the use of fire in heavily inhabited areas is controversial[2] .

Option 3: Selective thinning and other mechanical treatments (biomass harvesting): The purpose of this tool is to selectively harvest small-diameter trees and mimic the natural effects of insects, disease, weather, and fire. This option reduces fuel load, helps restore a mosaic pattern to the forest, and prepares areas for prescribed fires. It also creates a marketable product from unwanted biomass, which helps reimburse landowners for part of the operational costs.

Option 4: Selective Thinnings and Prescribed Fire: Combining prescribed fire with selective thinning of small-diameter woods will yield long-term forest health benefits. These forests will be more resistant to insect and disease attacks and destructive wildfire and therefore require less effort and fewer resources to suppress fires; recover and rehabilitate resources after insect, disease, or fire events; and help maintain and improve state and local economies. Integrating these two methods would mitigate air pollution. This allows the fire manager control over the amount and type of fuel present. Thus, fire can be used in forest types and situations where it previously would have been extremely risky or inappropriate[2]. To the extent that fire is needed to recycle nutrients in the system, a combined thinning/fire program may prove to be more sustainable on many forest sites[12] .

Dr. Bill Romme of Fort Lewis College and Dr. Denny Lynch of Colorado State University are respected forest health specialists who have conducted extensive research on forest health restoration. Both Dr. Lynch and Dr. Romme support mechanical removal and prescribed fire as forest restoration techniques that are unlike traditional logging or timber sales. In these forest restoration techniques, trees of all ages are removed and the site is burned to restore forest health. Large old-growth trees are left and small unwanted material is removed. Some biomass remains on the forest floor for nutrient recycling. These tools constitute a new, ecologically sound, socially acceptable, and economically sustainable way of managing forested areas[2].

Costs

- **High costs to fight fires.** During the past 10 years, the cost to fight fires in the forested areas of the Rocky Mountains has averaged $350–$400/acre. The average cost to fight fires in UWI areas is more difficult and costs approximately $1,500/acre[13].

- **Costs of selective thinning/mitigation costs.** One of the most effective methods used to restore forest health and reduce forest fire risk is to selectively cut small-diameter trees near structures. Selective thinning efforts (approximately $100/acre) in combination with prescribed fires ($25-$100/acre), to reduce hazards and rejuvenate the land is much less expensive than fighting fires.

  A forest health ecosystem restoration project in southwest Colorado, (Pine Zone Project) showed a cost of $390/acre ($39 bdt x 10 bdt/acre) to harvest and prepare timber stands for the safe, restorative application of fire[13]. Without viable end markets for small-diameter woods, necessary forest health restoration on forested lands and wildfire mitigation projects in UWI areas are difficult to implement.

- **Wood waste disposal options.** Slash (limbs and branches that remain after harvests), is typically piled for burning during fire-safe periods or lopped and scattered (the unmerchantable material is cut up and spread on the ground to decompose). Neither piling and burning nor lop-and-scattering are well accepted by the public. To address this need, some concerned counties and other organizations have developed slash collection and wood chipping programs to help reduce burning and its associated air pollution and reduce the volume of material that is landfilled. These programs are positive, but are expensive to operate, require large volumes of slash to be transferred to a chipping location, and have been met with varying levels of success. Unused piles of wood chips must be disposed into landfills or brought to a wood recycling facility. Wood from forested areas that must be landfilled costs $5.50/yd^3 while wood brought to a wood recycling facility costs an average of $4.75 yd^3[7]; chipping wood into mulch can cost $10–$18/yd^3. If wood chips cannot be used, both woodchipping and landfill costs are incurred[13]. See Table 1.

Table 1: Costs Associated with Forest Fires, Mitigation Efforts, and Waste Disposal

Activities	Costs
Fire Fighting	
• fight fires in forested areas with no structures	$350-$400/acre
• fight fires in UWI with structures	$1,500 or more/acre
Mitigation	
• selective thinning without salvage	$100-$400/acre
• forest ecosystem restoration projects	$390/acre
• prescribed burning	$25-$100/acre
Wood Waste Disposal	
• landfill disposal	$5.50/yd^3
• wood recycling facility	$4.75/yd^3
• chipped mulch (reused)	$10-$18/yd^3

Urban Wood Wastes and Air Quality Issues

Front Range Urban Wood Wastes

Urban environments include trees, which provide many benefits. In addition to providing aesthetics, trees absorb pollutants from air, water, and soil. A typical tree (30 years old, 39 feet high, 16 in. diameter at breast height) can remove 2.19 lb particulate matter, 0.79 lb ozone, 0.55 lb nitrogen dioxide, 0.51 lb sulfur dioxide, 0.04 lb CO, and 112 lb carbon dioxide (CO_2) in a single year. The same tree can absorb heavy metals from the soil[14] and help control water runoff.

In many states, urban tree and yard wastes cannot be landfilled and are recycled through composting and mulching programs; or are used as fuel for biomass power facilities[15]. In Colorado there are no such regulations, and 8,095 bdt of urban wood wastes are landfilled annually [7]. In Denver, if urban tree wastes were removed from landfills, about one-third of the waste volume would be reduced, thus extending the life of landfills.

Air Quality Issues

Air pollution is a complex issue influenced by many factors that contribute to its concentration levels. The major factors are geography, climate, population patterns, industry, motor vehicle fleet, and air pollution reduction programs. The largest source of air pollution in the Denver metropolitan area is CO from automobiles. The Colorado Regional Air Quality Council forecasted growth in population and vehicle travel between now and 2020 threaten to erase the hard-won progress made in improving air quality during the past 20 years. Between 1995 and 2020, the population is expected to grow by about 750,000 and vehicle miles traveled are expected to increase from 49 million mi/day today to 75 million mi/day in 2020.

The Front Range Biomass Supply and Costs to Selectively Thin Forests

The USFS Region 2 contracted with NEOS corporation to conduct a Colorado Front Range biomass supply study and assess the potential amount of biomass available to feed an ethanol facility. Biomass is defined to include wood that could be obtained from forest health restoration operations and wood available from urban areas. The purpose of this resource analysis was to document available quantities, prices, and current uses for biomass resources and provide input to a siting analysis for an ethanol facility. The information presented here summarizes the full report entitled "Colorado Front Range Wood Resource Assessment" in Appendix D.

Forest Resources

Methodology

NEOS worked with multiple USFS databases to determine the number of acres that could be thinned along the Front Range area in the Arapahoe, Roosevelt, and Pike, and San Isabel National Forests. Data for state and private lands are publicly available on the World Wide Web through the Forest Inventory and Analysis Data Base Retrieval system maintained by the USFS. The database was queried using specific criteria to determine the total state and private land acreage by county and tree species. The criteria used to estimate the total acreage are: Colorado state and private lands, county-level data, Ponderosa Pine, Douglas Fir, Lodgepole Pine, slopes less than or equal to 30°, sawtimber and poletimber classification, forest type specific to species of interest, and timberland. State and private lands represent approximately 1.2 million acres and Ponderosa Pine is the predominant species. The county with the largest biomass resource acreage is Las Animas; the second largest is Larimer County.

The purpose of the Front Range resource assessment was to determine (1) the amount of biomass in high and medium fire risk ("Red Zone") areas (see Figure 3); (2) the forest type in these risk areas (Ponderosa Pine, Lodgepole Pine, and Douglas Fir (see Figure 2); and (3) the amount of biomass in each county. The databases revealed that approximately 1.9 million acres of forest are at risk to catastrophic fire. Ponderosa Pine and Douglas Fir mix are the predominant species. The amount of biomass by county is listed in Table 2.

Table 2: Summary of National Forest, State, and Private Biomass Potential, Colorado Front Range (bdt)

County	Arapahoe & Roosevelt	Pike & San Isabel	State & Private	Total Biomass	% of Total Biomass
Boulder	738,742		282,282	1,021,024	6%
Chaffee			52,311	52,311	0%
Clear Creek	318,440		345,450	663,890	4%
Custer		338,259	210,231	548,490	3%
Douglas		377,615	209,244	586,859	4%
El Paso		84,582	911,988	996,570	6%
Fremont		31,413	784,665	816,070	5%
Gilpin		250,964	190,491	441,455	3%
Grand			694,848	694,848	4%
Huerfano		132,711	911,001	1,043,712	6%
Jefferson	21,497	372,931	967,260	1,361,688	8%
Lake			207,270	207,270	1%
Larimer	1,006,950		1,654,212	2,661,162	16%
Las Animas		225	2,476,383	2,476,608	15%
Park	8,398	594,176	523,110	1,125,684	7%
Pueblo		79,485	238,854	318,339	2%
Saguache			464,877	464,877	3%
Teller		421,162	717,549	1,138,711	7%
Total	**2,344,992**	**2,432,558**	**11,842,026**	**16,619,576**	**100%**
%of Total	14%	15%	71%	N/A	N/A

Data estimates represent the total quantity rather than an annual production estimate. The data represent a snapshot in time and do not account for forest growth, removals, disease, and other associated factors.

Biomass Resources Available

The amount of biomass that may be harvested from national forests and state and private lands depends on a complex interrelationship of forest biology, technology, politics, and economics. Estimates of biomass that may be harvested from the forests were obtained from studies conducted in the San Juan National Forest of southern Colorado. Lynch et. al April 1996 report that in the size class of 5 in. to 11.9 in., d.b.h., there are approximately 10 bdt/acre removed through thinning treatments. All potential biomass resources on the Front

Range were calculated by estimating the number of suitable acres on national forest and state and private lands and multiplying this acreage by 10 bdt.[7]

Table 3 provides summary data for projected Colorado Front Range forest biomass resources. An estimated 16.6 million bdt of wood are potentially available from national forest, state, and private lands. Approximately 71% of the resource base comes from state and private lands, and Larimer and Las Animas counties have the largest resource base. In the northern portion of the Front Range, Lodgepole Pine is the dominant species; Douglas Fir is the predominant species in the southern areas.

Costs

Product cost estimates were based on felling, skidding, equipment mobilization, operations, maintenance, administrative, and transportation. Product costs were developed county by county for all forest resources, and all base costs were consistent for each county. Only transportation varied (see Table 3). The average cost is nearly $67/bdt or approximately $3.70/MMBtu. The selected delivery site was the Denver metropolitan area; thus, delivered costs are least expensive for counties near Denver. Transportation represents the single largest component of the delivered product cost (42% of total costs).

Table 3: Delivered Forest Biomass Costs for the Colorado Front Range

County	Distance to Denver (mi)	Haul Cost ($)	Haul Cost ($/bdt)	Total Cost* ($/bdt)	Total Cost ($/MMBtu)
Boulder	50	165.00	14.67	54.12	3.00
Chaffee	140	350.00	31.11	70.56	3.91
Clear Creek	50	165.00	14.67	54.10	3.00
Custer	180	450.00	40.00	79.44	4.40
Douglas	50	165.00	14.67	54.12	3.00
El Paso	75	187.50	16.67	56.12	3.11
Fremont	130	325.00	28.89	68.34	3.79
Gilpin	50	165.00	14.67	54.12	3.00
Grand	150	375.00	33.33	72.78	4.03
Huerfano	180	450.00	40.00	79.45	4.40
Jefferson	50	165.00	14.67	54.12	3.00
Lake	150	375.00	33.33	72.78	4.03
Larimer	150	375.00	33.33	72.78	4.03
Las Animas	220	550.00	48.89	88.34	4.90
Park	75	187.50	16.67	56.12	3.11
Pueblo	160	400.00	35.56	75.00	4.16
Saguache	200	500.00	44.44	83.85	4.65
Teller	70	175.00	15.56	55.00	3.05
Average		306.94	27.28	66.73	3.70
Minimum		165.00	14.67	54.12	3.00
Maximum		550.00	48.89	88.34	4.90

*Total cost includes stumpage, harvest costs, and transportation[7]

Urban Resources

Considerable amounts of urban wood resources are not being used. A telephone survey was conducted during January and February 1997 to estimate the amount of urban wood resources in the Front Range area. The survey data were then augmented with additional data taken from previous studies. Organizations contacted included primary and secondary wood processors, wood recycling firms, landfill operators, commercial tree care firms, municipal forestry operations, utility line clearance operations, and landscapers. Organizations

were queried as to the type, amount, seasonal patterns, cost or price of their wood residues, and the types of products made from these resources.

Primary and secondary wood manufacturers survey results show that a minimum of 20,000 bdt/yr of wood waste are generated by 63 companies in this sector, of which 8,200 bdt (41%) are sold. The remaining waste is landfilled (6,400 bdt), given away (3,500 bdt), or used on site (1,900 bdt).

The urban tree residue (UTR) sectors generate a relatively low-value, diverse resource mix composed of chips from multiple species, leaves, grass clippings, and assorted branches and logs. The annual UTR production, based on the 69 entities studied, is estimated at 98,291 bdt/yr.

Area wood recycling companies process more than 58,000 bdt/yr of wood waste into products such as mulch, animal bedding, and compost. Prices for finished products are $15–$70/bdt, depending on the final product and current market conditions (see section Markets for Small-Diameter Woods and Urban Wood Waste). The wood recyclers represent a current infrastructure, and many may be potential suppliers to an ethanol facility.

For the urban component, at least 169,354 bdt/yr of material is available at an average cost of $23.39/bdt as summarized in Table 4. UTR is the primary and least expensive resource. Table 4 also provides rankings from the lowest- to the highest-cost materials and shows a cumulative total cost and a blended cost for each successively higher-priced resource added to the mix. For example, using only primary/secondary waste, UTR, and the animal bedding stream from recyclers, the total amount available would be 119,601 bdt/yr at an average price of $15.85/bdt.

Table 4: Summary of Available Urban Wood Residue Production and Prices

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	11,905	11,905	15.00	15.00
UTR	98,291	110,196	15.00	15.00
Recycler—Animal Bedding	9,405	119,601	25.78	15.85
Recycler—Mulch	12,486	132,088	26.79	16.88
Recycler—Compost	26,207	158,294	39.36	20.60
Recycler—Dyed Mulch	11,059	169,354	63.34	23.39
Total		169,354		23.35

Summary Information of the 11-County Core Area Urban and Forest Resources

Table 5 summarizes wood residue quantities available for an 11-county core area in the immediate vicinity of Denver. The forest residues have been annualized by dividing by 20 to represent a potential harvest schedule of 20 years. The data in Table 5 represent all residue available, and account for estimated sales and recycling levels.

As shown in Table 5, more than 7.3 million bdt of wood resources are estimated to be available for ethanol production in a 50–100 mile radius (11-county area) of the Denver metropolitan area and approximately 500,000 bdt are available annually. The data listed for forest residues represent the total amount of residue available, and only a few thousand acres are likely to be harvested annually from the forest. Urban wood resources reflect the amount of wood available annually.

Table 5: Annual Available Wood Residue for Core Counties

County Name	Study Class[a]	Primary and Secondary[b]	Urban Tree Residues	Total Forest Biomass Removals[c]	Estimated Annual Yield[d]
Adams	1	5,480	7,737		13,217
Arapahoe	1	21	6,890		6,911
Boulder	2	1,273	2,015	1,021,024	54,343
Clear Creek	2			663,890	33,195
Denver	1	2,264	18,948		21,212
Douglas	2	2	20	586,859	29,365
El Paso	2	21	3,021	996,570	52,870
Gilpin	2			441,455	22,073
Jefferson	2	250	27,522	1,361,688	95,856
Park	2			1,125,684	56,284
Teller	2	722		1,138,711	57,658
Multiple/Unknown			23,911		23,916
Wood Recyclers					59,158
Total		**10,033**	**90,073**	**7,335,881**	**526,057**

[a]1=urban only; 2=urban and forest
[b]bdt/yr
[c]bdt
[d]For 20 years (bdt/yr)

Table 6 shows the estimated cost of each residue type found in the 11-county core area. The average price for the material is approximately $45/ton and prices range from free (with an assumption of $15/bdt for trucking) to $63.35 for the material presently being sold as dyed mulch. For all processed residue that has present markets, the ethanol facility must presumably at least match current market prices if that resource is to be available to the ethanol facility.

Table 6: Estimated Annual Costs of Biomass for the Core Front Range

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	10,033	10,033	15.00	15.00
UTR	90,073	100,106	15.00	15.00
Recycler—Animal Bedding	9,405	109,511	25.78	15.93
Recycler—Mulch	12,486	121,997	26.79	17.04
Recycler—Compost	26,207	148,204	39.36	20.98
Core Counties Forest Residues (Annual)	366,794	514,998	54,83	45.09
Recycler—Dyed Mulch	11,059	526,057	63.35	45.47
Total		**526,057**		**45.47**

Markets for Small-Diameter Woods and Urban Wood Wastes

In the Rocky Mountain region, the average tree diameter available for harvest during the past century has decreased from approximately 27 in. to 8 in. Forest managers and the forest products industry are seeking markets for small-diameter woods to enhance the overall supply base and solve forest health problems associated with overstocking small trees.

The generally small size of timber and relatively low value available from these forests limit traditional raw material marketing opportunities. Markets for Front Range forest products have been firewood, post-and-poles, and small amounts of lower-quality sawn products. Since the early 1980s, markets for these forest products have decreased. A lack of dependable timber supply is due to legal and procedural constraints, urban development, and international competition from suppliers in Canada and Mexico.

Current Markets for Small-Diameter Woods

This section describes briefly the current markets and uses for small-diameter woods and wood wastes both nationally and in Colorado. Its purpose is to identify the products that may compete for wood resources needed to produce fuel-grade ethanol.

A description of the types of forest products produced from small-diameter trees and under used wood wastes nationwide follows. Those marked with an asterisk (*) are forest products made in Colorado[16].

- **Animal Bedding.*** Consists of sawdust and shavings.
- **Bark Mulch/Ground Cover/Bedding.*** Wood bark and wood are used to hold moisture, limit weed growth, insulate soil, and prevent erosion around trees and gardens. Wood residues can be used as ground cover for landfill cover, forest roads, or mine reclamation.
- **Compost.*** Wood residues are mixed with natural sources of nitrogen (manure) and organic waste to produce plant mixes, soil amendments, and pelletized organic fertilizer.
- **Fiber Cement Boards.** Flaked wood is incorporated in cement that is compressed and heated. A Portland Oregon cement plant uses dead standing trees that would not be used otherwise. About 30 plants worldwide create this product. The boards are used for fire-resistant flooring, fire doors, roofing, and weather boarding.
- **Firewood.*** Many wood residues are used as firewood.
- **Waferboard.*** Wood residues are compressed with glues to create industrial packaging, crating, and pellet decks.
- **Particleboard.** Sawdust and shavings are mixed with resin to create shelving, furniture, floor underlayment, mobile home decking, and door cores.
- **Sewage Treatment.** Sludge is mixed with bark and composted for sale.
- **Trail Surfacing.*** Wood chips are used on pathways of many trail ways.
- **Turf.** Sawdust is mixed with nutrients and grass seeds.

- **Molded Wood Products.** Wood residue is hogged, mixed with sawdust and dried, then mixed with resin and poured into molds to produce a variety of products for the automobile and furniture industries.

- **Bio-Oil.** A new technology that will reduce green wood and bark to an oil that can fuel a diesel engine or be burned in a boiler.

- **Woodstove Pellets.** Sawdust, shavings, or sander dust are processed into pellets and burned in woodstoves.

- **Wood Briquettes.** Pressed sawdust or shavings are shaped into cubes, cakes, or other shapes and used as fuel supply for energy production or heat recovery.

- **Charcoal Briquettes.** Hogged fuel is dried and charred to reduce its volume by 75%, then pressed with starch to form briquettes.

- **Electricity Production and Cogeneration.** Biomass is used as feedstock for electricity and thermal applications.

Colorado's Wood Waste Market

In the wood waste market, waste wood products are produced by primary wood processors (those that produce lumber), secondary wood processors (those that process lumber into final products), and wood recyclers (those who produce wood products from wood waste materials).

In Colorado, primary wood processors and secondary wood processors produce 20,000 bdt of wood waste per year, of which 8,000 bdt is sold as bedding, firewood, and mulch, the state's largest wood markets. Animal bedding at $52/bdt and firewood at $35/bdt are the highest-priced products sold.

Seven wood recyclers in the Denver metropolitan area produce products from wood waste materials and charge a tipping fee that averages $15/ton. The largest sources of raw material for end products are clean construction waste, pallets, and UTR, which together account for 73% of facility input. Approximately 60,000 tons of material per year is chipped and processed into end products.

Table 7 shows the type of products that wood recyclers manufacture and the prices received for each product. Primary products are mulch, dyed mulch, compost, and animal bedding. Dyed mulch is the highest priced seller on the market ($63/ton), whereas animal bedding ($25/ton) and mulch ($26/ton) receive lower prices.

Table 7: Wood Recyclers Forest Product Prices and Tonnage

Item	Total (bdt)	Mulch	Dyed Mulch	Compost	Animal Bedding
Low Price ($/bdt)		$15.32	$60.00	$35.41	$23.83
High Price ($/bdt)		$30.00	$70.00	$42.58	$30.00
Average Price ($/bdt)		$26.79	$63.35	$39.36	$25.78
Percentage of Product Sales		21%	19%	44%	16%
Product Tonnage (bdt)	59,158	12,486	11,059	26,207	9,405

Table 7 also shows the percentage of market share for each product. Compost has the largest segment of the market, followed by mulch, dyed mulch, and animal bedding. An ethanol facility would have to match or beat the current market prices to obtain a given stream of material. Currently there are no biomass power markets in the Front Range area. For additional information see Appendix D.

This information indicates that there are end markets for wood waste in Colorado. However, these markets are not large enough to use all the wood waste available. For example, primary and secondary wood waste data show that an additional 12,000 bdt/yr, and UTR's data show more than 98,000 bdt/yr would be available for an ethanol facility. Therefore, an ethanol facility in the Front Range would not directly compete with other forest product markets. The urban wood waste combined with wood waste from National Forest and state and private lands (200,000 bdt/yr) would be enough wood waste to run a 300,000 bdt/yr ethanol facility. An ethanol facility could compete for the 60,000 bdt/yr that wood recyclers receive, as they receive $15/bdt for this material.

Whether the other products listed earlier have large enough markets to attract new product industries in Colorado is unclear. An ethanol plant that uses these wood wastes could provide a much-needed market and outlet. The growing market for ethanol would provide a product that could offset the costs of forest health restoration efforts.

Ethanol Market

Ethanol, as a product made from wood materials, is a more attractive market option to pursue than the other products listed earlier because [17].

- **There is a large ethanol market in Colorado.** Colorado's mandated oxygenated fuel program increased the market for ethanol. Six Denver metropolitan counties are required to add oxygenates to gasoline from November 1 to February 7. Historically, ethanol and methyl tertiary butyl ether (MTBE) have been the oxygenates used. MTBE was initially favored by the refiners because it was a product of the petrochemical industry, but now ethanol has more than 80% of the blended fuels market. Fuel ethanol production in Colorado is 1.7 million gallons (about 0.1%) of the total ethanol production. U.S. ethanol production is currently 1.5 billion gallons. Colorado sold about 280 million gallons of ethanol-blended gasoline (28 million gallons of ethanol) in 1996, up from 235 million gallons of ethanol-blended gasoline in 1994.

  Reformulated gasoline (RFG) is more benign than traditional gas, makes gasoline cleaner, and reduces ozone pollution and air toxins. RFG constitutes 30% of the gasoline sold in the United States, and nine severe ozone non-attainment areas require it year round. Ethanol controls part of the RFG market in the Midwest. If the EPA's proposed tighter ozone and particulate matter standards are adopted, RFG may be required in Colorado and other regions of the country. This requirement would open new fuel markets to ethanol.

- **Two Federal laws will increase the demand for fuel ethanol.** (1) The Clean Fuel Fleet Program, under the Clean Air Act Amendments of 1990, requires that private fleets with 10 or more vehicles, that are or can be converted to be centrally fueled, purchase alternative fueled vehicles or low emission vehicles. (2) The Energy Policy Act of 1992 requires the federal government to purchase alternative fuel vehicles as a percentage of the new vehicles purchased. President Clinton signed an Executive Order in December 1997 recommitting the federal government to these purchase requirements.

- **Private industry supports the production of flexible fuel vehicles (FFVs) that can run on either 85% ethanol (E85) or gasoline.** Ford Motor Company recently announced plans to increase its production of cars and light trucks that can run on gasoline or E85. Ford said it will produce about 250,000 FFVs during the next 3-4 years. Chrysler anticipates producing 180,000 FFV minivans in 1998. Nationwide there are fewer than 60 service stations that sell the high-ethanol fuel (E-85) that Ford FFVs can use. During the summer of 1997, the first public E-85 refueling site in Colorado opened near the Federal Center on Alameda to fuel 75 E85 FFVs that the General Services Administration has purchased. There are 100 E85 FFVs within the State of Colorado; 60 E85 FFVs with a car rental firm at Denver International Airport, and an additional 35 E85 FFVs in other locations.

- **Federal tax incentives make ethanol price competitive.** The cost of producing gasoline is based on the cost of crude oil. Petroleum companies will evaluate the value of gasoline on the market and determine how much ethanol can be used to extend it. The federal government has provided an incentive to gasoline marketers who blend 10% ethanol with unleaded gasoline, in the form of a federal excise credit that makes ethanol an attractive fuel economically. For every gallon of ethanol sold in the marketplace, fuel blenders receive a $0.54 federal tax credit. For example, if ethanol today is $1.12/gal, a $0.54/gal tax credit drops the net cost of ethanol to $0.58/gal, which is below the current price of gasoline ($0.60/gal on the wholesale market). This illustrates why ethanol is competitive in the fuels manufacturing market, particularly during the winter.

  For the past 10 years, the average price of ethanol has been $1.20/gal, which is determined by the price of corn. In 1996, corn prices were the highest in history, more than $5/bushel compared with the normal price of $2.50/bushel. Denver's ethanol prices increased correspondingly from $1.25/gal in January 1996 to $1.61/gal in October 1996. As of March 10, 1997, fuel ethanol's terminal market price in Denver was $1.20/gal.

- **Air Quality Benefits.** (See Net Public Benefits.)

Facility Design and Financial Evaluation

Introduction

The purpose of this section is to determine the economic feasibility of siting one or more biomass-to-ethanol manufacturing facilities along the Colorado Front Range [18]. The biomass feedstocks of interest for the feasibility study include forest thinnings and urban green waste. For more information about feedstock resources in the Front Range area, see the *Colorado Front Range Wood Resource Assessment* report prepared by NEOS Corporation for the FRFHP.

The ethanol facility design presented here uses technology available from HFTA, a California corporation. HFTA's dilute nitric acid process for converting wood to fuel ethanol was developed at the University of California's Forest Products Laboratory in Richmond, California. HFTA has exclusive rights to license the process. NREL has worked closely with HFTA personnel to ensure that the information presented here accurately represents HFTA's dilute nitric acid technology applied to Colorado softwoods. The design and cost estimates presented in this report were prepared by NREL in cooperation with HFTA and are preliminary. Those interested in HFTA's technology should contact George Craig of HFTA at (510) 893-9657.

Other biomass-to-ethanol conversion technologies, at various stages of development, are available. Technologies and companies that should be contacted and evaluated before a biomass to ethanol project is pursued include:

- Concentrated acid technologies available from Arkenol of Mission Viejo, California; and MASADA Resource Group of Birmingham, Alabama

- Dilute sulfuric acid/enzymatic technologies available from BC International of Dedham, Massachusetts; SWAN Biomass of Illinois; and WEIS of Palo Alto, California.* Standards for these other biomass ethanol technology companies can be obtained from Art Wiselogel at (303) 275-4466.

The HFTA technology was selected as one that could be commercialized during the next 2-3 years, has relatively low capital cost, and is a relatively simple process. Major process equipment has been defined, and a +/- 30% budgetary capital cost estimate is presented. Operating costs are also estimated, also with an accuracy of +/- 30%.

The process description and process flow diagram for the dilute nitric acid technology are included in Appendix A.

The reader is reminded that this is a <u>feasibility</u> study. Time constraints did not allow detailed analysis of many design and process performance issues. These issues will need to be addressed in subsequent phases of the project.

Design Basis

The ethanol facility design is based on the following annual fuel ethanol product and coproduct production capacities:

Product and Coproducts	
Fuel-grade ethanol	14,800,000 gallons
CO_2	44,959 tons
Lignin fuel	253,589 tons
Yeast cell mass	398 tons

Biomass feedstock consumption is estimated at 300,000 bdt annually—100,000 bdt from urban green waste plus 200,000 bdt from forest thinnings. The combined feedstock is assumed to have the following average composition (dry weight):

Glucan	38%
Mannan	10%
Galactan	5%
Xylan	6%
Arabinan	4%
Lignin	25%
Extractives	10%
Ash	2%
Total	100%

Annual production and consumption rates are based on 345 operating days per year, allowing 20 days per year for scheduled and unscheduled maintenance.

Capital Cost Estimate

Two sites (Coors and Las Animas) were evaluated to determine the economic feasibility of converting forest thinnings and urban green waste to ethanol. Coors is an industrial site with significant infrastructure that is assumed to be used by the biomass ethanol facility. Las Animas represents an undeveloped greenfield site that would require significant investment in support infrastructure in addition to the ethanol facility.

Unlike the Coors site cost estimate, the Las Animas site capital cost estimate includes the cost for site improvements, rail spur, 600-psi steam boiler, wastewater recovery facility, process buildings, air and process water systems, office buildings, lunchroom, maintenance facilities, and medical facilities. The cost of these facilities significantly increases the capital cost of the facility.

Estimated capital costs for the proposed ethanol facilities at the Coors site are $33,606,000; for the Las Animas site, $48,814,000 (includes working capital). The accuracy of these estimates is +/-30%. Details of the capital and operating cost estimates can be found in the *Manufacturing Cost Summary Reports* included in Appendix B for the Coors site and Appendix C for the Las Animas site.

Financial Evaluation

To determine project profitability, a 20-year ethanol plant life, and a 2-year period for ethanol facility design, construction, and startup have been assumed. Project financing assumptions include 75% debt financing at

10% annual interest and a 10-year long term with interest-only payments during construction and startup. Additional assumptions include 34% federal and 5% state income tax rates and 3% inflation rate.

The economic analysis assumes the following credits for product and coproduct sales and raw material costs:

Products and Coproducts	
Fuel ethanol	$1.20/gal
CO_2	$40/ton (Coors site only)
Lignin fuel	$15/bdt
Yeast cell mass	$250/ton
Raw Materials	
Urban green waste	$15/bdt (100,000 bdt/yr)
Forest thinnings	$15–$60/bdt (200,000 bdt/yr)
Nitric acid	$162/ton
Ammonia	$181/ton
Denaturant	$0.60/gal

At the Coors site, all the fermentation CO_2 coproduct is assumed to be sold "over the fence" to the Coors brewery. At the Las Animas site there is no obvious buyer for the CO_2, so it is assumed to be vented to the atmosphere. No coproduct credit is received.

A complete breakdown of the fixed and variable operating costs is included in the *Manufacturing Cost Summary Reports* in Appendix B for the Coors site and Appendix C for the Las Animas site.

Utility cost assumptions are:

Electricity	$0.05/kWh
Process water	$0.31/1000 gal
Boiler feed water	$5.18/1000 gal
Cooling water	$0.09/1000 gal
Chilled water	$5.48/1000 gal
Low-pressure steam, 3.5 atm	$1/1000 lb
High-pressure steam, 40 atm	$3/1000 lb
Secondary wastewater treatment	$3/1000 gal
Diesel fuel	$1.20/gal

Salaries and wages required to operate and maintain the ethanol facility are included in the ethanol plant operating expenses. The Coors facility will presumably employ 27 people; Las Animas will employ 41 people. These figures include all operations, maintenance, administrative, and support personnel for the ethanol facility. The Las Animas site requires more people to operate and maintain the boiler, water treatment, wastewater, and other equipment operated by others at the Coors site. Total direct labor costs are estimated to be $1,273,000 for the Coors site and $1,936,000 for the Las Animas site. Details of the labor costs, labor categories, and annual salaries are included in the *Manufacturing Cost Summary Reports* in Appendices B and C.

The internal rate of return (IRR) for a 14.8 million gal/yr ethanol facility that uses the dilute nitric acid process for the Coors and the Las Animas sites versus average feedstock cost is shown in Table 8 and Figure 4. Calculation of the average feedstock cost assumes one-third urban green waste is combined with two-thirds forest thinnings to produce 300,000 bdt of feedstock annually.

Manufacturing Cost Summary Reports are included in Appendices B and C for the $20/bdt average feedstock cost cases. A biomass ethanol plant located at the Coors site may be viable if the average feedstock cost can be kept below about $25/bdt. Because of the higher facility capital cost, the Las Animas site does not appear to be competitive. The impact of ethanol plant size on the profitability as measured by IRR will be explored next (see Table 9 and Figure 5).

The effect of ethanol plant size was evaluated for the Coors site only. The amount of urban green waste was held constant at 100,000 bdt/yr at a cost of $15/bdt, and the amount of forest thinnings was varied from 0 to 400,000 bdt at a cost of $40/bdt, the average cost of forest thinning operations in the Northeastern Sierras in California and in the Black Hills of South Dakota. This cost should be achievable in Colorado if a highly mechanized industry is established similar to California and South Dakota.

Table 8: Internal Rate of Return versus Feedstock Cost

Average Feedstock Cost	Coors Site IRR	Las Animas Site IRR
$15/bdt ($15 urban, $15 thinnings)	35%	8%
$25/bdt ($15 urban, $30 thinnings)	21%	-2%
$35/bdt ($15 urban, $45 thinnings)	5%	--
$45/bdt ($15 urban, $60 thinnings)	-12%	--

Figure 4

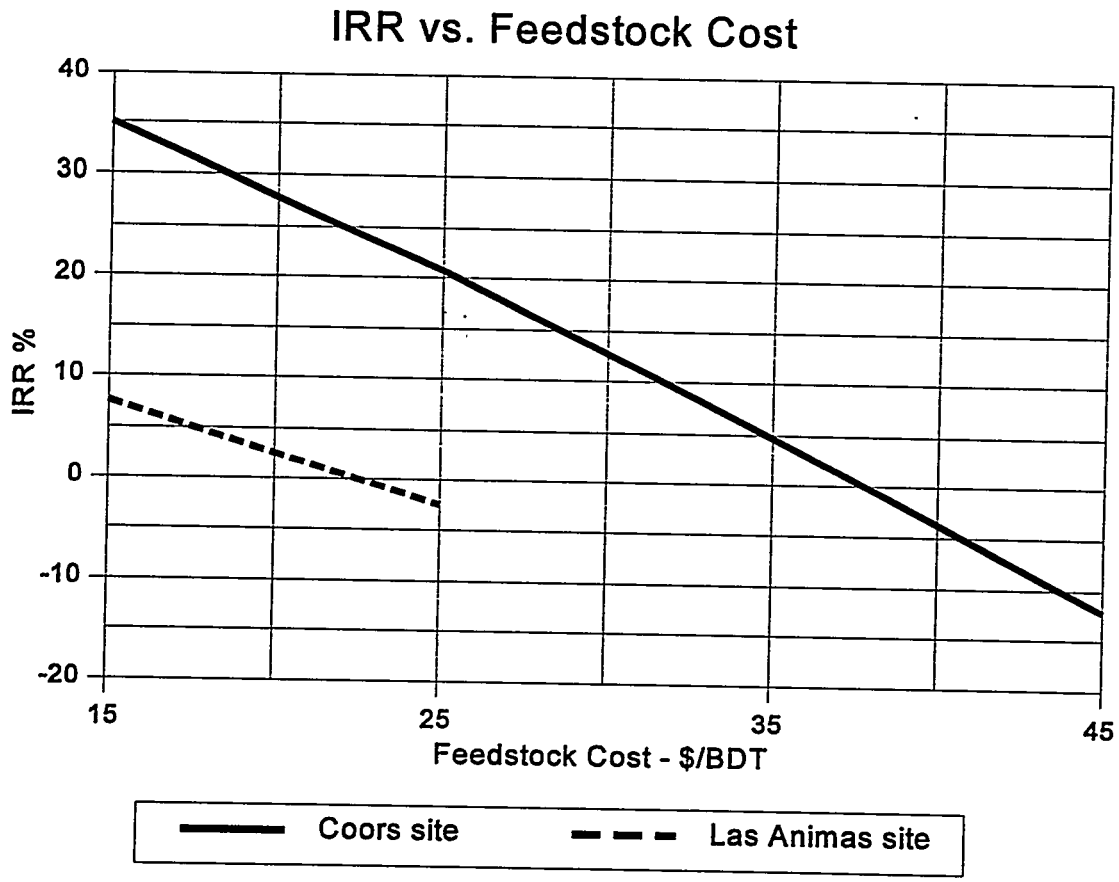
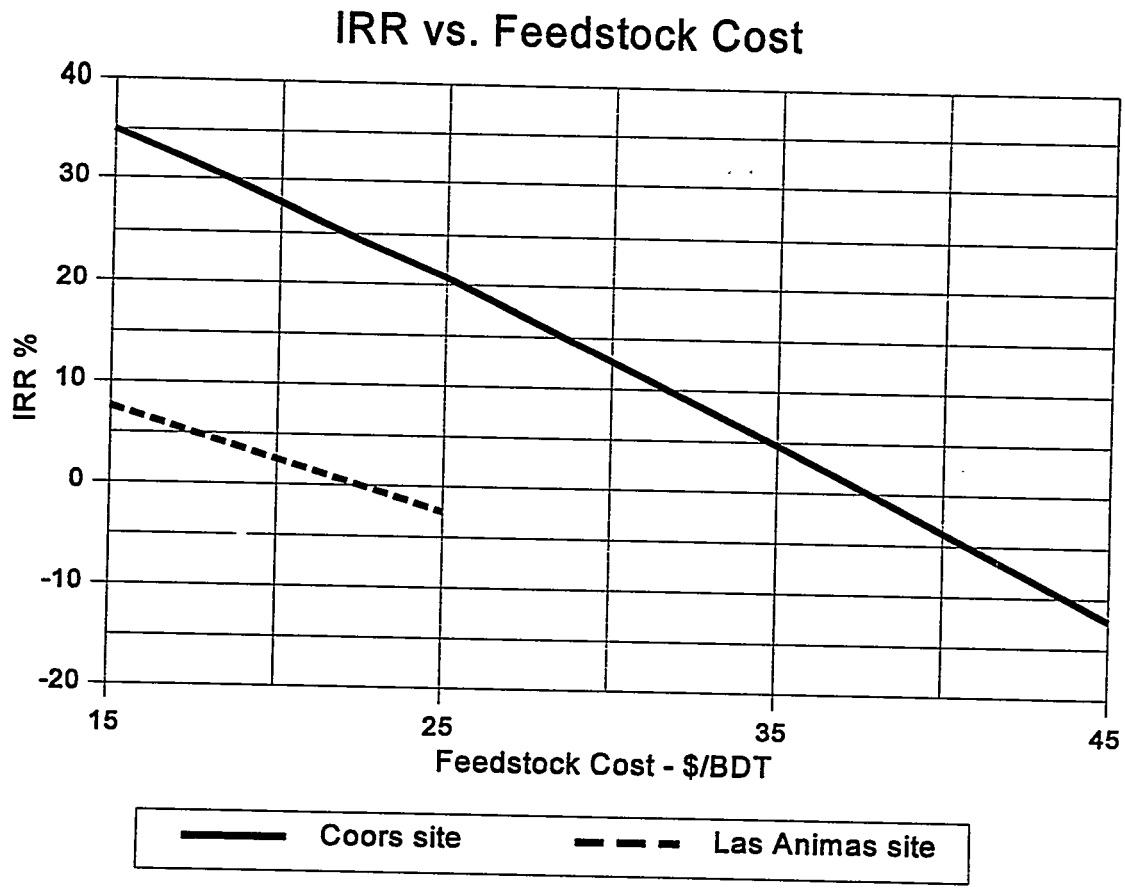


Table 9: Internal Rate of Return versus Ethanol Plant Size versus Coors Site

Annual Feedstock Use Average Feedstock Cost	Ethanol Plant Size (gallons per year)	Coors Site IRR
100,000 bdt/yr $15.00/bdt	4,900,000	1%
200,000 bdt/yr $27.50/bdt	9,900,000	6%
300,000 bdt/yr $31.67/bdt	14,800,000	10%
400,000 bdt/yr $33.75/bdt	19,800,000	13%
500,000 bdt/yr $35.00/bdt	24,700,000	15%

Figure 5



For this analysis, the benefits of increasing plant size are partially offset by the increasing feedstock cost. A relatively large ethanol plant results in an IRR of only 15% when the forest thinning feedstock cost is $40/bdt. If that could be reduced to $30/bdt, the IRR for a 500,000 bdt/yr ethanol plant (25 million gal/yr) results in an IRR of 30%.

Conclusions and Recommendations

Converting biomass to ethanol using the dilute nitric acid technology presented here (and in more detail in Appendix A) appears to be economically feasible if the infrastructure assumed to be available at the Coors site is used and forest thinning biomass is available at a cost of $30-$40/bdt. Using the infrastructure at the Coors site reduces the capital cost of a 14.8 million gal/yr ethanol facility from $49 million to $34 million, a saving of 30%.

Many technical, economic, and other assumptions have been made to perform the analyses reported in this study. Additional work is needed to prove or disprove these assumption and reduce the uncertainty of the results.

Site Identification and Evaluation Study

Purpose and Scope

NREL contracted with Merrick Engineering to identify a number of potentially suitable sites along the Front Range for locating a wood-to-ethanol production facility and establish the evaluation criteria for selecting the final site(s)[19].

Final site recommendation will require one or more evaluation cycles of site attributes and evaluation criteria as the detailed design of the ethanol production facility develops. For example, water and wastewater utility requirements can be re-evaluated after the process mass and energy balances are calculated.

Methodology

Potential sites were identified from three alternative sources—self-identified, FRFHP suggestions, and the Merrick & Co. Planning and Development Department databases. (The identification source for a site is not an evaluated criterion.) Twelve potential sites along the metropolitan Denver Front Range (approximately Fort Collins to Castle Rock) were identified and investigated. See Appendix E. After preliminary evaluation, three additional sites in southern Colorado were identified and evaluated.

Telephone surveys were developed and used to gather the information required to perform the site evaluations. When possible, information was obtained directly from property owners or managers. In some cases, information was obtained from realtors who listed the properties for sale or lease.

Criteria Description

Site selection criteria for a waste wood-to-ethanol facility were developed primarily based on requirements and site preferences previously identified by NREL. This document provides the best estimates for facility requirements based on previous feasibility studies conducted by NREL and its subcontractors. Additional selection criteria were added based on industrial site selection experience and specific concerns of the project. They include potential environmental concerns, lease or sale cost and terms, and the potential for nearby sources of feedstock.

The selection criteria identified for this site selection study include:

- **Willingness of the site owner/contact to have the site considered for a waste wood-to-ethanol plant.** No single site is a "one and only" suitable location, and ethanol production is envisioned as a commercial endeavor. No involuntary site use, such as through eminent domain, is considered necessary or possible.

- **Size of the available parcel.** The process vessels and piping for an ethanol production facility can be located on a parcel smaller than 20 acres. Feedstock storage could require an additional 90 acres (6 months feedstock storage at 15 acres/month of feedstock storage). Sites smaller than 20 acres were eliminated as too restrictive, and sites that required an all or nothing purchase or lease of parcels larger than 120 acres were screened out as uneconomic.

- **Location.** Ethanol production costs are lowered by reducing feedstock transportation costs, i.e., by the plant being closer to the forest, or closer to an urban waste collection point. Assuming a transportation mileage surcharge of $1/mile for a truckload of 20 bdt and an ethanol yield of 50 gal/bdt, a 50-mile

forest-to-plant distance adds $0.05/gallon to the ethanol production cost. This amount, though economically significant, is within the uncertainty of other production cost parameters. Accordingly, sites within 50 miles of the nearest national forest boundaries were investigated. All the Front Range sites are within 50 miles of an urban waste centralized collection or disposal site. For site locations see Appendix C.

- **Zoning.** The wood-to-ethanol plant will have processing steps similar to pulp and paper production and the brewing/distillation of alcoholic beverages. Many truck shipments could arrive and depart each hour, depending on plant capacity. Zoning for heavy industrial use will be required. Such zoning should already be in place, as the delay and controversy likely if a zoning change is required will eliminate a site's commercial viability.

- **Shape.** A regularly shaped site (square or rectangle) is desirable for ease in facility layout. However, any shape that does not require excessively long or tortuous pipe runs is acceptable. All the sites identified in this report are acceptable; thus, this criterion was not included in relative site evaluations.

- **Terrain.** Sites with slopes greater than about 4% are less desirable because of adverse impacts on construction, equipment layout, and plant operability.

- **Utility availability.** Utility availability will result in lower construction and equipment costs for the ethanol plant, and avoid delay or controversy associated with tie-ins or discharge permits, thereby reducing ethanol production costs. The necessary utilities include power, steam, water, and wastewater treatment. Of these, steam supply and wastewater treatment are more expensive to provide.

- **Road access.** All-weather, year-round road access is desirable.

- **Rail connection.** Access to rail transportation, especially for feedstock, can reduce transportation costs.

- **Residential developments.** The fumes, odors, and truck traffic associated with this plant will not be acceptable to nearby current or planned residential developments.

- **Cost and terms of sale or lease.** Land costs rate an element of ethanol production costs; high costs may prevent the economic viability of the plant. Lease terms of at least 5 years will be necessary to secure commercial investment.

- **Potential environmental problems.** Known or potential environmental legacies may disqualify a site. Commercial investors will avoid becoming potentially responsible parties to a superfund action, for example.

- **Nearby sources of feedstock.** A properly designed ethanol plant can distill, dry, and blend fuel-grade ethanol from virtually any source of fermentable sugars. The availability of forest wastes may be seasonal, so nearby alternative feedstocks (sawmills, paper disposal, cheese production, etc.) are desirable.

Go/No-Go Criteria for Site Selection

Criteria used to immediately evaluate whether a particular site would be amenable to housing a waste wood-to-ethanol facility were identified as go/no-go. These criteria included:

- Willingness of the site owner/contact to have the site considered for a waste wood to ethanol plant.

- Size of the available parcel (at least 20 acres).
- Site zoning for heavy industrial use or equivalent in place.
- Lease terms for at least 5 years available.
- If the site owner/operator was not willing to consider the site as a potential location for the waste wood-to-ethanol facility, it was eliminated from further consideration.
- The size of the available parcel must be large enough to accommodate a plant that can produce 5-20 million gallons of ethanol per year as discussed in Minimum Facility Requirements. The acreage necessary to house this type of facility with associated structures, equipment, and biomass feedstock storage area is expected to be 20-120 acres. Sites without adequate acreage were eliminated from further evaluation. A site that houses a waste wood-to-ethanol plant requires zoning for heavy industrial use. Sites not already zoned for heavy industrial use (agricultural use) or currently in the process of being zoned heavy industrial were eliminated from further consideration. Sites with lease terms of less than 5 years were also eliminated because the likelihood of attracting commercial investors would be low.

Weighting of Criteria

Following evaluation based on go/no-go criteria, remaining sites were evaluated using a weighting system that consisted of points and percentages. Evaluation criteria were assigned point values based on the desirability of certain site attributes. For example, a potential site might receive as many as 20 points, based on its location relative to the primary sources of feedstock—forest and urban wastes. A site within 10 miles of the forest waste feedstock would receive all 20 points and sites further from the site received fewer points. The maximum total number of points assigned to the two location criteria was 40 points.

Each site was assigned a point value for each criterion. Sites with a configuration amenable to industrial applications were assigned a point value of 10 for site shape. A site terrain that was fairly level (less than a 4% grade), received five points for terrain. Sites with a steeper grade received fewer points. Site road access, rail accessibility, location relative to residential developments, and availability of site utilities were evaluated similarly by awarding up to a maximum number of points for the most desirable traits in each criterion. Table 10 summarizes a description of the site selection criteria, point basis, and weighting factors used in the site evaluation.

The lease or sale cost of each site was rated independently as consideration for lease terms, site size, and additional factors were taken into consideration. The cost was then defined as an excellent, acceptable, or low value and assigned points accordingly. The lease or sale cost numbers given by landowners or their agents in response to this study's questionnaire were typically rough estimates, and should not be considered actual offers. Actual costs for any particular site, if formally negotiated, could be higher or lower than the questionnaire responses.

Table 10: Site Scoring Matrix

Criteria	Points	Weighting Factor
Site Location - Forest	# miles to primary source of feedstock <10 — 20 points 10-20 — 15 points 20-30 — 10 points 30-50 — 05 points >50 — 02 points	15%
Site Location - Urban Waste	# miles to primary source of feedstock <10 — 20 points 10-20 — 15 points 20-30 — 10 points 30-50 — 05 points >50 — 02 points	15%
Terrain	Grade <4% — 10 points 4%-5% — 05 points 5%-6% — 02 points >6% — 00 points	5%
Road Access	Availability year round — 10 points summer access — 05 points no road access — 00 points	10%
Closest Rail Connection	# miles from site on site — 10 points <2 — 05 points 2-5 — 02 points >5 — 00 points	5%
Nearest Residential Development	# miles from site >3 — 10 points .5-3 — 5 points <5 — 00 points	10%
Utilities Steam Power Water Wastewater Treatment	Available on site 10 points each for steam and wastewater treatment, 5 points each for water and power Available near site one-half of maximum Not available 0 points each	30%
Lease or Sale Cost	Evaluated independently; values rated as Excellent — 10 points Acceptable — 05 points Low — 02 points	15%

The criterion of nearby sources of additional feedstock (e.g., an adjacent lumber mill's waste sawdust and wood chips) was evaluated independently of the point system and considered an added site benefit to be considered during final site selection. Potential environmental problems at individual sites were also evaluated separately from the point system. If such a problem might eventually cause the buyer to become a responsible party in a later cleanup action, the site would be eliminated from further consideration. Before purchasing or leasing any of these sites, an environmental property assessment is recommended.

After points were assigned for each site criterion, a weighting factor was applied to determine the final site ranking. For example, if a site scored 20 points for location close to the forest boundary, the 20 points were multiplied by the 15% weighting factor to give the site a total score of 300 for the site location criteria. The weighted scores for individual site criteria were added to arrive at the total weighted site score, presented in the Results section.

Results

The evaluation results for the 12 identified Front Range sites are listed in Table 11. The detailed evaluation/calculation for each site is included with the site questionnaire in the full report. As noted, three sites did not pass the go/no-go evaluation. The remaining nine remain potentially usable, pending re-evaluation as process and cost data improve. The Coors site scores highest, because of on-site availability of a steam supply. Determining whether there is enough available steam to meet the wood-to-ethanol facility requirements is not yet possible. The Gun Club/Jewell/E-470 site, which scores lowest, expects to add municipal water and wastewater utilities within the year. The site will then score in the mid-range. Table 12 shows the southern Colorado sites.

Table 11: Front Range Site Ratings

Site	Score
1. Weld County Landfill	960
2. Morrison Area	0
3. Elias Property @ Moore Rd.	1150
4. Idaho Springs	0
5. 120th and E-470	1200
6. Brighton, I-76 & Baseline	1225
7. Watkins Property	825
8. Gun Club/Jewell/E-470	735
9. Titan Road West of S. Santa Fe	1135
10. Stapleton Redevelopment	0
11. Coors	1675
12. I-25 & Erie Exit, Purevision	1350

Table 12: Southern Colorado Site Ratings

Site	Score
1. Steffens Choman Land	1025
2. Hot Creek	0
3. 448 Beck Place	0

Front Range Forest Health Partnership Challenges

The following challenges were identified by FRFHP members at the July 10 FRFHP meeting.

Forest Health Issues

- Securing a steady supply of wood materials from forested lands is difficult.
- Transportation costs are high (42 % of total costs) from forested areas to the Denver metropolitan area.
- Current USFS timber sale contract procedures do not lend themselves to stewardship and ecosystem restoration projects (although this is slowly changing).
- Harvesting/collection and material handling process costs remain high.
- Public land current contract procedures do not lend themselves to stewardship/ecosystem restoration
- Opposition to forest harvest and prescribed fire.
- Lack of public understanding for relationships between water quality, air quality, and forest health.

Urban/Wildland Interface Issues

- Many mountain home owners deny fire risks and do not take the necessary steps to thin vegetation around their homes.
- There are insufficient funds and incentives to selectively thin vegetation on public and private lands on a landscape level.
- Lack of political will at the local level to support wildfire mitigation efforts.

Urban Forests

- Competing uses for wood and variability of supply.
- The types of woods generated in an urban environment need to be identified because the ethanol technology for hardwoods may be different than the technology for softwoods.
- Urban areas do not have sufficient storage areas for wood.
- Local government budgets prohibit new hauling program development and manpower.

Ethanol

- Current lack of "market pull" for bioenergy.
- Changing and uncertain government roles, subsidies, and incentives.
- Lack of capital and investor confidence, need for new types of contractor arrangements and risk sharing.
- Forest feedstock supplier profit requirements and ethanol price realities do not match.

Recommendations for Future Work

FRFHP members have identified five major objectives to further the FRFHP's mission. These objectives are recommended for action after Phase I, and are ranked and discussed here.

1. **Conduct feasibility studies.** A follow-up study based on the results of Phase I should be initiated to gain technical information needed to overcome wood waste to ethanol barriers. Also, many technical, economic, and other assumptions have been made to perform the ethanol facility design and financial analyses. Additional work is needed to prove or disprove these assumptions and reduce the uncertainty of the results. The following suggestions are made for the FRFHP to consider:

   a. Distribute Phase I study results to interested stakeholders and potential equity players.

   b. The delivered feedstock price and supply are the most sensitive economic factors in the feasibility study. The FRFHP should seek opportunities for cost shared research on wood harvesting technology and securing commitments for steady wood supplies.

   c. Numerous engineering and design issues are unresolved. The FRFHP should pursue partnerships and funding for these activities.

   d. Investigate biomass green power energy.

   e. Investigate value added forest product opportunities.

   f. Collect additional economic pro-forma information.

   g. Evaluate other ethanol technologies.

2. **Identify equity partners.** FRFHP group members should collect information and find contacts who know potential equity partners. These people will be surveyed to identify their interest in a potential ethanol site.

3. **Collaborate with other groups that support the FRFHP mission statement (e.g., Red Zone, CTIA).** A list of groups in the Front Range area related to forest health, fire mitigation, water, and air alliances needs to be created, and information needs to be exchanged consistently.

4. **Support ecosystem sustainability pilot projects.** Obtaining the biomass is a complicated process that requires interagency partnerships and federal policy modifications. To promote large-scale forest health restoration thinning efforts, members of the FRFHP need to seek opportunities along the Front Range where pilot forest health restoration projects could be conducted during the short term. Tasks to complete this are:

   a. Identify costs for water yield, sedimentation, and hydrogeneration treatment.

   b. Compile economic benefits and identify monetary values, a budget, and priorities.

   c. Develop a proposal to be marketed to other stakeholders.

5. **Participate in public information and outreach activities.** Outreach activities are crucial to the development of the FRFHP. Some recommended activities are:

   a. Create a briefing paper package for local, state, and national groups, (congressional, environmental, economic).

   b. Create an overhead/slide presentation to be used by all FRFHP members

   c. Work to include other groups of interest in partnership efforts

   d. Send public relations materials to newspapers.

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APPENDIX A

DILUTE NITRIC ACID TECHNOLOGY PROCESS DESCRIPTION, FLOW DIAGRAMS, AND EQUIPMENT LIST

Dilute Nitric Acid Technology

The dilute nitric acid technology presented here has been developed during more than 20 years at the University of California's Forest Products Laboratory at Richmond, California, and is protected by several patents held by the University. In recent years, funding to further develop the process and prosecute the University's patents has been provided by HFTA, a corporation initiated by the inventors. The design and cost estimates presented here were prepared by NREL engineers in cooperation with HFTA and are preliminary. HFTA has exclusive rights to negotiate licenses for the technology. Interested parties should contact George Craig of HFTA at (510) 893-9657.

A simple process flow diagram for the HFTA dilute nitric acid process is shown in Figure A1. The detailed process flow diagrams that were used to develop the material and energy balance and the capital cost estimate for the process are available from NREL.

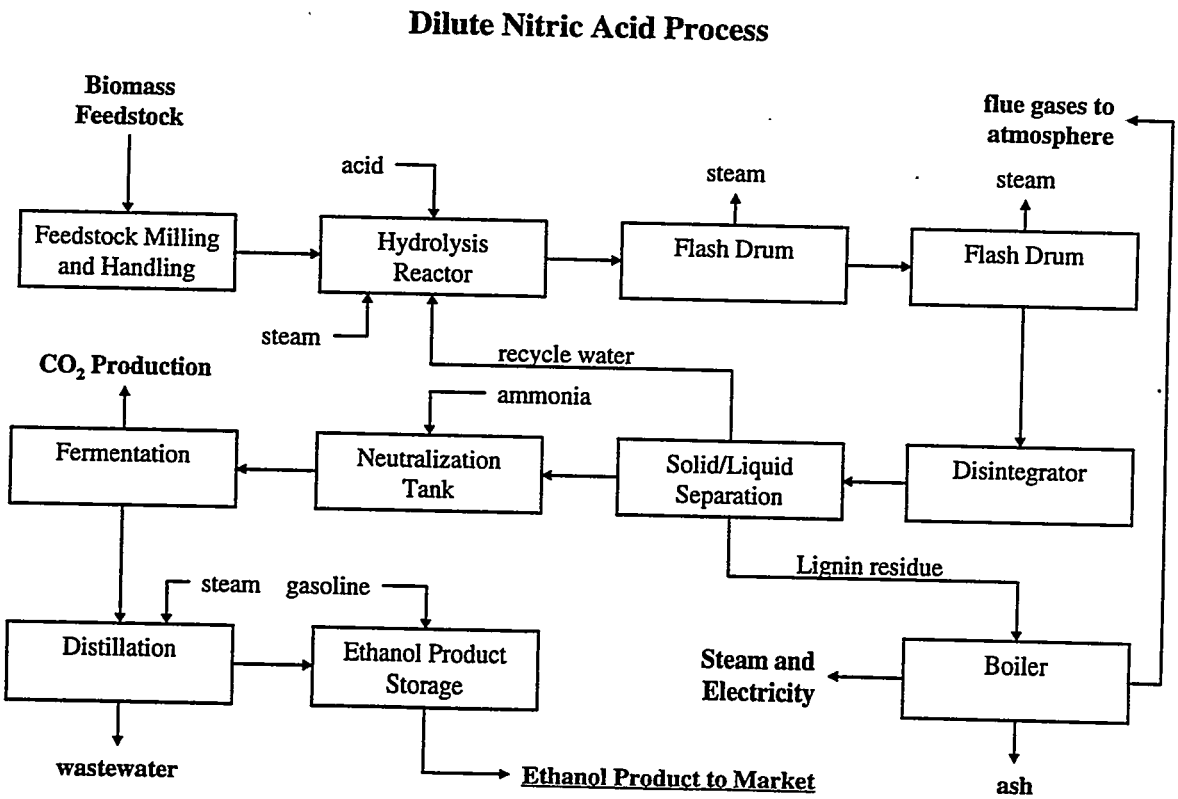

Figure A1 Dilute nitric acid process flow diagram

The hydrolysis of cellulose and hemicellulose is carried out in one stage. Wood chips are mixed with acid and fed to a hydrolysis reactor. All parts of the reactor (as well as other items of equipment in the flow diagram) that come in contact with the process stream are made of either 304 or 316 stainless steel, which are inert to dilute nitric acid at the process temperatures. A tub grinder has been eliminated based on HFTA's evaluation of wood chips obtained from the Quincy area.

The gross feed to the hydrolysis reactor is preimpregnated with dilute nitric acid and compressed into the reactor at about 33% suspended solids by a screw feeder. Enough steam is added to raise the temperature to 210°-220°C; the corresponding saturation pressure is 18–23 atm. In this temperature range, the hydrolysis of the hemicellulose to C_5 and C_6 sugars (primarily the latter) is very rapid. A large fraction (less than 85%) of the C_5 sugars (about 7.8% of the gross feed) will then be converted to furfural, its decomposition products, and water. After a residence time of the order of 5 minutes, about 75% of the cellulose in the solids will also be hydrolyzed. The yield of C_6 sugars is equivalent to about 50% of the glucan (cellulose plus hemicellulosic C_6 sugars); the remainder of the hydrolyzed C_6 sugars are converted to hydroxymethyl furfural, its degradation products, and water.

The hydrolyzed biomass leaves the reactor and is flashed in two (or possibly three) stages to atmospheric pressure. The steam released from the first flash shown, although at a relatively low pressure, is significantly more in energy content than will be required to distill the alcohol that will be formed by fermenting the C_6 sugars produced by the wood hydrolysis. If additional low-pressure steam can be used, optimization will determine the pressures of the flashes to be employed. Some soluble organic compounds, such as methanol and furfural, will be volatilized during the flash steps. The fractions of these materials that report in the vapor streams have not yet been estimated quantitatively, but their total is expected to be about 1-2 mol % in the vapor stream. This quantity would not prevent use of the vapor as steam for heating, but would place some constraints on the use of the condensate.

The chips leaving the reactor will retain much of their original shape but will have become very friable. During the flash steps there will be some disintegration of the chips into particles. The slurry leaving the second flash drum will be fed to a disintegrator as shown, to reduce the particle size and thereby improve sugar recovery in the centrifugal filter. Whether the disintegration caused by the flash steps will be sufficient to allow a high fraction of the sugar solution to be recovered from the solid material during the drainage and washing steps in the centrifugal filter is not yet known. If this is the case, the disintegrator shown on the flow diagram will not be needed.

The solids content of the slurry leaving the atmospheric-flash vessel is 11%-12 % by weight, and the C_6-sugar content of the solution is 12-14 wt %. The method of solid/liquid separation that will keep the sugar content of the solution at its maximum value is centrifugal filtration, with provision for two separate wash steps and separate collection of the wash liquid. An automated basket centrifuge has been specified for the solid/liquid separation equipment. Another option would be a pusher-type centrifuge. Laboratory filtration data indicates that about 95% of the solution entering the centrifugal filter can be recovered with minimal dilution. The remainder will be recycled and diluted with wash water to form the makeup water feed to the process.

The solids content of the cake solids leaving the centrifuge is 25%-33%. Because the solid particles, unlike wood fibers, have a relatively high settling velocity, the higher number is more probable. The solid content of the solids stream (after passing through a screw press or similar equipment), is specified to be about 50% and will serve as a boiler fuel.

The sugar stream and some of the wash water from the automated basket centrifuge is sent to the neutralization tank. Ammonia is added to neutralize the nitric acid and raise the pH to the fermentation pH (about 5.5).

The relatively solids-free sugar stream is cooled to 35°C and sent to the first fermenter. Total fermenter volume is set to provide 24-h fermentation time. This should be more than adequate for the relatively clean sugar stream; however, compounds that may be toxic or inhibitory to the yeast (*Saccharomyces cerevisiae*) could increase the required fermentation time. If inhibition is too great, the hydrolyzate would need to be detoxified. This step is not included in the present design. The need for detoxification needs to be determined through additional tests.

Ammonia, and if necessary nutrients such as corn steep liquor (CSL), are added to the fermenters along with recycled yeast recovered from the fermentation broth that leaves the last fermenter. We assume that CSL is not required. Overall ethanol yield in the fermenters is 85% of the six-carbon sugars entering the fermenters. No ethanol is produced from the five-carbon sugars. In the future, substituting a genetically engineered yeast or bacteria for the yeast to ferment the five- and six-carbon sugars may be possible.

The fermentation broth, also known as beer, is sent to the distillation/molecular sieve dehydration systems where the ethanol and water are separated. The ethanol distillation/dehydration technology is well developed and will not be described in detail here. The anhydrous ethanol is denatured with 5% gasoline and sent to storage. The water from the distillation column is sent to the process water tank for reuse. A 20% purge stream is sent to wastewater treatment.

A small amount of fusel oils (higher alcohols) will be produced as fermentation by-products. The fusel oils are removed from the rectification column (in the distillation area), decanted to remove water, and mixed with the ethanol going to the ethanol storage tank. The fusel oils add to the volume of product and, therefore, improve the process economics. Approximately 1% of the glucose going to the fermenters is assumed to be converted to fusel oil.

Fermentation also produces a large amount of CO_2, which is removed from the fermenters and washed with water to remove ethanol vapors. The wash water, which contains a small amount of ethanol, is sent to the distillation column for ethanol recovery. The amount of CO_2 produced is equal to about 90% by weight of the amount of ethanol produced.

Process Concerns and Recommendations

The dilute nitric acid process design presented here was prepared by NREL engineers in cooperation with HFTA and is preliminary. Time constraints did not allow detailed analysis of many design and process performance issues. Several assumptions made in the process design and performance need to be verified before a commercial facility is built. NREL recommends additional design investigations and test work be conducted to resolve the following issues.

Hydrolysis Sugar Yields

The projected hydrolysis sugar yields presented here are preliminary. Hydrolysis sugar yield is an important parameter that directly affects the ethanol yield and should be confirmed by bench- and pilot-scale tests.

Hydrolyzate Fermentability

The filtered hydrolyzate produced by the dilute nitric acid hydrolysis may be toxic to the fermentation yeast. The design and economic analysis presented here assumes that the hydrolyzate is not toxic and does not adversely affect the assumed fermentation time (24 h) or ethanol yield (85% of available six-carbon sugars).

Fermentation Ethanol Yield

Like the hydrolysis sugar yield, the fermentation ethanol yield directly affects the plant's ethanol production capacity and, therefore, the facility's profitability. The 85% overall fermentation yield used for the dilute nitric acid process needs to be confirmed at the bench and pilot scale. The yield is based on the amount of available six-carbon sugars entering the fermenters. This fermentation yield is assumed to be achievable without adding expensive nutrients such as CSL to the fermenters.

Fermenter Yeast Propagation

A small percentage of the glucose that enters the fermenters is converted to yeast cell mass; 2% has been assumed for this design. This decreases the ethanol yield and the 2% value needs to be confirmed. If yeast production is relatively high, removing the excess and selling it as animal feed may be possible. This has a relatively high value.

The design also assumes that a yeast seed train is not needed to provide fresh yeast to the fermenters. This is a fairly safe assumption for the fermentation considered here, but needs to be confirmed by continuous bench- or pilot-scale fermentation tests.

Facility Thermal Design

The overall plant thermal design and energy use for the process presented has not been optimized. A chilled water system is presumably required to maintain the fermenter temperature at 32°–35°C. Maintaining the fermenter temperature with the cooling water system (cooling tower) only may be possible. This could result in significant capital and operating cost savings. Thermal optimization of the facility design is recommended when conducting follow-on engineering work.

Lignin/Cellulose Residuals

The lignin/cellulose residuals removed by the centrifuge following hydrolysis are assumed to be sold for boiler fuel. Representative residue samples need to be produced for characterization tests (composition and heating value). Larger quantities of residue need to be produced for test burns to determine whether this fuel would cause boiler fouling or problems with boiler emissions or ash characteristics (hazardous waste).

Water Recycle

The amount of process water recycle that is feasible needs to be determined. Buildup of by-products in the recycle water could adversely affect the fermentation time and ethanol yield. An 80% recycle rate has been assumed for the design presented here. If the amount of recycle water is reduced, additional makeup water will be required. The impact on overall costs and economics should not be significant.

APPENDIX B

COORS SITE
MANUFACTURING COST SUMMARY REPORT

PROFORMA SYSTEMS

Biofuels Economic Assessment Model

Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Manufacturing Cost Summary Report

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Manufacturing Cost Summary Report for the Front Range Forest Health Partnership
Ethanol Manufacturing Feasibility Study

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Key Economic Assumptions	
Plant location	Colorado
Plant life, years	20
Plant start up	1997
Reference year	1997
Plant construction cost index	CE
Index value for reference date	385
Hurdle Rate / Internal Rate of Return	35.0%
Net present worth at end of project life	$0
Inflation rate	3.00%
Federal income tax rate	34.00%
State income tax rate	5.00%
Combined federal and state income tax rate	37.30%
Owner equity financing	25%
Effective loan rate	10.0%
Annuitized loan payment	$4,017,000

Plant nameplate product capacity	14,800,000	gallons per year
Plant nameplate feedstock capacity	300,000	BDT per year
	870	BDT per day
Facility Capital Cost		
Fixed capital investment	$31,109,000	
Working capital investment	$2,496,000	
Total capital investment	$33,606,000	
Facility installed cost	$2.27	per annual gallon
Assumed fuel ethanol selling price	$1.20	per gallon
Assumed feedstock cost	$15.00	per BDT
Ethanol yield per BDT feedstock	49.5	gallon per BDT
Facility electrical power requirement	2.67	MW

Notes: (1) BDT = bone-dry short ton (2,000 lbs.)

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Production cost in 1997 dollars for year 5, 2001 — Manufacturing capacity: 100%

			$ per year	$ per lb	$ per gallon
1		Raw materials cost	$5,468,000	$0.056	$0.369
2		Processing materials cost	$14,000	$0.000	$0.001
3		Utilities cost	$3,398,000	$0.035	$0.230
4		Coproduct credit	-$3,800,000	-$0.039	-$0.257
5	5=1+2+3+4	Variable cost	$5,080,000	$0.052	$0.343
6		Operating labor	$1,273,000	$0.013	$0.086
7		Labor related cost	$414,000	$0.004	$0.028
8		Investment related cost	$1,129,000	$0.012	$0.076
9		Plant overhead cost	$575,000	$0.006	$0.039
10	10=6+7+8+9	Fixed cost	$3,391,000	$0.035	$0.229
11	11=5+10	Plant gate cost, (variable + fixed costs)	$8,471,000	$0.087	$0.572
12		Sales related cost	$248,000	$0.003	$0.017
13	13=11+12	Full cash cost of production	$8,719,000	$0.089	$0.589
14		Net financing cost	$1,097,000	$0.011	$0.074
15		Capital depreciation cost	$1,555,000	$0.016	$0.105
16	16=13+14+15	Net production cost	$11,371,000	$0.116	$0.768

Plant System 1	Material receiving	$5,005,000	$0.051	$0.338
Plant System 2	Material shipping	$190,000	$0.002	$0.013
Plant System 11	Raw Material Preparation	$95,000	$0.001	$0.006
Plant System 12	Dilute acid pretreatment	$4,119,000	$0.042	$0.278
Plant System 13	Concentrated acid pretreatment			
Plant System 29	Fermentation	$1,234,000	$0.013	$0.083
Plant System 35	Cell-recycle	$693,000	$0.007	$0.047
Plant System 37	Stripping/rectifying distillation	$632,000	$0.006	$0.043
Plant System 39	Molecular sieve dehydration	$628,000	$0.006	$0.042
Plant System 40	Residual process solids recovery and recycle water	-$1,314,000	-$0.013	-$0.089
		$11,282,000	$0.115	$0.762

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Products	cost/unit [$/lb]	item/product [lb/lb]	[lb/gallon]	amount [ton/yr]	credit/cost [$/yr]	per unit of product [$/gallon]
fuel product	$0.1823	1.000	0.152	48,851	**$17,808,000**	**$1.200**
					$17,808,000	**$1.200**
Coproducts						
amounts shown are in green tons						
yeast cell mass	$0.125	0.008	0.024	398	**$100,000**	**$0.007**
carbon dioxide	$0.020	0.920	2.747	44,959	**$1,798,000**	**$0.121**
lignin/cellulose residue	$0.004	5.191	15.497	253,589	**$1,902,000**	**$0.129**
					$3,800,000	**$0.257**
Raw Materials						
amounts shown are in green tons						
Urban Green Waste	$0.004	4.094	12.222	199,998	**$1,497,000**	**$0.101**
Ponderosa pine	$0.004	8.188	24.444	400,002	**$2,994,000**	**$0.202**
nitric acid	$0.081	0.060	0.180	2,418	**$476,000**	**$0.032**
ammonia, anhydrous	$0.091	0.006	0.019	312	**$57,000**	**$0.004**
denaturant	$0.091	0.050	0.149	2,443	**$445,000**	**$0.030**
					$5,468,000	**$0.056**
Processing Materials						
zeolite	$4.001	0.000	0.000	2	**$14,000**	**$0.001**
					$14,000	**$0.000**
Utilities	[$/unit listed]	[lb/lb]	[unit/k-gallon]	[unit/yr]	[$/yr]	[$/gallon]
electricity, per kW-hr	$0.050	0.24 kW-hr/lb	1564.254	23,150,953	**$1,158,000**	**$0.078**
water: process, per 1000-gal	$0.308	1.274	1.009	14,926	**$5,000**	**$0.000**
water: boiler feed, per 1000-gal	$2.591	4.859	3.846	56,923	**$148,000**	**$0.010**
water: cooling tower, per 1000-gal	$0.094	120.599	95.460	1,412,814	**$132,000**	**$0.009**
water: chilled, per 1000-gal	$5.485	1.464	1.159	17,146	**$94,000**	**$0.006**
steam: low pressure, 3.5 atm, per 1000-lb	$1.000	2.637	17.407	257,619	**$257,615**	**$0.017**
steam: high pressure, 40 atm, per 1000-lb	$3.000	4.859	32.077	474,741	**$1,424,000**	**$0.096**
wastewater treatment: secondary, per 1000-gal	$2.989	4.402	3.485	51,571	**$154,000**	**$0.010**
wastewater recovery, per 1000-gal	$0.000	0.000	0.000	0	**$0**	**$0.000**
diesel fuel, per gal	$1.200	0.001	1.491	22,073	**$26,000**	**$0.002**
					$3,398,000	**$0.035**

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Labor and other Factored costs

		annual salary	$ per year	$ per lb	$ per gallon
1 Operations supervisors per day		$56,160	$62,619	$0.001	$0.004
3 Shift supervisors per day		$45,760	$213,646	$0.002	$0.014
6 Operators per day		$31,200	$291,336	$0.003	$0.020
2 Technicians per day		$31,200	$70,631	$0.001	$0.005
6 Non-skilled laborers per day		$19,968	$186,455	$0.002	$0.013
2 Maintenance personnel per day		$43,680	$136,637	$0.001	$0.009
0 Maintenance supervisors per day		$56,160	$0	$0.000	$0.000
1 Plant manager per day		$70,720	$70,720	$0.001	$0.005
1 Plant engineer per day		$56,160	$60,312	$0.001	$0.004
1 Chemist/microbiologist per day		$43,680	$46,486	$0.000	$0.003
1 Feedstock buyer per day		$43,680	$46,486	$0.000	$0.003
1 Shipping/receiving personnel per day		$31,200	$33,205	$0.000	$0.002
1 Payroll/HR/accounting personnel per day		$31,200	$33,205	$0.000	$0.002
1 Administrative personnel per day		$19,968	$21,251	$0.000	$0.001
		Total direct labor	$1,272,990	$0.013	$0.086
Payroll overhead	32.50%	of operating labor	$413,722	$0.004	$0.028
Laboratory charges	1.50%	of operating labor	$19,095	$0.000	$0.001
		Total labor related cost	$432,816	$0.004	$0.029
Maintenance	2.00%	of plant cost	$593,992	$0.006	$0.040
Operating supplies	0.25%	of plant cost	$74,249	$0.001	$0.005
Environmental permitting	0.05%	of plant cost	$14,850	$0.000	$0.001
Local taxes	1.00%	of plant cost	$296,996	$0.003	$0.020
Insurance	0.50%	of plant cost	$148,498	$0.002	$0.010
		Total investment related cost	$1,128,584	$0.012	$0.076
Overhead cost	25.00%	of labor and maintenance cost	$574,949	$0.006	$0.039
Running royalties and patents	0.50%	of annual sales	$108,038	$0.001	$0.007
Distribution and sales	0.50%	of annual sales	$108,038	$0.001	$0.007
Research and development	0.150%	of annual sales	$32,411	$0.000	$0.002
		Total sales related cost	$248,486	$0.003	$0.017

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Equipment Cost

Purchased equipment cost	$11,477,000	100.00%
Shipping cost	$364,000	3.17%
Foundations cost	$353,000	3.08%
Insulation cost	$144,000	1.25%
Painting cost	$180,000	1.57%
Piping cost	$2,213,000	19.28%
Electrical cost	$539,000	4.70%
Instrumentation cost	$1,060,000	9.24%
Spare parts cost	$219,000	1.91%
ISBL utility cost	$0	0.00%
Equipment erection and installation cost	$2,095,000	18.25%
Total purchased equipment installed	$18,644,000	162.45%

"Lang" factor (fixed capital investment / purchased equipment cost): 2.70

Capital Investment

Purchased equipment installed	$18,644,000	60.20%
Engineering and design	$2,823,000	9.12%
Land	$0	0.00%
Yard improvements	$70,000	0.23%
Construction	$1,410,000	4.55%
Contractors fee	$846,000	2.73%
Contingency	$3,111,000	10.05%
OSBL utilities and service facilities	$1,851,000	5.98%
Buildings	$240,000	0.77%
Start up costs	$1,410,000	4.55%
Licensing fees	$0	0.00%
Environmental Permitting Fees	$281,960	0.91%
Warehouse Equipment Spares	$281,960	0.91%
Total fixed capital investment	$30,968,921	100.00%
Working capital investment	$2,496,000	
Total capital investment	$33,464,921	

OSBL utilities and service facilities cost breakdown

Package boiler, gas or oil fired	$0
Boiler water treatment	$0
Steam distribution systems	$180,000
Cooling water systems	$113,000
Chilled water system	$424,000
Process water clarification	$42,000
Drinking and service water systems	$42,000
Electrical substations and distribution systems	$795,000
Plant air systems	$32,000
Instrumentation air systems	$42,000
Conventional wastewater treatment	$70,000
Mechanical vapor recompression wastewater recovery	$0
Fire protection systems	$81,000
Building services - HVAC	$30,000
Yard lighting and communications	$0
Fences and gatehouse	$0
Railroad sidings	$0
	$1,851,000

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

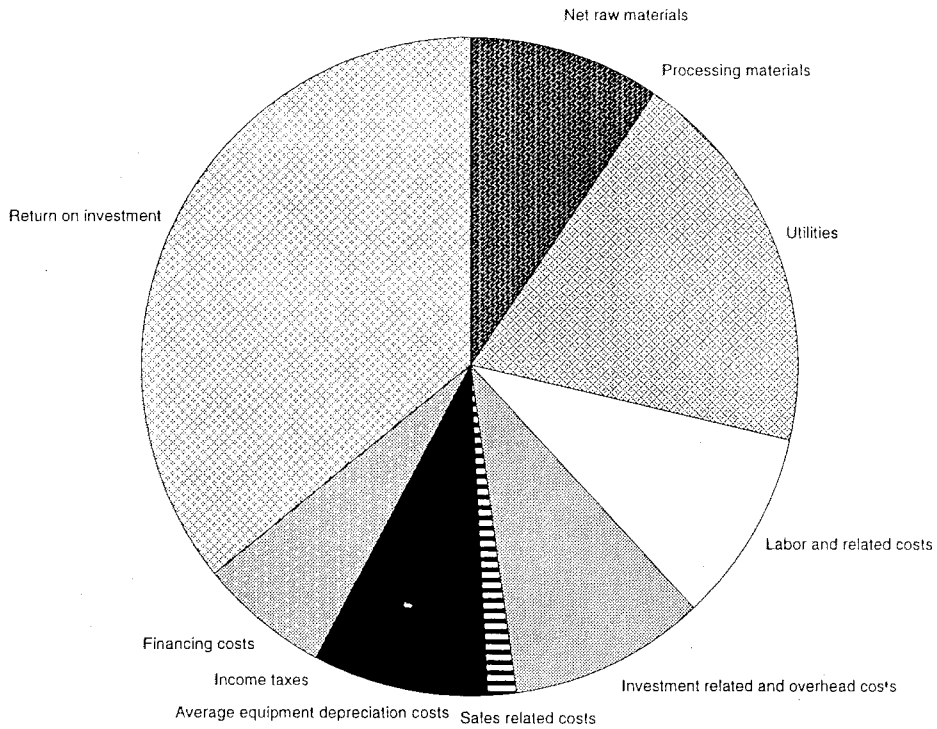
Equipment Cost Summary (Inside Battery Limits)

			Purchased	Installation Factor	Installed
Plant System 1	Material receiving		$513,000	1.68	$862,000
Plant System 2	Material shipping		$248,000	1.87	$464,000
Plant System 11	Raw Material Preparation		$93,000	1.89	$175,000
Plant System 12	Dilute acid pretreatment		$4,284,000	1.59	$6,825,000
Plant System 13	Concentrated acid pretreatment				
Plant System 29	Fermentation		$1,618,000	1.53	$2,475,000
Plant System 35	Cell-recycle		$899,000	2.14	$1,921,000
Plant System 37	Stripping/rectifying distillation		$2,863,000	1.55	$4,444,000
Plant System 39	Molecular sieve dehydration		$786,000	1.49	$1,171,000
Plant System 40	Residual process solids recovery and recycle water		$173,000	1.78	$307,000
		Total Plant	$11,477,000	1.62	$18,644,000
Equipment Class 1	Agitators	10	$857,000	1.68	$1,439,000
Equipment Class 2	Blowers	2	$209,000	1.53	$319,000
Equipment Class 3	Bins	1	$15,000	1.93	$29,000
Equipment Class 4	Centrifuges	2	$982,000	2.13	$2,096,000
Equipment Class 5	Columns	5	$765,000	1.73	$1,320,000
Equipment Class 6	Compressors	0			
Equipment Class 7	Column Trays	69	$186,000	1.00	$186,000
Equipment Class 8	Conveyors	6	$182,000	1.90	$346,000
Equipment Class 9	Dryers	0			
Equipment Class 10	Ejectors	1	$107,000	1.52	$163,000
Equipment Class 11	Evaporators	0			
Equipment Class 12	Filters	0			
Equipment Class 13	Fermentors	4	$1,283,000	1.57	$2,009,000
Equipment Class 14	Heat Exchangers	14	$2,022,000	1.50	$3,026,000
Equipment Class 15	Magnetic Cleaners	1	$10,000	1.90	$19,000
Equipment Class 16	Mills	1	$282,000	1.90	$535,000
Equipment Class 17	Mixers	2	$5,000	1.40	$7,000
Equipment Class 18	Processing Material	2	$105,000	1.09	$114,000
Equipment Class 19	Pumps	41	$621,000	1.58	$979,000
Equipment Class 20	Presses	1	$157,000	1.89	$297,000
Equipment Class 21	Reactors	1	$2,628,000	1.49	$3,915,000
Equipment Class 22	Screens	0			
Equipment Class 23	Transportation Equipment	1	$120,000	1.30	$156,000
Equipment Class 24	Tanks	23	$783,000	1.77	$1,388,000
Equipment Class 25	Weigh Scales	2	$160,000	1.89	$303,000
		Total Plant	$11,479,000	1.62	$18,646,000

Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

Product Cost Contributions

Item	#	% of Selling Price	$ per gallon
Net raw materials	1	9.4%	$0.1127
Processing materials	2	0.1%	$0.0009
Utilities	3	19.1%	$0.2296
Labor and related costs	4	9.5%	$0.1140
Investment related and overhead costs	5	9.6%	$0.1151
Sales related costs	6	1.4%	$0.0168
Average depreciation	7	8.8%	$0.1051
Income taxes	8	0.0%	$0.0001
Financing costs	9	6.2%	$0.0741
Return on investment	10	36.0%	$0.4316
		100.0%	$1.2000



Case Study: Single-Stage Dilute Nitric Acid Hydrolysis, Coors site

APPENDIX C

LAS ANIMAS SITE
MANUFACTURING COST SUMMARY REPORT

ProForma Systems

Biofuels Economic Assessment Model

Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Manufacturing Cost Summary Report

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Manufacturing Cost Summary Report for the Front Range Forest Health Partnership
Ethanol Manufacturing Feasibility Study

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Key Economic Assumptions

Plant location	Colorado
Plant life, years	20
Plant start up	1997
Reference year	1997
Plant construction cost index	CE
Index value for reference date	385
Hurdle Rate / Internal Rate of Return	7.6%
Net present worth at end of project life	$0
Inflation rate	3.00%
Federal income tax rate	34.00%
State income tax rate	5.00%
Combined federal and state income tax rate	37.30%
Owner equity financing	25%
Effective loan rate	10.0%
Annuitized loan payment	$5,832,000

Plant nameplate product capacity	14,800,000	gallons per year
Plant nameplate feedstock capacity	300,000	BDT per year
	870	BDT per day

Facility Capital Cost

Fixed capital investment	$46,404,000
Working capital investment	$2,410,000
Total capital investment	$48,814,000

Facility installed cost	$3.30	per annual gallon
Assumed fuel ethanol selling price	$1.20	per gallon
Assumed feedstock cost	$15.00	per BDT
Ethanol yield per BDT feedstock	49.5	gallon per BDT
Facility electrical power requirement	3.56	MW

Notes: (1) BDT = bone-dry short ton (2,000 lbs.)

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Production cost in 1997 dollars for year 5, 2001

Manufacturing capacity: 100%

			$ per year	$ per lb	$ per gallon
1		Raw materials cost	$5,468,000	$0.056	$0.369
2		Processing materials cost	$14,000	$0.000	$0.001
3		Utilities cost	$3,523,000	$0.036	$0.238
4		Coproduct credit	-$2,001,000	-$0.020	-$0.135
5	5=1+2+3+4	Variable cost	$7,004,000	$0.072	$0.473
6		Operating labor	$1,936,000	$0.020	$0.131
7		Labor related cost	$629,000	$0.006	$0.043
8		Investment related cost	$1,684,000	$0.017	$0.114
9		Plant overhead cost	$870,000	$0.009	$0.059
10	10=6+7+8+9	Fixed cost	$5,119,000	$0.052	$0.346
11	11=5+10	Plant gate cost, (variable + fixed costs)	$12,123,000	$0.124	$0.819
12		Sales related cost	$228,000	$0.002	$0.015
13	13=11+12	Full cash cost of production	$12,351,000	$0.126	$0.835
14		Net financing cost	$1,592,000	$0.016	$0.108
15		Capital depreciation cost	$2,314,000	$0.024	$0.156
16	16=13+14+15	Net production cost	$16,257,000	$0.166	$1.098
	Plant System 1	Material receiving	$5,160,000	$0.053	$0.349
	Plant System 2	Material shipping	$276,000	$0.003	$0.019
	Plant System 11	Raw Material Preparation	$128,000	$0.001	$0.009
	Plant System 12	Dilute acid pretreatment	$5,394,000	$0.055	$0.364
	Plant System 13	Concentrated acid pretreatment	$1,697,000	$0.017	$0.115
	Plant System 29	Fermentation	$1,053,000	$0.011	$0.071
	Plant System 35	Cell-recycle	$2,957,000	$0.030	$0.200
	Plant System 37	Stripping/rectifying distillation	$847,000	$0.009	$0.057
	Plant System 39	Molecular sieve dehydration	-$1,255,000	-$0.013	-$0.085
	Plant System 40	Residual process solids recovery and recycle water	$16,257,000	$0.166	$1.098

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Products

	cost/unit [$/lb]	item/product [lb/lb]	[lb/gallon]	amount [ton/yr]	credit/cost [$/yr]	per unit of product [$/gallon]
fuel product	$0.1823	1.000	0.152	48,851	$17,808,000	$1.200
					$17,808,000	$1.200

Coproducts

amounts shown are in green tons

yeast cell mass	$0.125	0.008	0.024	398	$100,000	$0.007
carbon dioxide		0.920	2.747	44,959		
lignin/cellulose residue	$0.004	5.191	15.497	253,589	$1,902,000	$0.129
					$2,001,000	$0.135

Raw Materials

amounts shown are in green tons

Urban Green Waste	$0.004	4.094	12.222	199,998	$1,497,000	$0.101
Ponderosa pine	$0.004	8.188	24.444	400,002	$2,994,000	$0.202
nitric acid	$0.081	0.060	0.180	2,418	$476,000	$0.032
ammonia, anhydrous	$0.091	0.006	0.019	312	$57,000	$0.004
denaturant	$0.091	0.050	0.149	2,443	$445,000	$0.030
					$5,468,000	$0.056

Processing Materials

zeolite	$4.001	0.000	0.000	2	$14,000	$0.001
					$14,000	$0.000

Utilities

	[$/unit listed]	[lb/lb]	[unit/k-gallon]	[unit/yr]	[$/yr]	[$/gallon]
electricity, per kW-hr	$0.050	0.32 kW-hr/lb	2085.671	30,867,938	$1,543,000	$0.104
water: process, per 1000-gal	$0.308	1.274	1.009	14,926	$5,000	$0.000
water: boiler feed, per 1000-gal			0.536	7,931		
water: cooling tower, per 1000-gal	$0.094	120.599	95.460	1,412,814	$132,000	$0.009
water: chilled, per 1000-gal	$5.485	1.464	1.159	17,146	$94,000	$0.006
steam: low pressure, 3.5 atm, per 1000-lb	$1.000	2.637	17.407	257,619	$257,615	$0.017
steam: high pressure, 40 atm, per 1000-lb	$3.000	4.859	32.077	474,741	$1,424,000	$0.096
wastewater treatment: secondary, per 1000-gal		0.000	0.000	0		
wastewater recovery, per 1000-gal	$0.000	4.402	3.485	51,571	$0	$0.000
diesel fuel, per gal	$1.200	0.001	1.491	22,073	$26,000	$0.002
					$3,523,000	$0.036

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Labor and other Factored costs

		annual salary	$ per year	$ per lb	$ per gallon
1 Operations supervisors per day		$56,160	$62,619	$0.001	$0.004
3 Shift supervisors per day		$45,760	$213,646	$0.002	$0.014
9 Operators per day		$31,200	$437,004	$0.004	$0.030
3 Technicians per day		$31,200	$105,420	$0.001	$0.007
9 Non-skilled laborers per day		$19,968	$279,683	$0.003	$0.019
6 Maintenance personnel per day		$43,680	$407,870	$0.004	$0.028
1 Maintenance supervisors per day		$56,160	$62,619	$0.001	$0.004
1 Plant manager per day		$70,720	$70,720	$0.001	$0.005
1 Plant engineer per day		$56,160	$59,768	$0.001	$0.004
1 Chemist/microbiologist per day		$43,680	$46,486	$0.000	$0.003
1 Feedstock buyer per day		$43,680	$46,486	$0.000	$0.003
1 Shipping/receiving personnel per day		$31,200	$33,205	$0.000	$0.002
2 Payroll/HR/accounting personnel per day		$31,200	$67,415	$0.001	$0.005
2 Administrative personnel per day		$19,968	$43,146	$0.000	$0.003
		Total direct labor	$1,936,089	$0.020	$0.131
Payroll overhead	32.50% of operating labor		$629,229	$0.006	$0.043
Laboratory charges	1.50% of operating labor		$29,041	$0.000	$0.002
		Total labor related cost	$658,270	$0.007	$0.044
Maintenance	2.00% of plant cost		$886,126	$0.009	$0.060
Operating supplies	0.25% of plant cost		$110,766	$0.001	$0.007
Environmental permitting	0.05% of plant cost		$22,153	$0.000	$0.001
Local taxes	1.00% of plant cost		$443,063	$0.005	$0.030
Insurance	0.50% of plant cost		$221,532	$0.002	$0.015
		Total investment related cost	$1,683,640	$0.017	$0.114
Overhead cost	25.00% of labor and maintenance cost		$870,121	$0.009	$0.059
Running royalties and patents	0.50% of annual sales		$99,046	$0.001	$0.007
Distribution and sales	0.50% of annual sales		$99,046	$0.001	$0.007
Research and development	0.150% of annual sales		$29,714	$0.000	$0.002
		Total sales related cost	$227,805	$0.002	$0.015

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Equipment Cost

Purchased equipment cost	$11,477,000	100.00%
Shipping cost	$364,000	3.17%
Foundations cost	$353,000	3.08%
Insulation cost	$144,000	1.25%
Painting cost	$180,000	1.57%
Piping cost	$2,213,000	19.28%
Electrical cost	$539,000	4.70%
Instrumentation cost	$1,060,000	9.24%
Spare parts cost	$219,000	1.91%
ISBL utility cost	$0	0.00%
Equipment erection and installation cost	$2,095,000	18.25%
Total purchased equipment installed	$18,644,000	162.45%

"Lang" factor (fixed capital investment / purchased equipment cost): 4.03

Capital Investment

Purchased equipment installed	$18,644,000	40.36%
Engineering and design	$2,823,000	6.11%
Land	$120,000	0.26%
Yard improvements	$839,000	1.82%
Construction	$2,098,000	4.54%
Contractors fee	$1,259,000	2.73%
Contingency	$4,640,000	10.04%
OSBL utilities and service facilities	$10,765,000	23.30%
Buildings	$1,860,000	4.03%
Start up costs	$2,098,000	4.54%
Licensing fees	$0	0.00%
Environmental Permitting Fees	$839,231	1.82%
Warehouse Equipment Spares	$209,808	0.45%
Total fixed capital investment	$46,195,038	100.00%
Working capital investment	$2,410,000	
Total capital investment	$48,605,038	

OSBL utilities and service facilities cost breakdown

Package boiler, gas or oil fired	$1,797,000
Boiler water treatment	$32,000
Steam distribution systems	$449,000
Cooling water systems	$565,000
Chilled water system	$424,000
Process water clarification	$424,000
Drinking and service water systems	$424,000
Electrical substations and distribution systems	$2,120,000
Plant air systems	$159,000
Instrumentation air systems	$212,000
Conventional wastewater treatment	$0
Mechanical vapor recompression wastewater recovery	$2,478,000
Fire protection systems	$806,000
Building services - HVAC	$376,000
Yard lighting and communications	$122,000
Fences and gatehouse	$214,000
Railroad sidings	$162,000
	$10,764,000

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

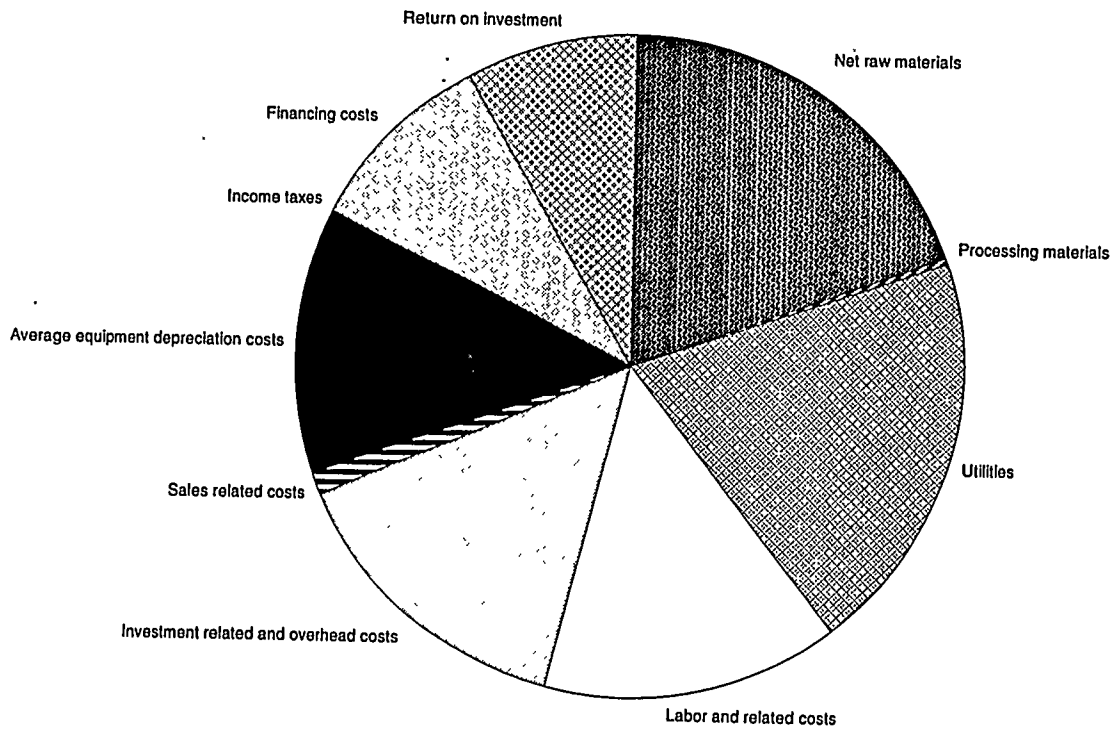
Equipment Cost Summary (Inside Battery Limits)

			Purchased	Installation Factor	Installed
Plant System 1	Material receiving		$513,000	1.68	$862,000
Plant System 2	Material shipping		$248,000	1.87	$464,000
Plant System 11	Raw Material Preparation		$93,000	1.89	$175,000
Plant System 12	Dilute acid pretreatment		$4,284,000	1.59	$6,825,000
Plant System 13	Concentrated acid pretreatment				
Plant System 29	Fermentation		$1,618,000	1.53	$2,475,000
Plant System 35	Cell-recycle		$899,000	2.14	$1,921,000
Plant System 37	Stripping/rectifying distillation		$2,863,000	1.55	$4,444,000
Plant System 39	Molecular sieve dehydration		$786,000	1.49	$1,171,000
Plant System 40	Residual process solids recovery and recycle water		$173,000	1.78	$307,000
		Total Plant	$11,477,000	1.62	$18,644,000
Equipment Class 1	Agitators	10	$857,000	1.68	$1,439,000
Equipment Class 2	Blowers	2	$209,000	1.53	$319,000
Equipment Class 3	Bins	1	$15,000	1.93	$29,000
Equipment Class 4	Centrifuges	2	$982,000	2.13	$2,096,000
Equipment Class 5	Columns	5	$765,000	1.73	$1,320,000
Equipment Class 6	Compressors	0			
Equipment Class 7	Column Trays	69	$186,000	1.00	$186,000
Equipment Class 8	Conveyors	6	$182,000	1.90	$346,000
Equipment Class 9	Dryers	0			
Equipment Class 10	Ejectors	1	$107,000	1.52	$163,000
Equipment Class 11	Evaporators	0			
Equipment Class 12	Filters	0			
Equipment Class 13	Fermentors	4	$1,283,000	1.57	$2,009,000
Equipment Class 14	Heat Exchangers	14	$2,022,000	1.50	$3,026,000
Equipment Class 15	Magnetic Cleaners	1	$10,000	1.90	$19,000
Equipment Class 16	Mills	1	$282,000	1.90	$535,000
Equipment Class 17	Mixers	2	$5,000	1.40	$7,000
Equipment Class 18	Processing Material	2	$105,000	1.09	$114,000
Equipment Class 19	Pumps	41	$621,000	1.58	$979,000
Equipment Class 20	Presses	1	$157,000	1.89	$297,000
Equipment Class 21	Reactors	1	$2,628,000	1.49	$3,915,000
Equipment Class 22	Screens	0			
Equipment Class 23	Transportation Equipment	1	$120,000	1.30	$156,000
Equipment Class 24	Tanks	23	$783,000	1.77	$1,388,000
Equipment Class 25	Weigh Scales	2	$160,000	1.89	$303,000
		Total Plant	$11,479,000	1.62	$18,646,000

Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

Product Cost Contributions

Item	#	% of Selling Price	$ per gallon
Net raw materials	1	19.5%	$0.2343
Processing materials	2	0.1%	$0.0009
Utilities	3	19.8%	$0.2380
Labor and related costs	4	14.4%	$0.1733
Investment related and overhead costs	5	14.4%	$0.1726
Sales related costs	6	1.3%	$0.0154
Average depreciation	7	13.0%	$0.1564
Income taxes	8	0.0%	$0.0000
Financing costs	9	9.0%	$0.1076
Return on investment	10	8.5%	$0.1016
		100.0%	$1.2000



Case Study: Single-Stage Dilute Nitricc Acid Hydrolysis, Las Animas site

APPENDIX D

Colorado Front Range Wood Resource Assessment

Acknowledgments

This report was prepared for the Front Range Forest Health Partnership with funding provided by the US Forest Service. Ms. Paula Volkin, Project Manager, was responsible for establishing timetables and coordinating resources. Her assistance and leadership helped to ensure a quality product.

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Mr. Chuck Dennis of the Colorado State Forest Service was an initial reviewer of select forest data. His input was important to confirm that certain assumptions and results reflected a plausible account of reality. Mr. John Edwards at Wood Recovery Systems allowed the authors to tour his recycling facility and he provided considerable information on present wood markets in the Denver metropolitan area. He also provided assistance on transportation of biomass.

Ms. Barbara Charnes, Executive Director of Coloradans for Clean Air, helped to secure funding for the study. She has been an active supporter of clean energy technologies and fuels and is a founding member of the Front Range Forest Health Partnership. We have enjoyed working with her and look forward to future collaborative efforts.

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At NEOS Corporation, Jack Whittier and Scott Haase were responsible for collecting and analyzing data and writing the final report. Ms. Pam Jensen, a cooperative student from the University of Colorado, Denver, was responsible for making hundreds of telephone calls to obtain information. Her tireless efforts to secure current data helped ensure that the information reported in this document is the most current and accurate available. She is to be commended for her fine effort.

Despite the best efforts of the authors, mistakes may still remain in the report. We would appreciate your contacting us should you desire further information or if certain information needs to be corrected or clarified.

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EXECUTIVE SUMMARY

This report provides an initial inventory of woody biomass resources located along the Colorado Front Range. The resource base includes wood that may be obtained from forest thinning operations designed to improve forest health as well as wood available from urban sources. The purpose of the resource analysis was to document available quantities, prices, and current uses for biomass resources. The resource information is to be used for input to a siting analysis for a potential ethanol facility.

FOREST RESOURCES

The "Red Zone" map produced by the US Forest Service serves to identify geographic locations along the Front Range that are at risk to forest fires. The Red Zone map identifies areas that are at three levels of risk (high, medium and low) to forest fires. Table S-1 shows the acreage, by county, for the high and medium risk areas, and the state and private lands. There is a total of 1.6 million acres that could potentially be treated under a forest health restoration program.

Table S-1. Forest Acreage by County and Risk Class

County	High Risk w/Buffer	Medium Risk w/Buffer	State & Private	Total	% of Total Biomass
Boulder	59,004	15,843	28,600	103,447	6%
Chaffee			5,300	5,300	0%
Clear Creek	11,509	20,754	35,000	67,263	4%
Custer	8,156	26,115	21,300	55,571	3%
Douglas	5,406	32,853	21,200	59,459	4%
El Paso	6,994	1,576	92,400	100,970	6%
Fremont	416	2,767	79,500	82,683	5%
Gilpin	14,580	10,847	19,300	44,727	3%
Grand			70,400	70,400	4%
Huerfano	7,226	6,220	92,300	105,746	6%
Jefferson	9,492	30,470	98,000	137,962	8%
Lake			21,000	21,000	1%
Larimer	59,913	42,108	167,600	269,621	16%
Las Animas	23		250,900	250,923	15%
Park	21,151	41,743	53,000	115,894	7%
Pueblo	7,845	208	24,200	32,253	2%
Saguach			47,100	47,100	3%
Teller	19,716	22,955	72,700	115,371	7%
TOTAL	**231,431**	**254,459**	**1,199,800**	**1,685,690**	
Percent	**14%**	**15%**	**71%**		

For the Red Zone map, risk is defined to address the probability of catastrophic disturbance events as a result of the combination of disturbance regime and housing density. Short interval (high) or medium interval (medium) disturbance regimes, when combined with high or medium housing density, result in a probability factor of high risk. Short or medium interval disturbance regimes with low housing density result in medium probability, as do high and medium housing density with long interval (low) disturbance. Low disturbance and low housing result in a low probability factor. Further, the Forest Service established buffer zones of two miles around the high risk zones.

The forest resource assessment performed under this effort is an initial estimate of the biomass resources contained within the Red Zone map's high and medium risk areas, including a two mile buffer around each zone. This effort entailed using vastly different data sets and attempting to reconcile differing assumptions.

Resource data for national forests and state and private forests are reported for three species (Ponderosa Pine, Lodgepole Pine, and Douglas Fir), by county for lands that are suitable for commercial harvest for sawtimber and poletimber classifications. The Colorado Front Range National Forests of interest are the Arapaho - Roosevelt and the Pike - San Isabel. Biomass data are estimated as a total quantity rather than as an annual production estimate. The data represent a snapshot in time and thus do not account for forest growth, removals, disease and other associated factors.

Table S-2 provides summary data for projected Colorado Front Range forest biomass resources. An estimated 16.6 million bone dry tons (bdt) of wood are theoretically available for harvest from the forest. Harvest estimates are based on forest ecology / restoration efforts that are on-going in the San Juan National Forest. State and private lands represent 71 percent of the resource base. Two counties, Larimer and Las Animas, have the largest resource base. In the northern portion of the Front Range, Lodgepole Pine is the dominant species while in the southern areas, Douglas Fir is predominant.

Table S-2. Summary of National Forest, State, and Private Biomass Potential, Colorado Front Range (bdt)

County	Arapaho - Roosevelt	Pike - San Isabel	State & Private	Total Biomass	% of Total Biomass
Boulder	738,742		282,282	1,021,024	6%
Chaffee			52,311	52,311	0%
Clear Creek	318,440		345,450	663,890	4%
Custer		338,259	210,231	548,490	3%
Douglas		377,615	209,244	586,859	4%
El Paso		84,582	911,988	996,570	6%
Fremont		31,413	784,665	816,078	5%
Gilpin	250,964		190,491	441,455	3%
Grand	-		694,848	694,848	4%
Huerfano		132,711	911,001	1,043,712	6%
Jefferson	21,497	372,931	967,260	1,361,688	8%
Lake			207,270	207,270	1%
Larimer	1,006,950		1,654,212	2,661,162	16%
Las Animas		225	2,476,383	2,476,608	15%
Park	8,398	594,176	523,110	1,125,684	7%
Pueblo		79,485	238,854	318,339	2%
Saguach			464,877	464,877	3%
Teller		421,162	717,549	1,138,711	7%
TOTAL	2,344,992	2,432,558	11,842,026	16,619,576	100%
% of TOTAL	14%	15%	71%	N/A	N/A

Estimated delivered costs were developed on a county basis for the forest resources (see Table S-3). The average cost is nearly $67/bdt or approximately $3.70/MMBtu. The selected delivery site was the Denver metropolitan area and thus delivered costs are least expensive for counties located nearby to Denver.

Transportation costs represent the single largest component of the delivered product cost. For locations within the extended Denver metropolitan area, approximately 7.3 million bdt are available at an average cost of $55/bdt. The counties included in the extended Denver metropolitan area are listed in Table S-5.

Table S-3. Delivered Forest Biomass Costs for the Colorado Front Range

County	Distance to Denver (miles)	Haul Cost ($)	Haul Cost ($/bdt)	Total Cost* ($/bdt)	Total Cost ($/MMBtu)
Boulder	50	$165.00	$14.67	$54.12	$3.00
Chaffee	140	$350.00	$31.11	$70.56	$3.91
Clear Creek	50	$165.00	$14.67	$54.12	$3.00
Custer	180	$450.00	$40.00	$79.45	$4.40
Douglas	50	$165.00	$14.67	$54.12	$3.00
El Paso	75	$187.50	$16.67	$56.12	$3.11
Fremont	130	$325.00	$28.89	$68.34	$3.79
Gilpin	50	$165.00	$14.67	$54.12	$3.00
Grand	150	$375.00	$33.33	$72.78	$4.03
Huerfano	180	$450.00	$40.00	$79.45	$4.40
Jefferson	50	$165.00	$14.67	$54.12	$3.00
Lake	150	$375.00	$33.33	$72.78	$4.03
Larimer	150	$375.00	$33.33	$72.78	$4.03
Las Animas	220	$550.00	$48.89	$88.34	$4.90
Park	75	$187.50	$16.67	$56.12	$3.11
Pueblo	160	$400.00	$35.56	$75.00	$4.16
Saguach	200	$500.00	$44.44	$83.89	$4.65
Teller	70	$175.00	$15.56	$55.00	$3.05
Average		$306.94	$27.28	$66.73	$3.70
Minimum		$165.00	$14.67	$54.12	$3.00
Maximum		$550.00	$48.89	$88.34	$4.90

*Total cost includes stumpage, harvest costs, and transportation

URBAN RESOURCES

Considerable urban woody resources are known to exist and much of the material is presently landfilled. Provision of opportunity to find alternative uses for a waste material may help both producers of wood waste and potential users.

A telephone survey was conducted in January and February of 1997. Survey data were augmented with additional data. Organizations contacted included primary and secondary wood processors, wood recycling firms, landfills, commercial tree care firms, municipal forestry operations, utility line clearance operations, and landscapers. Organizations were queried as to the type, amount, seasonal patterns, and cost or price of their wood residues.

Area wood recycling companies were also contacted in an effort to determine current wood waste markets, products and competing prices. Local recyclers process more than 58,000 bdt per year into products such as mulch, animal bedding and compost. Prices for finished products range from $15 to $70 per bdt, depending upon the final product and current market conditions. The wood recyclers represent existing infrastructure and many may be potential suppliers to any ethanol facility.

The total amount of urban wood residue available to supply a potential ethanol facility is summarized in Table S-4. The table provides rankings for the materials from lowest to highest cost and shows a cumulative total as well as a blended cost as each successively higher priced resource is added to the mix. For example, utilizing only primary/secondary waste, urban tree residue (UTR), and the animal bedding stream from recyclers, the total amount available would be 119,601 bdt/year at an average price of $15.85/bdt.

For the entire Front Range, it is estimated that a minimum of 169,354 bdt/yr. of material is available at an average cost of $23.39 per bdt. UTR is the primary resource and also the least expensive. UTR represents a diverse resource mix composed of chips from multiple species, leaves, grass clippings, and assorted branches and logs.

Table S-4. Summary of Available Urban Wood Residue Production and Prices

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	11,905	11,905	$15.00	$15.00
UTR	98,291	110,196	$15.00	$15.00
Recycler - Animal Bedding	9,405	119,601	$25.78	$15.85
Recycler - Mulch	12,486	132,088	$26.79	$16.88
Recycler - Compost	26,207	158,294	$39.36	$20.60
Recycler - Dyed Mulch	11,059	169,354	$63.35	$23.39
TOTAL		169,354		$23.39

SUMMARY

It is estimated that more than 7.3 million bdt of material is available within a 50 - 100 mile radius of the Denver metro area. The reader should keep in mind that the forest residues represent the total amount of residue available and do not account for time. It is likely that only a few thousand acres would be harvested in any one year from the forest. The numbers for urban wood waste reflect the amount available on an annual basis.

Table S-5 is a summary table of the amounts of wood residue available for an 11 county "core" area within the immediate vicinity of Denver. The forest residues have been annualized by dividing by 20 to represent a potential harvest schedule of 20 years. The data in Table S-5 are for residue available, thus accounting for estimated sales and recycling levels. More than 500,000 bdt per year are available within the core Front Range counties listed in table S-5.

Figure S-1 provides a graphic representation of the available urban and forest resources. For purposes of the map, the forest resources were divided by 20 to represent a potential harvest schedule of 20 years.

Table S-5. Annual Available Wood Residue for Core Counties

County Name	Study Class (1=Urban Only; 2=Urban & Forest)	Primary and Secondary Available (bdt/yr)	UTR Available (bdt/yr)	Total Forest Biomass Available (bdt)	Estimated Annual Total (for 20 years) (bdt/yr)
Adams	1	5,480	7,737		13,217
Arapahoe	1	21	6,890		6,911
Boulder	2	1,273	2,019	1,021,024	54,343
Clear Creek	2			663,890	33,195
Denver	1	2,264	18,948		21,212
Douglas	2	2	20	586,859	29,365
El Paso	2	21	3,021	996,570	52,870
Gilpin	2			441,455	22,073
Jefferson	2	250	27,522	1,361,688	95,856
Park	2			1,125,684	56,284
Teller	2	722		1,138,711	57,658
Multiple/Unknown			23,916		23,916
Wood Recyclers					59,158
TOTAL		**10,033**	**90,073**	**7,335,881**	**526,057**

Table S-6 shows the estimated costs of each residue type found within the core Front Range area. The estimated prices range from "free" (with an assumption of $15/bdt for trucking) to $63.35 for the material presently being sold as painted, or dyed, mulch. For all processed residue that has present markets, it is assumed that the ethanol facility must at least match existing market prices if that resource is to be available to the ethanol facility.

Table S-6. Estimated Annual Costs of Biomass for the "Core" Front Range

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	10,033	10,033	$15.00	$15.00
UTR	90,073	100,106	$15.00	$15.00
Recycler - Animal Bedding	9,405	109,511	$25.78	$15.93
Recycler - Mulch	12,486	121,997	$26.79	$17.04
Recycler - Compost	26,207	148,204	$39.36	$20.98
"Core" Forest Residues (Annual)	366,794	514,998	$54.83	$45.09
Recycler - Dyed Mulch	11,059	526,057	$63.35	$45.47
TOTAL		**526,057**		**$45.47**

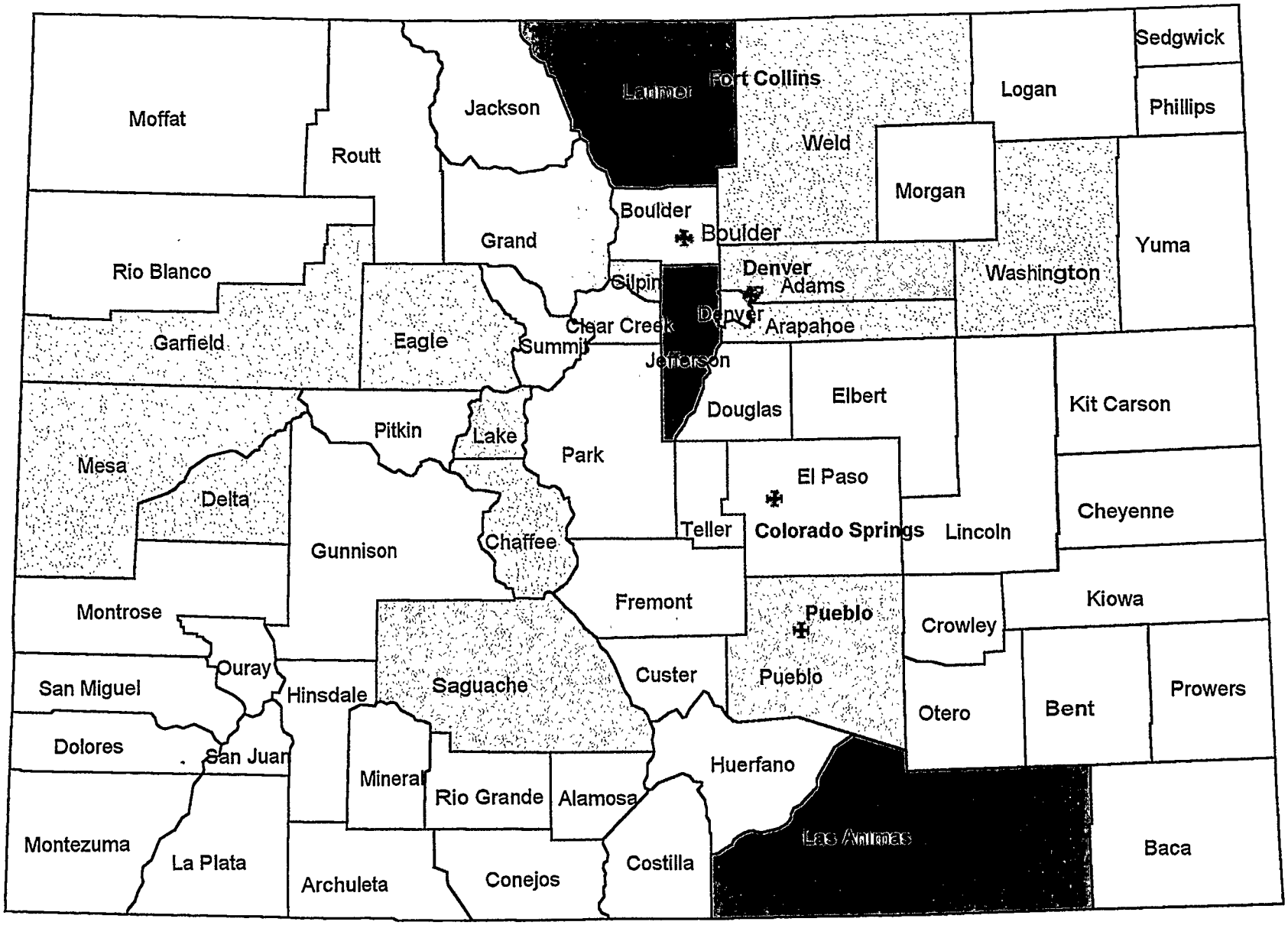


Figure S-1. Estimated Biomass Available (bdt/yr)

1. INTRODUCTION

This report documents the results of a wood resource assessment conducted for the Colorado Front Range. The Front Range is broadly defined to include the areas from Fort Collins in the north to Pueblo in the south, and from Mesa County in the west to approximately Limon in the east.

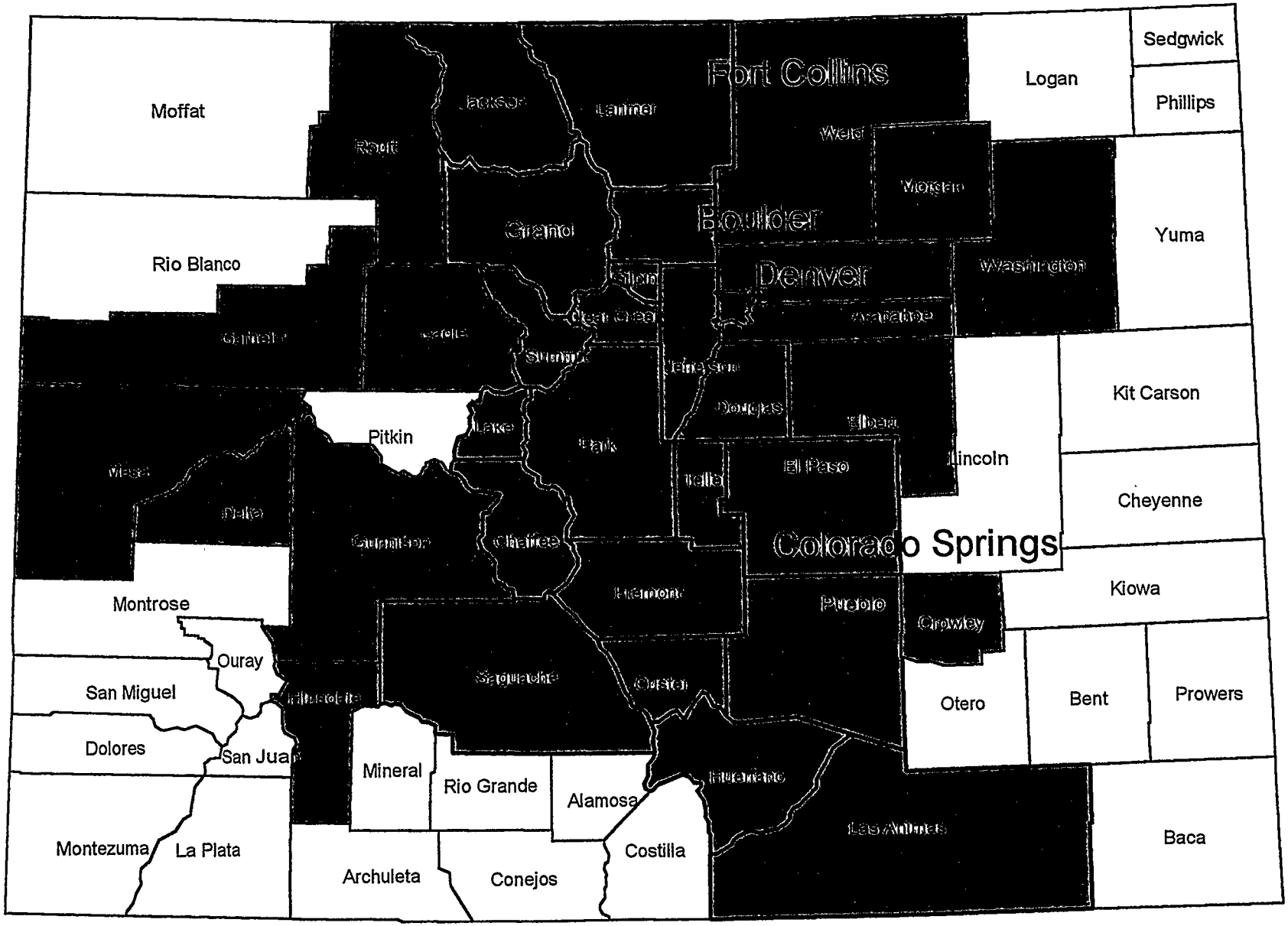
Figure 1 shows the geographic area of focus for the study. Some counties were assessed for both urban and forest residues while others were assessed for only urban residues. Counties located far from Denver with low population density and poor transportation routes to Denver were excluded from the study. The study area represents a radius of approximately 100-150 miles from Denver.

The resource assessment is part of a larger effort being conducted by the Front Range Forest Health Partnership (FRFHP), a coalition of public, private, and citizen groups that have come together to investigate possible utilization options for wood residues generated in thinning of forests and through commercial activities in urban communities of the Colorado Front Range. The present focus of the FRFHP is to investigate the feasibility of developing a wood waste to ethanol conversion facility in the Denver metro area. Additional details on the proposed wood to ethanol facility can be obtained by contacting Paula Volkin, FRFHP Project Manager, at (303) 554-9530.

The purpose of the resource assessment effort is to determine the quantity, cost, location, availability, form and type of wood residue resources in the geographic region of focus. The study focuses on two distinct sources of wood residues:

- State, Private and National Forests
- Urban Wood Residues

Section 2 summarizes the methodology and results of the forest resource assessment. Section 3 contains the results of the urban residue assessment, and Section 4 contains summary results for both sources of material combined.



Major Cities

County Status

- Not Included
- Urban Only
- Urban and Forest

Figure 1. Study Area

2. FOREST RESOURCES INVENTORY AND COSTS

2.1 Introduction

This chapter presents documentation and results of the inventory of forest biomass resources along the Colorado Front Range. The objective was to both determine the amount of biomass theoretically "available" for removal from forests and to determine the cost of the biomass delivered to the Denver metropolitan area. The term "available" refers to wood that may be harvested from the forest to mitigate forest fire potential. [Note, this definition differs from the US Forest Service definition of available lands.]

In the context of this report, available wood is represented by species common to the Colorado Front Range located in areas where forest health is at risk due to combined effects of heavy logging coupled with fire suppression. Thinning of forest stands can have significant positive impacts on large forested areas.[1]

Quantities of biomass are identified by land classification, species, and location. Land classification refers to ownership and includes federal, state, and private lands. Species of trees include Ponderosa Pine, Lodgepole Pine, and Douglas Fir. Data are reported at the county level.

The Colorado Front Range is defined to include the geographic area described in Figure 1. The designation of the Colorado Front Range geographic area was determined in part by prior work performed by the US Forest Service to identify areas at risk to forest fires (i.e., the "Red Zone" map)[2] Further, the Colorado Front Range designation is also determined by the extent of national forests within Colorado.

2.2 Resource Base

The US Forest Service effort to identify areas at risk to forest fires was a driving force to initiate the resource assessment effort. The "Red Zone" map produced by the US Forest Service served to identify geographic locations at risk to forest fires (see Figure 2). The forest resource assessment is an initial estimate of the biomass resources contained within the "Red Zone" map areas. This effort entailed using vastly different data sets and attempting to reconcile differing assumptions.

Common resource base methodology and attributes were employed for different land classifications (i.e., federal and non-federal). However, data reporting and data availability between federal and non-federal lands are sufficiently varied to warrant separate discussion for each of the two major land classifications.

The first element of the common methodology was to determine the attributes that are of interest for the resource assessment. The first data attribute is the number of acres that are populated by species of concern (i.e., Ponderosa Pine, Lodgepole Pine, and Douglas Fir). Subsequently, acreage estimates are modified to reflect lands that are commercially harvestable. Acreage was further delimited to include only sawtimber and poletimber classifications with an interest in small diameter material between 5.9" and 11.9" diameter at breast height (dbh).

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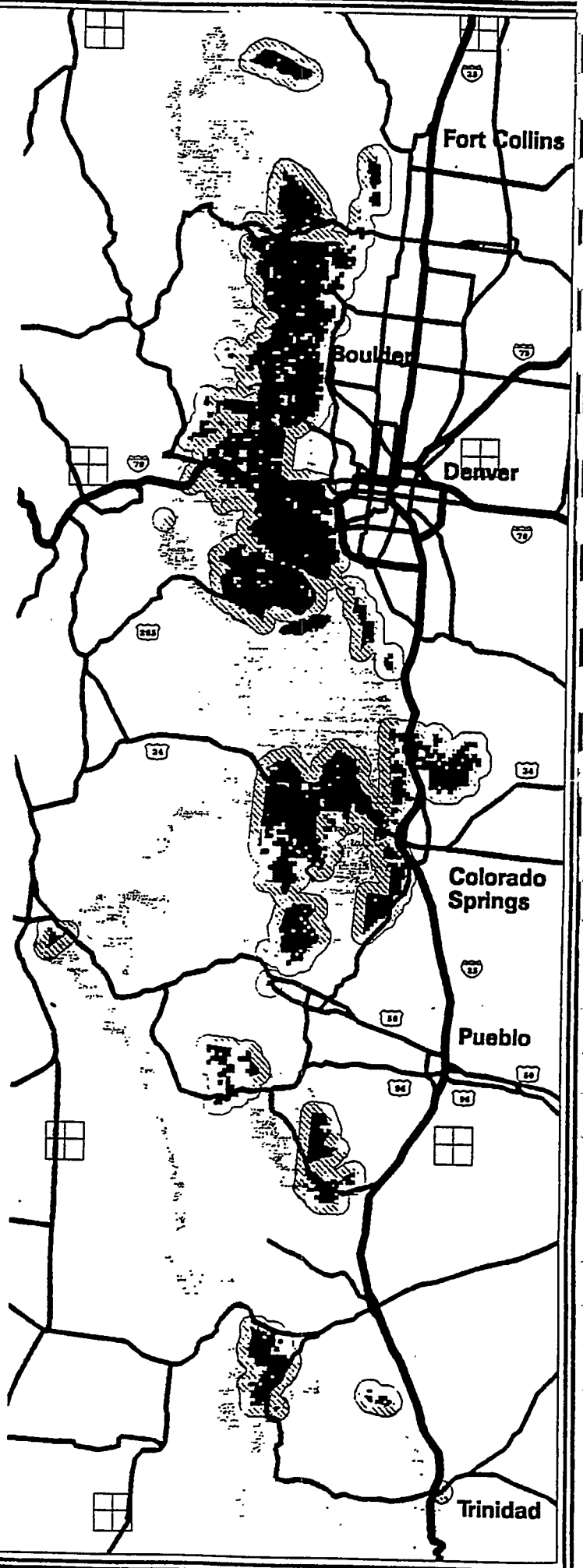
[1] Carlson, W.H., and Duffy, J.L., "Using an Integrated Forest Thinning / Biomass Power Strategy to Save Northwest Forests," proceedings, Second Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry, August 21-24, 1995, Portland, OR.

[2] US Forest Service, map produced by Region 2, "Probability of Catastrophic Disturbance Events," Denver, CO September 11, 1996.

Figure 2. U.S. Forest Service Red Zone Map



Probability of Catastrophic Disturbance Events

- High –1528.45 sq miles
- Medium –4412.94 sq miles
- Low –883.96 sq miles
- High Area Buffers –3735.09 sq miles

Mapscale 1:1,750,000

Miles: 0, 12.5, 25, 37.5, 50

Kilometers: 0, 12.5, 25, 37.5, 50, 62.5, 75

This GIS product was compiled from various sources and may be corrected, updated, modified, or replaced at any time.

September 27, 1996

Where possible, estimates were made to identify geographic locations that fit the probability of catastrophic disturbance events (i.e., high, medium, low). Finally, a biomass quantity estimate, reported in bone dry tons per acre, was multiplied by the acreage estimates to determine the biomass resource.

2.2.1 Federal Lands Resource Base Methodology

The objective was to determine the number of acres that could be harvested along the Colorado Front Range in both the Arapaho - Roosevelt and the Pike - San Isabel National Forests. The intent of the resource assessment was to determine the amount of biomass located within the "Red Zone."

Biomass resources were estimated with data obtained from the Pueblo Integrated Resource Inventory Center, a US Forest Service office.[3] Similar data were obtained from the Fort Collins US Forest Service office.[4] Information was developed from multiple internal US Forest Service data bases and was manipulated to match with the "Red Zone" map produced by the Region 2 US Forest Service headquarters. The primary data set was the Resource Inventory System (RIS). The RIS spatial layer has a Minimum Mapping unit of 2 acres and attribute fields for timber component (suitability), tree-size, species (Cover-type), owner, and district. The minimum map unit for this layer is one kilometer. The "Red Zone" spatial layer was obtained from the Regional Office, and all attribute items except for risk were removed. Risk was assessed as high, medium, or low. Risk was defined to address the "probability of catastrophic disturbance events as a result of the combination of disturbance regime and housing density. Short interval (high) or medium interval (medium) disturbance regimes when combined with high or medium housing density result in a probability factor of high. Short or medium interval disturbance regimes with low housing density result in medium probability, as do high and medium housing density with long interval (low) disturbance. Low disturbance and low housing result in a low probability factor. The high area buffers are the high probability areas buffered by two miles."[5] Further, buffer zones were established around high risk zones.

The final RIS / "Red Zone" data set was developed to contain only information within the US Forest Service Congressional Boundaries, clipped by the "Red Zone" area. A map of the County boundaries was intersected with the RIS / "Red Zone" coverage to produce the final spatial coverage and data set.

Combining information within the RIS and the "Red Zone" data sets is not a straightforward task. The RIS data is of high resolution and a high percentage of the polygons were field verified as to attributes (i.e., cover-type, tree-size, etc.). At a minimum the polygons were developed through photo interpretation.

By contrast, the "Red Zone" risk data were developed through an AVHRR classification for cover-type, aggregated by cover-type for fire regime, and compared to housing density to produce the risk estimate. There could be up to 300+ acre stands that meet or do not meet the "Red Zone" criteria in the RIS layer, (finer detail information within the one kilometer cells). There also could be differences in the cover-type. It is likely that after further refinements to the RIS data set and the aggregation of its cover-types, the refined "Red Zone" risk acreage calculations will be different, possibly as much as ± 20 percent. The US Forest Service will be refining the "Red Zone" risk during the Summer of 1997 and revisions are likely to the preliminary data provided in this report.

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[3] Data provided by Mr. Mike Morrison, US Forest Service, Pueblo Integrated Resource Inventory Center, Team Leader / PKSI GIS Coordinator, March 26, 1997.

[4] Data provided by Mr. Mark Faughn, US Forest Service, Fort Collins, CO, April 14, 1997.

[5] text from US Forest Service "Red Zone" map, September 11, 1996.

Table 1 provides summary resource data for the Arapaho - Roosevelt National Forests by species, county, and risk designation. There are approximately 148,000 acres in the "high" risk category with a two-mile buffer representing approximately 12 percent of the total national forest acreage. Boulder and Larimer counties have nearly equal acreage at risk to fire. For the combined "high" and "medium" categories, there are potentially 240,000 acres of forest (about 19 percent of the total forest), that are at risk to catastrophic fire. Lodgepole pine is the predominant species (41 percent), followed by Ponderosa Pine and Douglas Fir / mix.

Table 1. Forest Resource Base, Arapaho - Roosevelt National Forests (acres)

County	Douglas Fir/ Mix	Lodgepole Pine	Ponderosa Pine	Total Acres	% of Total Forest
High Risk w/Buffer					
Boulder	15,627	15,109	28,268	59,004	5%
Clear Creek	2,732	7,707	1,071	11,509	1%
Gilpin	2,161	11,888	531	14,580	1%
Grand	-	-	-	-	0%
Jefferson	118	1,948	2	2,068	0%
Larimer	12,981	21,508	25,424	59,913	5%
Park	574	277	-	851	0%
TOTAL	34,193	58,437	55,295	147,925	12%
Medium Risk w/Buffer					
Boulder	7,653	7,056	1,134	15,843	1%
Clear Creek	9,195	11,152	408	20,754	2%
Gilpin	6,403	4,420	24	10,847	1%
Grand	-	-	-	-	0%
Jefferson	110	-	-	110	0%
Larimer	7,523	15,458	19,127	42,108	3%
Park	1,210	632	-	1,843	0%
TOTAL	32,095	38,718	20,693	91,506	7%
High and Medium Risk Combined w/ Buffer					
Boulder	23,280	22,165	29,402	74,847	6%
Clear Creek	11,926	18,859	1,479	32,263	3%
Gilpin	8,564	16,307	556	25,427	2%
Grand	-	-	-	-	0%
Jefferson	229	1,948	2	2,178	0%
Larimer	20,504	36,966	44,551	102,021	8%
Park	1,784	910	-	2,693	0%
TOTAL	66,287	97,154	75,989	239,430	19%

Table 2 provides summary resource data for the Pike - San Isabel National Forests by species, county, and risk designation. There are approximately 84,000 acres in the "high" risk category with a two-mile buffer representing approximately 4 percent of the total national forest acreage. Park and Teller counties have nearly equal acreage at risk to fire. For the combined "high" and "medium" categories, there are potentially 246,000 acres of forest (about 11 percent of the total forest), that are at risk to catastrophic fire. Douglas Fir / Mix and Ponderosa Pine are the predominant species (51 and 44 percent, respectively). Lodgepole Pine represents only five percent of the acreage in the high and medium risk categories.

Table 2. Forest Resource Base, Pike - San Isabel National Forests (acres)

County	Douglas Fir/ Mix	Lodgepole Pine	Ponderosa Pine	Total Acres	% of Total Forest
High Risk w/Buffer					
Custer	7,645	27	484	8,156	0.4%
Douglas	3,286	-	2,120	5,406	0.2%
El Paso	5,152	-	1,842	6,994	0.3%
Fremont	262	-	154	416	0.0%
Huerfano	6,204	644	379	7,226	0.3%
Jefferson	1,318	220	5,886	7,424	0.3%
Las Animas	23	-	-	23	0.0%
Park	1,841	5,690	12,769	20,300	0.9%
Pueblo	6,342	14	1,489	7,845	0.4%
Teller	11,587	-	8,129	19,716	0.9%
TOTAL	43,661	6,595	33,251	83,506	3.7%
Medium Risk w/Buffer					
Custer	22,521	793	2,802	26,115	1.2%
Douglas	15,088	3,587	14,178	32,853	1.5%
El Paso	1,247	270	58	1,576	0.1%
Fremont	2,117	130	520	2,767	0.1%
Huerfano	3,858	-	2,362	6,220	0.3%
Jefferson	10,116	286	19,958	30,360	1.4%
Las Animas	-	-	-	-	0.0%
Park	13,407	2,020	24,474	39,900	1.8%
Pueblo	208	-	-	208	0.0%
Teller	12,601	157	10,196	22,955	1.0%
TOTAL	81,163	7,243	74,548	162,954	7.3%
High and Medium Risk Combined w/ Buffer					
Custer	30,166	820	3,286	34,271	1.5%
Douglas	18,374	3,587	16,298	38,259	1.7%
El Paso	6,399	270	1,900	8,570	0.4%
Fremont	2,379	130	674	3,183	0.1%
Huerfano	10,061	644	2,741	13,446	0.6%
Jefferson	11,433	506	25,845	37,784	1.7%
Las Animas	23	-	-	23	0.0%
Park	15,248	7,710	37,242	60,200	2.7%
Pueblo	6,551	14	1,489	8,053	0.4%
Teller	24,188	157	18,325	42,671	1.9%
TOTAL	124,823	13,837	107,799	246,460	11.1%

2.2.2 State and Private Resource Base Methodology

Data for state forest lands and private lands are publicly available over the Internet through the Forest Inventory and Analysis (FIA) Data Base Retrieval system maintained by the US Forest Service

(http://www.srsfia.usfs.msstate.edu/scripts/ew.htm). This database was used exclusively in the analysis of available biomass for state and private lands.

The FIA database may be queried by over one hundred separate classifications and/or attributes. In this effort, the query was specified to the following entries:

- Colorado state and private lands,
- Country level data,
- Ponderosa Pine, Douglas Fir, and Lodgepole Pine,
- Slopes less than or equal to 30°
- Sawtimber and poletimber classification,
- Forest type specific to species of interest, and
- Timberland.

The results of the query process provided data on timberland acreage by county by species (see Table 3 and Appendix B). Acreage values for specific counties of interest were then multiplied by the biomass quantity factor to determine the amount of available biomass (see results in 2.2.5). State and private lands represent approximately 1.2 million acres and Ponderosa Pine is the dominant species. The county with the largest resource acreage is Las Animas, followed by Larimer County.

Table 3. Colorado Front Range, State and Private Lands Biomass Resource (acres)

County	Douglas Fir	Lodgepole	Ponderosa	Total Acres	% of Total Acres
Boulder	-	-	28,600	28,600	2%
Chaffee	1,400	3,900	-	5,300	0%
Clear Creek	6,500	18,800	9,700	35,000	3%
Custer	-	-	21,300	21,300	2%
Douglas	-	-	21,200	21,200	2%
El Paso	5,900	-	86,500	92,400	8%
Fremont	21,500	-	58,000	79,500	7%
Gilpin	-	11,500	7,800	19,300	2%
Grand	-	70,400	-	70,400	6%
Huerfano	5,300	9,700	77,300	92,300	8%
Jefferson	12,700	9,500	75,800	98,000	8%
Lake	-	19,100	1,900	21,000	2%
Larimer	31,700	29,900	106,000	167,600	14%
Las Animas	27,200	-	223,700	250,900	21%
Park	7,300	7,400	38,300	53,000	4%
Pueblo	-	-	24,200	24,200	2%
Saguach	35,600	2,700	8,800	47,100	4%
Teller	27,800	-	44,900	72,700	6%
TOTAL	182,900	182,900	834,000	1,199,800	100%
% of TOTAL	15%	15%	70%	N/A	N/A

2.2.3 Summary of Acreages

Table 4 shows a summary of the acreages available from the high and medium risk zones on federal land along with all state and private lands. A total of 1.6 million acres could be treated for forest health.

Table 4. Summary of Acreages by Ownership, County and Risk Class

County	High Risk w/Buffer	Medium Risk w/Buffer	State & Private	Total	% of Total Biomass
Boulder	59,004	15,843	28,600	103,447	6%
Chaffee			5,300	5,300	0%
Clear Creek	11,509	20,754	35,000	67,263	4%
Custer	8,156	26,115	21,300	55,571	3%
Douglas	5,406	32,853	21,200	59,459	4%
El Paso	6,994	1,576	92,400	100,970	6%
Fremont	416	2,767	79,500	82,683	5%
Gilpin	14,580	10,847	19,300	44,727	3%
Grand			70,400	70,400	4%
Huerfano	7,226	6,220	92,300	105,746	6%
Jefferson	9,492	30,470	98,000	137,962	8%
Lake			21,000	21,000	1%
Larimer	59,913	42,108	167,600	269,621	16%
Las Animas	23		250,900	250,923	15%
Park	21,151	41,743	53,000	115,894	7%
Pueblo	7,845	208	24,200	32,253	2%
Saguach			47,100	47,100	3%
Teller	19,716	22,955	72,700	115,371	7%
TOTAL	**231,431**	**254,459**	**1,199,800**	**1,685,690**	
Percent	**14%**	**15%**	**71%**		

2.2.4 Biomass Resource Approach

The amount of biomass that may be harvested is dependent upon a complex interrelationship of forest biology, technology, politics, and economics. Estimates of biomass that may be harvested from the forests were obtained from prior studies in the San Juan National Forest.[6] Lynch et al report that in the size class of 5 inches to 11.9 inches, dbh, approximately 19.7 wet tons of biomass were removed per acre. At an assumed moisture content of fifty percent, the biomass represents nearly ten bdt/acre. This biomass figure, 9.9 bdt/acre, was used for all calculations of potential biomass resources on the Colorado Front Range. The methodological approach employed in this report was to simply multiply the suitable acres value by the biomass quantity estimate.

2.2.5 Front Range Biomass Resource Base

A summary of the potential biomass resource base along the Colorado Front Range is presented in Table 5. State and private lands represent 71 percent of the resource potential and Larimer County has the largest resource base, closely followed by Las Animas County. The resource base is estimated at over 16.6 million bdt.

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[6] Lynch, D. L., and Jones, C.S., Summary Report, Timber Harvesting Study for Unit 1 - "Smoothing Iron" Ecosystem Restoration Project, Department of Forest Sciences, Colorado State University, April 1996.

Table 5. Summary of National Forest, State, and Private Biomass Potential, Colorado Front Range (bdt)

County	Arapaho - Roosevelt	Pike - San Isabel	State & Private	Total Biomass	% of Total Biomass
Boulder	738,742		282,282	1,021,024	6%
Chaffee			52,311	52,311	0%
Clear Creek	318,440		345,450	663,890	4%
Custer		338,259	210,231	548,490	3%
Douglas		377,615	209,244	586,859	4%
El Paso		84,582	911,988	996,570	6%
Fremont		31,413	784,665	816,078	5%
Gilpin	250,964		190,491	441,455	3%
Grand	-		694,848	694,848	4%
Huerfano		132,711	911,001	1,043,712	6%
Jefferson	21,497	372,931	967,260	1,361,688	8%
Lake			207,270	207,270	1%
Larimer	1,006,950		1,654,212	2,661,162	16%
Las Animas		225	2,476,383	2,476,608	15%
Park	8,398	594,176	523,110	1,125,684	7%
Pueblo		79,485	238,854	318,339	2%
Saguach			464,877	464,877	3%
Teller		421,162	717,549	1,138,711	7%
TOTAL	2,344,992	2,432,558	11,842,026	16,619,576	100%
% of TOTAL	14%	15%	71%	N/A	N/A

2.3 Biomass Supply Costs

Fuel supply may be obtained from the non-merchantable portion of the timber sales. Typically, the non-merchantable material consists of tops, limbs, and small diameter trees (usually less than 12 inches). The cost of the biomass fuel supply is a function of the effort required to purchase (i.e., timber sales), fell, bunch, chip, and transport the small diameter material. Each of these cost components is discussed below.

2.3.1 Harvest Cost

Costs associated with the harvest of trees have been documented by personnel at Colorado State University for the San Juan National Forest.[7] Harvest costs are reported for specific units and address felling, skidding, equipment mobilization, technology considerations, operations and maintenance costs, and administrative costs. In general, the demonstration units for this project experienced slightly higher than anticipated costs for material removal. To some extent, the higher cost was a result of the small size of the timber sale which resulted in the limited use of mechanical equipment specialized for small

[7] Lynch, D. L., and Jones, C.S., Summary Report, Timber Harvesting Study for Unit 1 - "Smoothing Iron" Ecosystem Restoration Project, Department of Forest Sciences, Colorado State University, April 1996.

diameter material. For example, feller/bunchers were not used, rather, the trees were felled by chainsaw and skidded from the forest to the landing with either a Cat 518 tractor or JD 540 skidder.

Lynch reports costs for waferwood harvest were $59.94 per hundred cubic feet (ccf). It is assumed that waferwood material is similar to biomass for energy material. One ccf is equivalent to 3.5899 wet tons. At an assumed moisture content of 50 percent, the average cost to deliver a bone dry ton of non-merchantable timber to the landing site in the test unit in the SJNF was $39.06/ bdt.

2.3.2 Grinding and Loading

Grinding costs for biomass are a function of the size of the material, the quantity of material, the equipment used for size reduction, the desired size reduction, and, sometimes, the location of the landing. Grinding costs were obtained from a prior study.[8] Grinding was accomplished with a Diamond Z PWG 1260 at a cost of $85/hour and a rate of 30 wet tons per hour. Wood was reduced in size to 1/2" or less. The average cost to grind the wood and blow it into a chip van was $5.67/bdt.

2.3.3 Transportation

Transportation of biomass fuels is a key cost component of the total expense of the delivered fuel. The low energy density of biomass fuels typically necessitates short hauls or inexpensive modes of transportation to be competitive with other energy forms.

Forests along the Colorado Front Range represent over 4 million acres in mountainous terrain along a broad swath from the Wyoming border to New Mexico. Haul distances to candidate sites are likely to be long and slow, leading to considerable expense.

The typical arrangement for moving chipped material is to use a large trailer common to the pulp industry. The trailer holds approximately 23 wet tons of material. The filling time is on the order of one half hour or less.

Haul costs were determined for each county of interest by determining the mileage from a centroid point in the county to Commerce City, Colorado. Haul costs were assumed to have a minimum threshold of $150 per trip. For more distant locations, haul costs were increased by $1.25 per mile for each mile beyond the $150 threshold. Haul costs were calculated to average approximately $27/bdt for all forest locations on the Colorado Front Range.

2.3.4 Stumpage

Stumpage reflects an additional cost to be incurred in the harvest process. Stumpage was assumed to be assessed at $0.25 per CCF (cunit) or $0.45 per bdt and reflects the National Forest Fund Rate which may be applied for forest restoration projects. An alternate stumpage rate would be $4.00 per CCF (cunit) or $7.18 per bdt and would reflect current stumpage rates for Products Other than Logs (POL) in USFS region 2.[9]

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[8] NEOS Corporation (1996), Biomass Co-Firing in Coal-Fired Power Plants, Preliminary Assessment for the Four Corners Area, prepared for US Department of Energy, Western Regional Biomass Energy Program, Golden, Colorado.

[9] Personal communication with Richard Dieckman, USFS Region 2.

2.3.5 Summary of Biomass Harvest Costs

In Table 6 costs associated with wood harvesting are shown for the SJNF (referenced as Lynch in Table 6) as well as for several other studies in the Southwest or eastern Oregon (Hemphill). The costs reported by Lynch were experienced by one logger in the SJNF and an itemized breakdown of costs are not shown to protect confidential information. The chipping cost was developed by NEOS Corporation and is shown for both Lynch and USFS. The Mescalero Apache Reservation costs were obtained from a pulp chip operation that was established to thin forest stands. The chipping operation was fully mechanized with reliance on modern feller/buncher machinery. Pulp chips from the Mescalero Apache Reservation were delivered to the Stone Container paper facility in Snowflake, AZ. The costs reported by Hemphill are from 1987 and 1988 and have been escalated at an annual rate of 3 percent to better reflect 1997 values. Costs for the four studies range from $34/bdt to $39/bdt, or a difference of approximately 15 percent.

Table 6. Summary of Costs Associated with Wood Harvesting

Activity	Study ($/bdt)				
	Lynch	USFS	Mescalero	Hemphill	Average
Fell, buck, limb	N/A	$9.47	N/A	N/A	N/A
Skid	N/A	$13.06	N/A	N/A	N/A
Chip[1]	$5.67	$5.67	N/A	N/A	N/A
Overhead	N/A	$8.06	N/A	N/A	N/A
TOTAL	$39.06	$36.26	$34.00	$34.22	$35.89

Sources: Lynch, D. L., and Jones, C.S., Summary Report, Timber Harvesting Study for Unit 1 - "Smoothing Iron" Ecosystem Restoration Project, Department of Forest Sciences, Colorado State University, April 1996. US Forest Service Region 2, FSH 2409.22 Timber Appraisal Handbook R2 Amendment 2409.22-95-3, effective 9/5/95, Central Rocky Zone. Mescalero Apache Reservation, personal conversation with Jim Kellar, wood pulp chip operator. Hemphill, D.C., The Economics of Forest Residue Recovery Systems in an Eastern Oregon Logging Operation, prepared for US Department of Energy, Pacific Northwest and Alaska Bioenergy Program and Kinzua Corporation, March 1989.

Note: 1) Chip costs were developed by NEOS Corporation.

For all Colorado Front Range locations, the distribution of estimated average delivered wood costs is shown in Figure 3. Transportation represents the major cost component (42 percent of total costs), followed by skidding (20 percent). Actual cutting (i.e., felling, bucking, limbing) represents 15 percent of the cost, overhead 13 percent, chipping 9 percent, and stumpage one percent of total wood harvest costs.

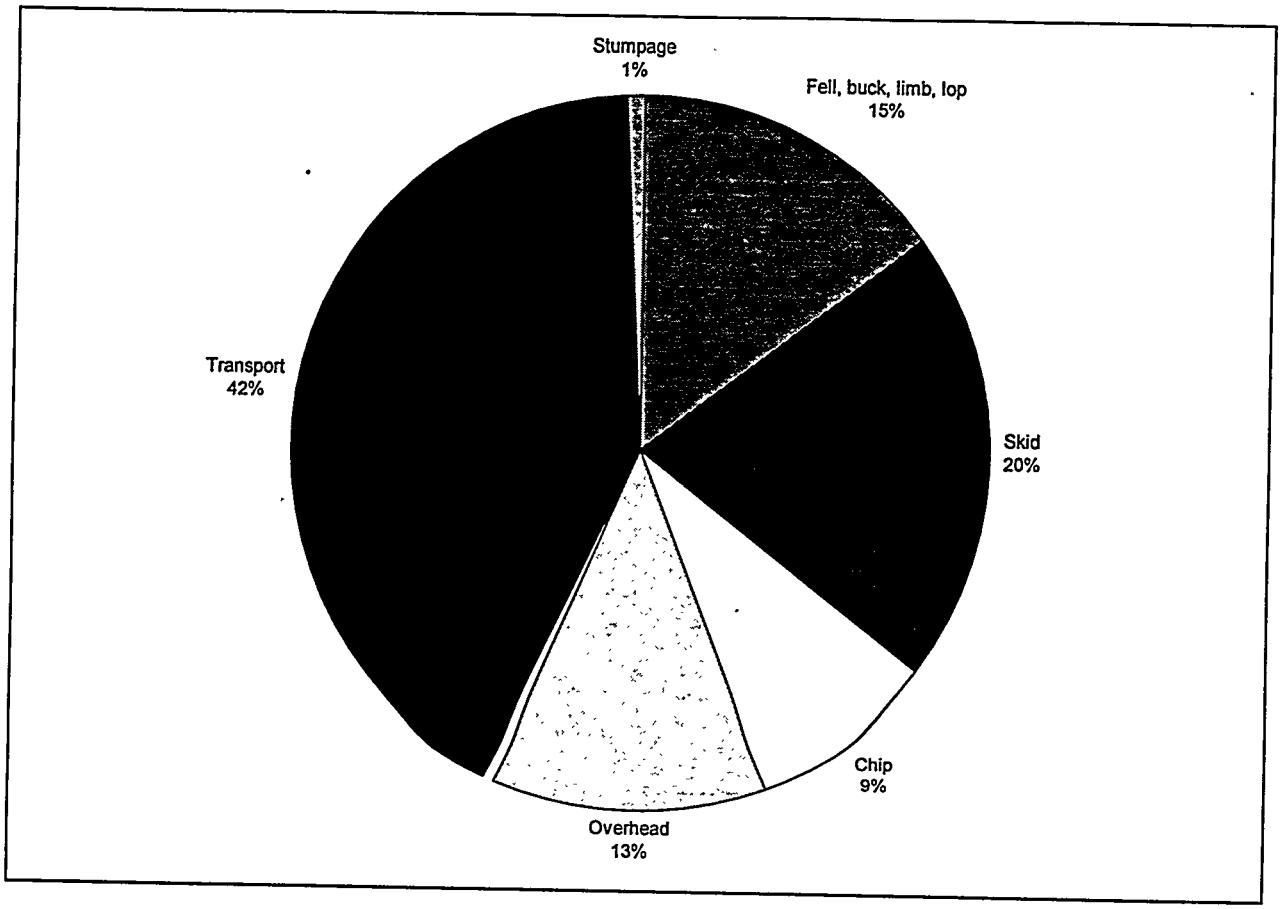

Figure 3. Distribution of Wood Harvest and Delivery Costs, Colorado Front Range

2.3.6 Colorado Forest Biomass Delivered Costs

Total delivered costs, by county, are shown in Table 7. The delivered costs include all harvest costs plus costs incurred for transportation and stumpage. The average cost is estimated to be almost $67/bdt or slightly over $3.70/MMBtu. The least expensive resources are located close to Denver as expected because of the large effect transportation costs have on the delivered price. Transportation charges range from 24 to 56 percent of the delivered cost, underscoring the importance of minimizing haul distances.

Table 7. Delivered Forest Biomass Costs for the Colorado Front Range

County	Distance to Denver (miles)	Haul Cost ($)	Haul Cost ($/bdt)	Total Cost* ($/bdt)	Total Cost ($/MMBtu)
Boulder	50	$165.00	$14.67	$54.12	$3.00
Chaffee	140	$350.00	$31.11	$70.56	$3.91
Clear Creek	50	$165.00	$14.67	$54.12	$3.00
Custer	180	$450.00	$40.00	$79.45	$4.40
Douglas	50	$165.00	$14.67	$54.12	$3.00
El Paso	75	$187.50	$16.67	$56.12	$3.11
Fremont	130	$325.00	$28.89	$68.34	$3.79
Gilpin	50	$165.00	$14.67	$54.12	$3.00
Grand	150	$375.00	$33.33	$72.78	$4.03
Huerfano	180	$450.00	$40.00	$79.45	$4.40
Jefferson	50	$165.00	$14.67	$54.12	$3.00
Lake	150	$375.00	$33.33	$72.78	$4.03
Larimer	150	$375.00	$33.33	$72.78	$4.03
Las Animas	220	$550.00	$48.89	$88.34	$4.90
Park	75	$187.50	$16.67	$56.12	$3.11
Pueblo	160	$400.00	$35.56	$75.00	$4.16
Saguach	200	$500.00	$44.44	$83.89	$4.65
Teller	70	$175.00	$15.56	$55.00	$3.05
Average		$306.94	$27.28	$66.73	$3.70
Minimum		$165.00	$14.67	$54.12	$3.00
Maximum		$550.00	$48.89	$88.34	$4.90

* Total cost reflects harvest cost, stumpage, and transportation.

2.3.7 "Core" Colorado Front Range

Because the potential delivery point was assumed to be in the Denver metropolitan area, delivered costs are least expensive for locations nearby to Denver. Eight counties, shown in Table 8, are representative of the locations nearest to Denver. The eight counties have an estimated resource base of 7.3 million bdt that is reasonably well distributed among the different counties. State and private lands account for approximately 57 percent of the resource.

As shown in Table 9, the blended delivered costs for the counties nearby to Denver is nearly $55/bdt or approximately $11/bdt less than the average delivered cost for the entire Front Range.

Table 8. "Core" Colorado Front Range Forest Biomass Resources (bdt)

County	Arapaho - Roosevelt	Pike - San Isabel	State & Private	Total Biomass	% of Total Biomass
Boulder	738,742	0	282,282	1,021,024	14%
Clear Creek	318,440	0	345,450	663,890	9%
Douglas	0	377,615	209,244	586,859	8%
Gilpin	250,964	0	190,491	441,455	6%
Jefferson	21,497	372,931	967,260	1,361,688	19%
Teller	0	421,162	717,549	1,138,711	16%
El Paso	0	84,582	911,988	996,570	14%
Park	8,398	594,176	523,110	1,125,684	15%
TOTAL	1,338,041	1,850,465	4,147,374	7,335,881	100%
% of TOTAL	18%	25%	57%	100%	N/A

Table 9. Delivered Costs for Forest Biomass Resources from the Core Colorado Front Range

County	Total Biomass	Cumulative Total (bdt)	Delivered Cost ($/bdt)	Blended Cost ($/bdt)
Boulder	1,021,024	1,021,024	$54.12	$ 54.12
Clear Creek	663,890	1,684,914	$54.12	$ 54.12
Douglas	586,859	2,271,773	$54.12	$ 54.12
Gilpin	441,455	2,713,228	$54.12	$ 54.12
Jefferson	1,361,688	4,074,915	$54.12	$ 54.12
Teller	1,138,711	5,213,626	$56.12	$ 54.55
El Paso	996,570	6,210,196	$56.12	$ 54.80
Park	1,125,684	7,335,881	$55.00	$ 54.83
TOTAL/ AVG	7,335,881	N/A	N/A	$ 54.83

2.4 Summary

Approximately 16.6 million bdt from nearly 1.9 million acres represent the potential biomass resource base along the Colorado Front Range. The resource base is predominantly located on state and private lands with two counties, Larimer and Las Animas, representing a large share of the total resource. The predominant species in the north is Lodgepole Pine and in the south, Douglas Fir. The average estimated delivered cost for the biomass is nearly $67/bdt for all counties and $55/bdt for the core counties..

Neither the Arapaho-Roosevelt nor the Pike-San Isabel National Forests experience significant commercial timber harvest activity, less than 12 million board feet per year over the past four years. Further, this level of commercial activity reflects a 60 percent reduction from FY 93 to FY 96.[10] These two forests represent less than 10 percent of total commercial timber activity on Colorado National Forest lands. See Appendix A for data on commercial activity in both the Pike - San Isabel and Arapaho - Roosevelt National Forests.

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[10] US Department of Agriculture, Rocky Mountain Region, Forest Service, Region 2, Record of Timber Sales and Cuts, 1997.

3. URBAN WOOD RESIDUES

The urban wood residue stream represents a significant potential source of raw material for the potential conversion facility. It is therefore desirable to determine current generation of wood residues from the various sectors that make up this category. NEOS divided the industry into two major sectors: 1) Generators, and 2) Processors. This approach allows for a comparison between the estimate of total material generated versus how much is currently being processed. The following sections define the generator groups and present the methodology and results of the assessment effort for the urban wood residue stream. Data were gathered during January and February 1997 by means of a telephone survey.

3.1 Definitions of Wood Residue Generators and Processors

For purposes of this resource assessment, "Generators" can be defined as entities that are original producers of wood residues. Generators may produce the materials themselves or hire contractors. In the case of contractors, every effort has been made to avoid double counting of the wood residues.

A second group involved with the urban wood residue stream can be defined as "processors" or wood recyclers. Processors do not generate material themselves but serve to concentrate and, in some cases, add value to the resource through grinding, transportation and/or provision of other services.

3.1.1 Primary Wood Products Processors

Primary wood processors are individual firms engaged in the production of lumber. Timber taken directly from forests and processed in saw and lumber mills is the main operation of these firms. Two SIC codes are classified as being primary wood processors. These SIC codes are:

- 2421 - Sawmills and Planing Mills
- 2426 - Hardwood Dimension and Flooring Mills

Within the target counties, a total of 68 primary wood processors were identified.

3.1.2 Secondary Wood Products Manufacturers

All firms engaged in processing lumber into a final product are defined under the secondary wood products manufacturers industry for this study. In general, most firms in this industry are categorized under SIC code 24: Lumber and Wood Products Excluding Furniture, or SIC code 25: Furniture and Fixtures. Pallet manufacturers and recyclers are classified under the SIC code 2448, Wood Pallets and Skids. This classification includes all manufacturers of wooden pallets, crates, and skids. For the study area, a total of 238 secondary wood processors were identified.

The following company types and SIC codes are generally described as secondary manufacturers:

- 2431 - Millwork
- 2434 - Wood Kitchen Cabinets
- 2435 - Hardwood Veneer and Plywood
- 2436 - Softwood Veneer and Plywood
- 2439 - Structural Wood Members
- 2441 - Nailed and Lock Corner Wood Boxes and Shook
- 2448 - Wood Pallets and Skids

- 2449 - Wood Containers
- 2451 - Mobile Homes
- 2452 - Prefabricated Wood Buildings and Components
- 2491 - Wood Preserving
- 2493 - Reconstituted Wood Products
- 2499 - Wood Products, Not Elsewhere Classified
- 2511 - Wood Household Furniture
- 2512 - Wood Household Furniture Upholstered
- 2521 - Wood Office Furniture
- 2531 - Public Building and Related Furniture
- 2541 - Wood Office and Store Fixtures
- 2599 - Furniture and Fixtures, Not Elsewhere Classified

3.1.3 Urban Tree Trimming and Landscape Residue (UTR)

Tree and landscape residues are estimated to account for approximately 18 percent of municipal solid waste (MSW) by weight and are the second largest contributor to the United States' MSW load.[11] It is estimated that during the past decade, the tree and landscape residue portion of the waste stream has been increasing by approximately 2.2 percent annually. Generator groups, and where applicable corresponding SIC codes, of the UTR sector include:

- Commercial Tree Care Firms (SIC 0783)
- Landscape Maintenance / Landscaper Firms (SIC 0782)
- Municipal Park and Recreation Departments
- Municipal Tree Care Divisions
- County Tree Care Divisions
- Electric Utility Power Line Maintenance
- Excavator / Land Clearance Firms (SIC 1794)

3.1.4 Construction and Demolition (C&D)

Construction firms are all general contractors engaged in the construction of buildings, both residential and non-residential.

Demolition firms, SIC code 1795, are considered special trade contractors engaged in the wrecking and demolition of buildings and other structures. They may or may not sell the wood wastes derived from demolishing the buildings.

Inventory work for this wood waste generator category is difficult to perform due to a lack of general accounting on the part of the firms when recording wood wastes. Also, based on conversations with several area wood recycling companies, it became evident that much of the waste from construction sites is either processed by recyclers or sent to landfills. Most of the wood waste from demolition activities is contaminated with metals, paints, concrete and is primarily landfilled. Only one Colorado Front Range wood recycler is known to accept demolition waste.

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[11] U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, EPA/530-S-92-019, July 1992.

It was decided that for purposes of this report, wood residue from this generator category would be captured to a great extent by the data reported by the wood recyclers. No effort was made to estimate the total amount of wood residue generated by this sector outside of this approach.

3.1.5 Wood Recyclers/Processors

Wood recyclers play an important role in the utilization of urban wood residues in the Denver metro area. At the present time, there are seven facilities operating in the region.

3.1.6 Landfills/Transfer Stations

Landfills and transfer stations were contacted in an effort to determine the quantity of wood residues going to landfills and their average tip fees.

3.2 Urban Wood Residue Production

This section documents the methodology and results of the urban wood residue resource assessment effort.

3.2.1 Methodology

The methodology utilized for this effort was straightforward. First, a database of generators and processors was developed. A listing of the primary and secondary wood products manufacturers and wood recyclers in Colorado was obtained from a directory compiled in 1995 by the Colorado State Forest Service (CSFS). Contact information for entities in the urban tree trimming sector was obtained from an in-house database developed by NEOS Corporation for a previous resource assessment effort. Landfills were identified through the Yellow Pages and through contacts provided by FRFHP members.

For each target group, a brief survey form was designed, and a telephone survey was undertaken. A copy of each sector's data collection form can be found in Appendix C. In most cases, the top parts of the form were completed by merging the mailing list with the survey from template to create an individual from for each target entity.

For the primary and secondary manufacturers, attempts were made to contact all 306 companies contained in the database. If the phone was disconnected and there was no forwarding number, it was assumed the entity was out of business. Also, if an answering machine was reached, it was assumed the entity was relatively small and no further effort was made to obtain data from that company.

For the UTR sector, two approaches were followed. Data were primarily obtained from a previous project NEOS undertook on behalf of the International Society of Arboriculture Research Trust.[12] An attempt was made to update the data developed under the previous effort (original data were collected in the Spring of 1994) by re-contacting 65 of the largest known UTR generators in the Front Range. Several large entities (e.g. Public Service Company of Colorado, Davey Tree Expert Company, City of Denver, City of Lakewood, City of Wheat Ridge) provided updated information. For entities that could not be reached, 1994 data were used.

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[12] NEOS Corporation, *Urban Tree Residues: Results of the First National Inventory*. Available from the ISA Research Trust, Savoy, IL, Phone: (217) 355-9491. September 1994

The second approach for the UTR sector involved using a commercially available business database (Phone Disc) to obtain a listing of all commercial tree care (SIC 0783) and landscaping (SIC 0782) companies with operations in the target area. More than 1,000 companies were identified. From this listing, a random sample of 200 companies was selected. These companies were then contacted by telephone. However, after approximately 80 contacts, it was found that most of the companies were either too small, out of business, or did not track their generation and disposal of materials; thus, this approach was abandoned and greater effort was placed on contacting the larger entities.

The wood recyclers were contacted by telephone, and one site was visited. In addition, NEOS staff had visited several of the other sites in the past. As with the generators, it is important to account for possible double counting when assessing the wood processors. Most wood recyclers receive material from a generator, thus the potential exists for the same material to get counted twice in the overall total.

The study attempts to minimize the potential for double counting by not including construction or used pallet waste in the generator category total (clean construction wood and used pallets make up more than 50 percent of the wood going to wood recycling companies) and subtracting the amount of UTR processed by recyclers from the UTR total.

Finally, all data were converted to standard units (bone dry tons), entered into a computer, cleaned, and incorporated into a Geographic Information System (GIS) format for manipulation and presentation.

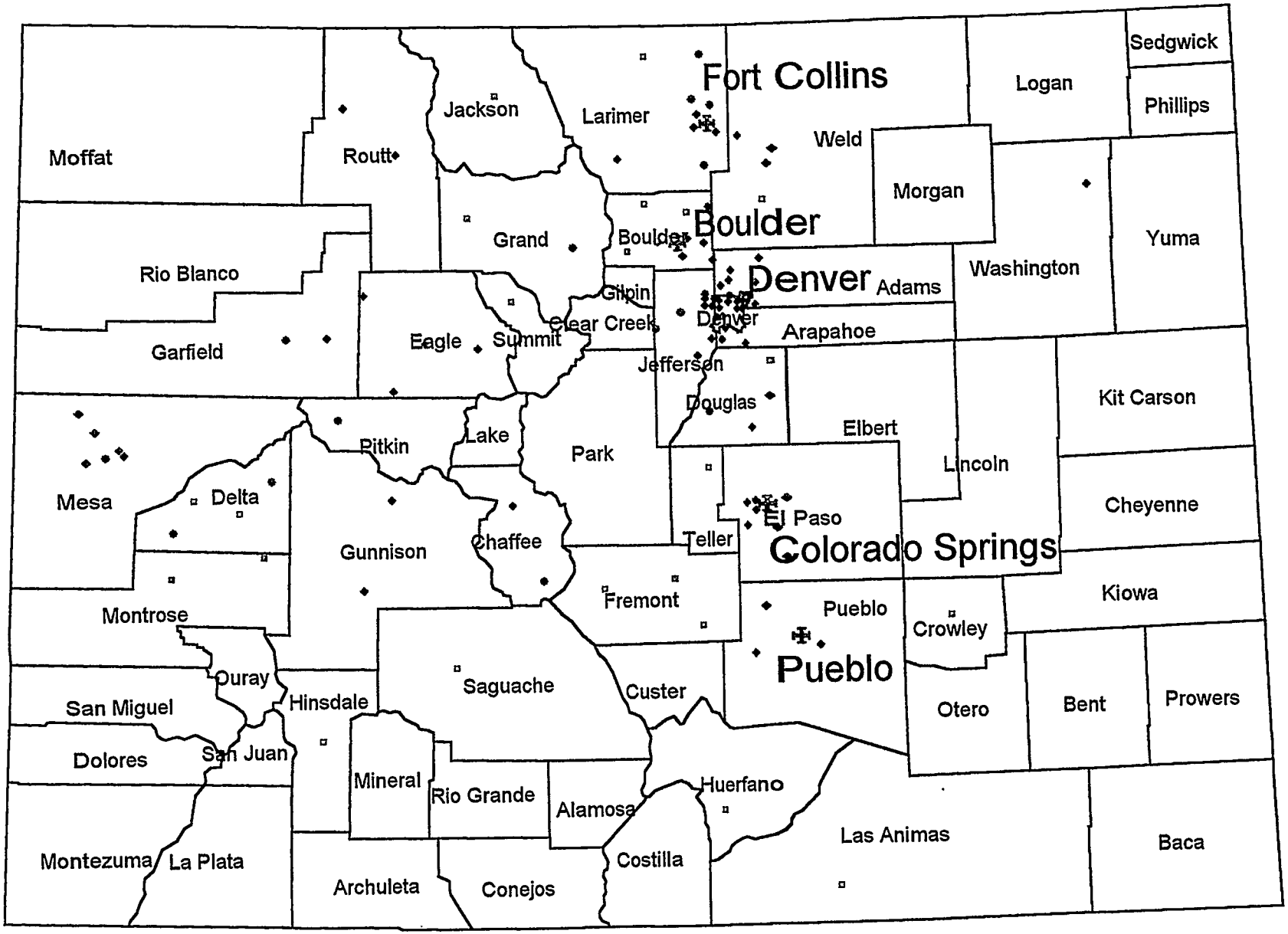
3.2.2 Results

This section contains the results of the Front Range urban wood residue resource assessment effort. In general, the reader should keep the following issues in mind as he or she reads this report:

- Very few, if any, companies actually track their generation of wood residues - most companies only provided estimates of the material they produce.
- The industries considered for this study are diverse, ranging from "mom and pop" operations to large corporations with several hundred employees.
- There is frequent turnover of companies within both the UTR and primary/secondary manufacturers sectors. New companies are constantly entering the market, and the failure rate for existing businesses is high. The annual turnover rate is estimated to be 25 percent.
- The issue of units is important. Entities provided data using units of tons, cubic yards, 55 gallon drums, pick-up trucks, dumpsters, boxes, and assorted others. Every effort was made to be consistent and conservative when converting numbers to bone dry tons (bdt).
- For the UTR sector, the potential for double-counting is significant. Many utilities and municipal departments use private sector companies to perform tree trimming, tree removal and landscaping operations. The 1994 ISA UTR study adjusted all data for contracting operations. Similar efforts were made to adjust newly collected data.
- Within the UTR sector, the influence of natural disasters is significant, but extremely difficult to measure. One-time events, such as the 1995 Colorado Front Range September snow storm, lead to the generation of significant quantities of material over a brief time period. Many municipalities along the Front Range still have materials left over from the 1995 storm.

3.2.2.1 Primary and Secondary Manufacturers

Table 10 shows an overview of the primary and secondary manufacturers contained in the CSFS Directory, and Figure 4 shows the locations (based on zip codes) that contain one or more processors.



Major Cities
Secondary Processors
Primary
Secondary
County Boundaries

Figure 4. Locations of Primary and Secondary Manufacturers

A total of 731 companies are contained in the Directory, of which 306 are located within the study area. Of the 306 target companies, 68 are classified as primary manufacturers and 238 are classified as secondary manufacturers. Telephone calls were placed to all 306 companies located within the area of interest. It was found that 82 (27%) of the 306 are out of business, leaving a viable population of generators in this sector of 224 companies.

Of the 224 companies still in business, 161 (72%) are considered too small to be significant sources. A company is classified as "too small" if an answering machine was reached or no one answered the telephone. Information on wood residue production was obtained from 63 companies.

Table 10. Status of Primary and Secondary Manufacturers

Description	Numbe	Percent
Total listed in Colorado	731	
Total listed in Front Range	306	42%
Out of business (Front Range only)	82	27%
Companies operating in Front	224	
"Too small"	161	72%
Responses obtained	63	28%

Table 11 shows the data for residue production and disposal by the primary and secondary manufacturers. It is conservatively estimated that a total of 20,163 bdt per year of wood waste is generated by this sector, of which 8,258 bdt (41 percent) is presently sold.

Table 11. Summary of Residue Generation and Disposal

Item	Quantity (bdt)
Total Production	20,163
Amount Sold	8,258
Amount Landfilled	6,493
Amount Given Away	3,519
Amount Used On-site	1,893

The residue being sold goes mainly for purposes of animal bedding, firewood and mulch. Only three companies reported data for sales prices. The values are $13.89, $34.74 and $52.47 per bdt. The highest value obtained is for animal bedding while the end-use of the lowest value was not reported. The middle value is for firewood.

Only one respondent reported data for the cost of landfilling wood waste. This value was $8 per cubic yard, or approximately $26/bdt. Most respondents indicated that they do not like to landfill their materials and they try to dispose of their wood waste by whatever means are cheap and easy.

For purposes of the scoping study, it is assumed that the material not being sold, 11,905 bdt/yr., would be available to the ethanol facility for the price of transportation only. Based on conversations with wood recyclers and trucking companies it is assumed that the approximate trucking cost would be $150/truck load for delivery anywhere in the metro area. Assuming an average load size of 10 bdt truck, the cost of transportation is estimated to be $15/bdt.

3.2.2.2 UTR

The UTR sector is more difficult to define and summarize than the primary/secondary manufacturers sector. The UTR industry is highly diversified, populated with a small number of large entities and a multitude of small companies. Most of the material generated by this sector is of relatively low value and disposal is often considered a problem. The material is mainly in the form of chips, tops and brush, and whole logs. Loads of UTR often include leaves, grass, bark and other debris. Most UTR generators are in the position of trying to minimize their costs associated with disposal, whether this entails stockpiling, using on site, give away, or illegal dumping. Nevertheless, UTR represents a large, inexpensive resource that might be tapped for the ethanol facility.

The number of entities in the Front Range UTR database is 69. These are believed to be the largest entities operating along the Front Range. This assumption is based on NEOS' knowledge of the industry and because the names were obtained from association lists that require payment of annual dues. Although attempts were made to contact all 69 entities, it was not possible to collect residue production data for all, thus it became necessary to develop estimates for those cases with missing values.

For the cases where data were not available, minimum, maximum, and median values for residue generation were developed for each sector (e.g. commercial tree care, municipal forestry, electric utility, etc.) based on the newly collected data as well as the data from 1994. For entities located in heavily populated areas (e.g. Denver), the median values were then applied to the cases with missing data. For entities located in less populated areas (e.g. Greeley), the minimum values were applied to cases with missing data. Mean values were not used due to the influence of either very large or very small values on the calculation of means for this industry. Table 12 shows the values developed from the data for the Colorado Front Range.

Table 12. Summary Statistics for UTR Production on the Colorado Front Range

UTR Generator	Number of Cases	Minimum ($yds^3/yr.$)	Maximum ($yds^3/yr.$)	Median ($yds^3/yr.$)
Commercial Tree Care	22	460	50,000	4,970
Parks and Recreation Dept.	5	2	7,500	546
Municipal Forestry Dept.	4	282	50,000	25,000
Electric Utility	4	6,760	30,000	25,500
Landscape Contractor	4	150	2,500	817

The estimate for annual UTR production for just the 69 entities included in the study is 551,474 cubic yards. Assuming 40 percent moisture content and an average conversion factor of 3.3 cubic yards per ton, the estimated annual production of UTR by these companies is 100,268 bdt.

Estimates for Additional UTR Generators

The UTR data presented thus far in this report are only for 69 entities, thus they are conservative with regards to the estimate of overall UTR production in the Front Range. In an effort to determine an estimate for overall UTR production in the region, some assumptions must be made.

There are over 1,000 commercial tree care and landscaping companies listed in PhoneDisc for the Front Range area of Colorado. There are also believed to be at least 10 municipal and county forestry departments, parks and recreation departments and electric utilities. Although many of the largest

entities were contacted for this effort, the sheer size of the industry and the concentration of trees in metro areas makes for a larger resource base than the 100,268 bdt accounted for through the survey. Table 13 shows an estimate of additional residue production along the Front Range.

Table 13. Estimate of Additional UTR Production in Front Range

Category	Number	Minimum Production ($yds^3/yr.$)	Estimated Total ($yds^3/yr.$)
Commercial Tree Care	150	460	69,000
Landscapers	500	150	75,000
Med.-Large Municipalities	10	282	2,820
Utility with multiple counties	2		30,760
Total [13]			177,580

The "number" column is a conservative estimate of additional entities located in the region. For Commercial Tree Care and Landscapers, the number listed in Table 13 is calculated by counting the SIC codes in the PhoneDisc database, then subtracting the number that provided data through the survey, and finally, subtracting 25 percent of the total to account for business failures. The number of municipalities accounts for several large cities that did not provide data. These include Arvada, Boulder, Cherry Creek, Longmont, Louisville, Parker, Pueblo and others. For each generator type, the number of entities is multiplied by the "minimum" production value first listed in Table 12.

The total additional material is therefore estimated to be 177,580 cubic yards/year, or 32,287 bdt/year. Thus, the total UTR production on the Front Range can be conservatively estimated at 132,555 bdt per year (100,268 bdt from the survey and the additional 32,287 bdt estimated above).

Figure 5 shows the estimated disposal methods for UTR based on those respondents who reported data for disposal. Most entities try to dispose of their material for as little cost as possible, and "give away" is the most common disposal method. Very little of the UTR appears to be landfilled. Of the 13 percent sold, the biggest market is firewood, followed by mulch. No information on selling price was obtained.

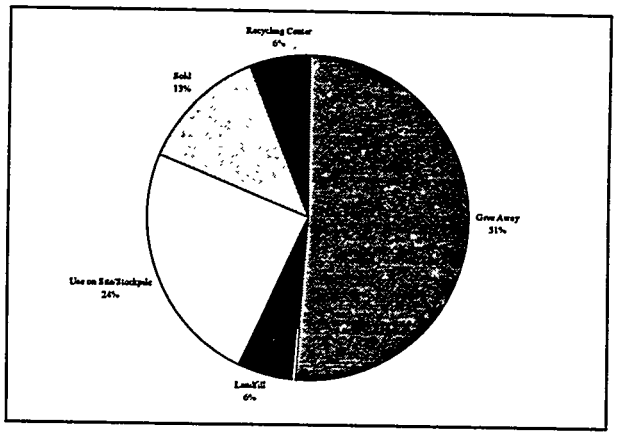


Figure 5. Disposal Methods for UTR

[13] The value of 30,760 cubic yards per year was obtained from actual data. However, because the two utilities operate across multiple county boundaries on the front range, their data are included in the additional section rather than the county-specific section.

For planning purposes, it can be assumed that 13 percent of the material presently has a market and is not available for ethanol production. Also, it known that approximately 17,000 bdt of material is going to wood recyclers each year (see Section 3.2.2.3). Subtracting the residue sold and recycled from the total leaves an estimated 98,291 bdt per year available to the ethanol facility.

It is expected that most of this material could be obtained for the cost of transportation only. However, it is also likely that for certain large generators (e.g. Public Service Company of Colorado, City of Lakewood, City of Denver) the UTR material could be obtained free of charge. To be conservative, this report will assume a price of $15/bdt for the UTR material. There are no significant seasonal variations in residue generation.

This report does not include any of the material stockpiled as a result of the 1995 snowstorm. For example, the City of Denver has approximately 150,000 cubic yards of UTR stored on an old runway at Stapleton Airport. Many other cities in the region reported similar, but smaller, stockpiles.

3.2.2.3 Wood Recyclers

The wood recyclers included in this study are listed in Table 14. Each facility was contacted, with the exception of Construction Recycling, Inc. (CRI). It has been reported by other recyclers that CRI is not accepting any materials at their facility at this time.

Table 14. List of Wood Recyclers

Company	Contact	Address	City	Zip	County	Phone
Renewable Fiber	Carl Spaulding	4500 South Clay	Englewood	80110	Arapahoe	303-798-1292
Wes Moser & Sons Inc	John R Moser	P O Box 205	Ft. Lupton	80621	Weld	303-785-2903
Wood Recovery Systems	John Edwards	3031 Hwy. 119	Longmont	80504	Weld	303-665-2274
Wood Recycling Inc.	Sherman Jensen	8980 S. Santa Fe Dr.	Littleton	80125	Douglas	303-791-4250
Construction Recycling Inc.	Not accepting residue now	3220 Weld County Rd #8	Erie	80304	Boulder	303-440-8777
A-1 Organics/Lost Antlers	Bob Yost	6569 Hwy 93	Golden	80403	Jefferson	303-384-9232
A-1 Organics	Bob Yost		Eaton		Weld	

Each recycling facility was asked questions regarding the amount of material they process each year, where their raw material comes from, what products they make, and what prices they receive for their finished products. All data for wood recyclers are reported after grinding has taken place. Most information was reported in cubic yards and then converted to bdt.

No individual facility data are reported in this study due to the request by many of the recyclers for confidential treatment of information provided. Table 15 shows the total amount of wood processed by all of the facilities (with the exception of CRI). A total of 59,158 bdt per of finished product is produced by area wood recyclers. The largest sources for their raw material are construction waste, used pallets, and UTR, which together account for 73 percent of facility input.

Table 15. Total Material Processed and Source of Raw Material (bdt/yr.)

Quantity (bdt/yr.)	Construction	Used Pallets	Primary Manufacturer	UTR	Unknown Source
59,158	19,405	12,289	1,909	17,069	8,485
	33%	21%	3%	29%	14%

All of the recyclers charge a tip fee for the material brought to their site. Typically, the tip fee covers the costs of grinding the material. All tip fees were lower than landfill costs. The average tip fee charged is $15.58 per bdt (range of $10.12 to $18.86).

Table 16 shows the prices received for each product that the recyclers manufacture. Primary products are mulch, dyed mulch, compost, and animal bedding. Dyed mulch brings the highest price on the market, whereas animal bedding and mulch fetch the lowest prices. The ethanol facility would have to match or beat the current market prices in order to obtain a given stream of material. Figure 6 shows the market share for each of the products. Compost is the largest, followed by mulch, dyed mulch, and animal bedding. There are no regional energy markets. Also, the closure of the Medite facility in New Mexico has hurt some recyclers. Figure 7 shows the location of local recyclers.

Table 16. Product Prices and Tonnage

Item	Total (bdt)	Mulch	Dyed Mulch	Compost	Animal Bedding
Low Price ($/bdt)		$15.32	$60.00	$35.41	$23.83
High Price ($/bdt)		$30.00	$70.00	$42.58	$30.00
Average Price ($/bdt)		$26.79	$63.35	$39.36	$25.78
Product Tonnage (bdt)	59,158	12,486	11,059	26,207	9,405

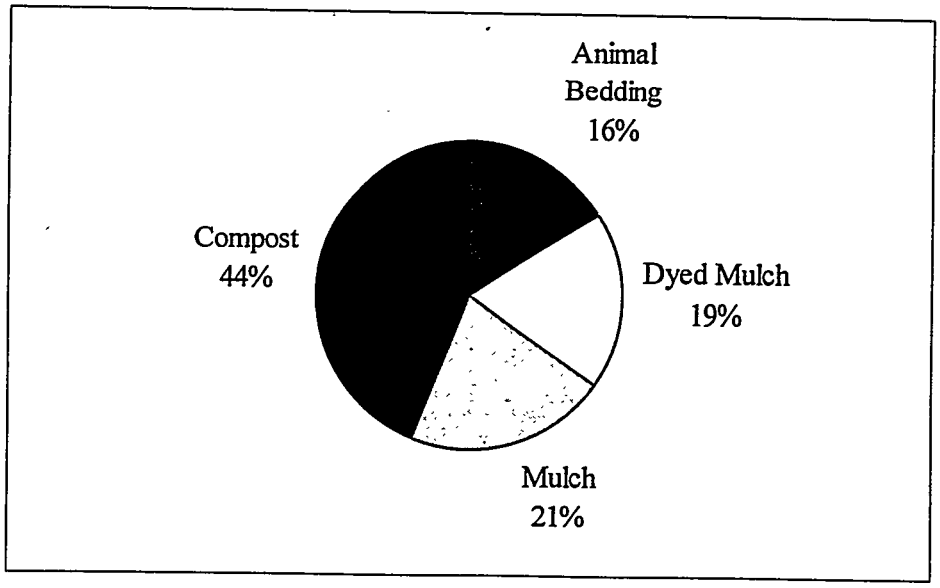


Figure 6. Percentage Breakdown of Wood Recycler Product Sales

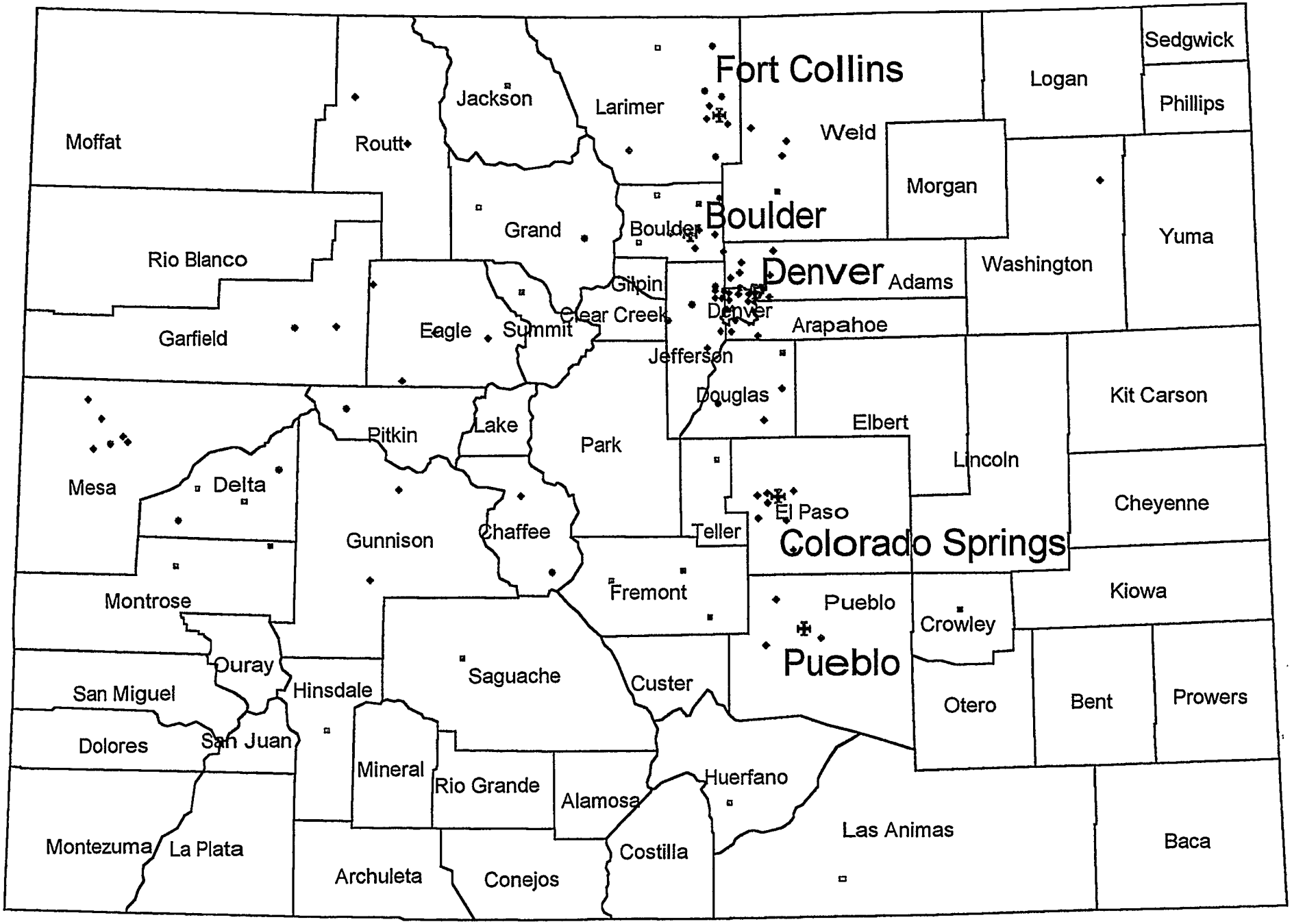


Figure 7. Locations of Wood Recycling Facilities

3.2.2.4 Landfills/Transfer Stations

Most landfills along the Front Range do not separate wood waste and thus could not provide any information on wood waste quantities going to area landfills. Of the eleven landfills and transfer stations contacted, only two, Evergreen transfer station and Boulder County, separate wood waste. Evergreen separated approximately 4,000 cubic yards of wood waste in 1996, and Boulder County separated 1,200 tons.

The average tipping fee at the landfills is $5.50 per cubic yard (roughly $18 per ton). However, Evergreen charges $16/yard for wood waste.

3.3 Summary of Urban Wood Waste

The total amount of urban wood waste available to supply a potential ethanol facility is summarized in Table 17. The table provides rankings for the materials from lowest to highest cost and shows a cumulative total as well as a blended cost as each successively higher priced resource is added to the mix. For example, utilizing only primary/secondary waste, UTR, and the animal bedding stream from recyclers, the total amount available would be 119,601 bdt/year at an average price of $15.85/bdt.

For the entire Front Range, it is estimated that a minimum of 169,354 bdt/yr. of material is available at an average cost of $23.39 per bdt. UTR is the primary resource and also the least expensive. UTR represents a diverse resource mix composed of chips from multiple species, leaves, grass clippings, and assorted branches and logs.

Table 17. Summary of Urban Wood Residue Production and Prices for Front Range

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	11,905	11,905	$15.00	$15.00
UTR	98,291	110,196	$15.00	$15.00
Recycler - Animal Bedding	9,405	119,601	$25.78	$15.85
Recycler - Mulch	12,486	132,088	$26.79	$16.88
Recycler - Compost	26,207	158,294	$39.36	$20.60
Recycler - Dyed Mulch	11,059	169,354	$63.35	$23.39
TOTAL		169,354		$23.39

4. SUMMARY OF FOREST AND URBAN WOOD RESIDUES

Table 18 shows the overall summary of "core" forest and urban wood residues. It is estimated that approximately 7.5 million bdt of material is available along the Front Range. The reader should keep in mind that the forest residues shown below represent the total amount of residue available and do not account for time, including tree growth. It is likely that only a few thousand acres would be harvested in any one year from the forest. The numbers for urban wood waste reflect the amount available on an annual basis. The forest data have been annualized in Table 19 through Table 21 below.

Table 18. Summary of Wood Residue Production

Source	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	11,905	11,905	$15.00	$15.00
UTR	98,291	110,196	$15.00	$15.00
Recycler - Animal Bedding	9,405	119,601	$25.78	$15.85
Recycler - Mulch	12,486	132,088	$26.79	$16.88
Recycler - Compost	26,207	158,294	$39.36	$20.60
Forest Residues Front Range "Core"	7,335,881	7,494,175	$54.83	$54.11
Recycler - Dyed Mulch	11,059	7,505,235	$63.35	$54.12
TOTAL		7,494,175		$54.12

** Not an annual figure, data are for core Front Range only*

Table 19 shows the estimated total annual biomass production for each county included in the study area. There is an estimated 1.1 million bdt of biomass produced in the study area on an annual basis.

It should be noted that the column entitled "Total Forest Biomass Production" is not an annual figure, whereas the data for UTR and Primary and Secondary production are based on annual estimates. To arrive at the final column (Estimated Annual Total), the forest data are annualized (assuming an estimated project life of 20 years) by dividing the number in the "Total Forest Biomass Production" column by 20 and then adding the UTR and Primary/Secondary values. The final row in Table 19 (Multiple/Unknown) is inserted to show the UTR generated by large electric utilities and the estimated additional total generation (32,287 bdt, see Section 3.2.2.2) for which no location information is available.

Table 20 shows the estimated amount of biomass available by county for the study area. The data for availability are calculated by subtracting the amount of residue known to be sold or recycled from the total biomass production numbers listed in Table 19. All of the forest biomass is assumed to be available because the methodology followed already adjusts for availability. Over 1 million bdt of wood waste are available from the entire Front Range study area on an annual basis.

Table 21 shows annual woody biomass availability for a sub-set of the counties included in the study. The counties listed in Table 21 are for a "core" group of counties located within a 50 - 100

mile radius of the Denver metro area. Total annual biomass availability for the core counties is 526,056 bdt/year. Most of this material is forest residues.

Table 22 shows an estimate for the total and blended costs of each residue stream. The forest resources have been annualized by dividing the total amount available by 20 years. The table shows that the 526,057 bdt are available at an average cost of $45.47 per bdt.

An ethanol facility may not require all of the available material. If less residue is required, it is likely that the facility could utilize the lower proceed resources first, thus lowering the overall average price paid for raw material. However, if the facility requires higher-quality raw material (e.g. free of bark, leaves and needles), overall processing costs might increase.

Figure 8 shows a summary map of biomass availability by county. To arrive at Figure 8, the forest biomass for each county was divided by 20 (assuming a 20 year supply for the ethanol facility is desired) to determine average annual forest biomass availability. This number was then added to the estimates of urban wood waste in order to determine total biomass available in each county on an annual basis. The UTR data used in Figure 8 are the actual data collected for the study. In other words, the estimate of additional UTR resources has not been scaled to the county-level at this time. Also, because utilities serve multiple counties, their data have not been used to create the map.

Table 19. Estimated Annual Biomass Production, by County

County Name	Study Class (1=Urban Only; 2=Urban & Forest)	Primary and Secondary Production (bdt/yr)	UTR Production (bdt/yr)	Total Forest Biomass Production (bdt)	Estimated Annual Total (for 20 years) (bdt/yr)
Adams	1	5,556	10,431		15,987
Arapahoe	1	21	9,289		9,310
Boulder	2	3,318	2,722	1,021,024	37,964
Chaffee	2	85		52,311	29,451
Clear Creek	2			663,890	24,875
Crowley	1				ND
Custer	2			548,490	24,467
Delta	1	2,397	904		3,301
Denver	1	3,559	25,547		29,106
Douglas	2	2	27	586,859	39,870
Eagle	1	82	84		166
El Paso	2	21	4,073	996,570	65,012
Elbert	1				ND
Fremont	2		84	816,078	49,698
Garfield	1	161	84		245
Gilpin	2			441,455	15,684
Grand	2			694,848	63,737
Gunnison	1				ND
Hinsdale	1				ND
Huerfano	2			1,043,712	55,061
Jackson	1				ND
Jefferson	2	250	37,106	1,361,688	105,440
Lake	2			207,270	17,626
Larimer	2	1,067	6,971	2,661,162	161,540
Las Animas	2			2,476,608	124,930
Mesa	1	1,118	84		1,202
Morgan	1				ND
Park	2			1,125,684	71,890
Pitkin	1				ND
Pueblo	2	1,676	480	318,339	18,347
Routt	1				
Saguache	2			464,877	25,663
Summit	2				ND
Teller	2	850		1,138,711	54,714
Washington	1		84		84
Weld	1		2,299		2,299
Multiple/Unknown			32,287		32,287
Wood Recyclers					59,158
TOTAL		**20,163**	**132,556**	**16,619,576**	**1,139,114**

ND = No Data

Table 20. Estimated Annual Biomass Availability, by County

County Name	Study Class (1=Urban Only; 2=Urban & Forest)	Primary and Secondary Available (bdt/yr)	UTR Available (bdt/yr)	Total Forest Biomass Available (bdt)	Estimated Annual Total (for 20 years) (bdt/yr)
Adams	1	5,480	7,737		13,217
Arapahoe	1	21	6,890		6,911
Boulder	2	1,273	2,019	1,021,024	54,343
Chaffee	2			52,311	2,616
Clear Creek	2			663,890	33,195
Crowley	1			-	ND
Custer	2			548,490	27,425
Delta	1	11	671	-	681
Denver	1	2,264	18,950	-	21,214
Douglas	2	2	20	586,859	29,365
Eagle	1	82	62	-	144
El Paso	2	21	3,021	996,570	52,871
Fremont	2	-	62	816,078	40,866
Garfield	1	161	62	-	223
Gilpin	2			441,455	22,073
Grand	2			694,848	34,742
Huerfano	2			1,043,712	52,186
Jackson	1			-	ND
Jefferson	2	250	27,523	1,361,688	95,858
Lake	2			207,270	10,364
Larimer	2	658	5,171	2,661,162	138,887
Las Animas	2			2,476,608	123,830
Mesa	1	355	62	-	417
Morgan	1			-	ND
Park	2			1,125,684	56,284
Pitkin	1			-	ND
Pueblo	2	606	356	318,339	16,879
Routt	1			-	ND
Saguache	2			464,877	23,244
Summit	2			-	ND
Teller	2	722		1,138,711	57,658
Washington	1		62	-	62
Weld	1		1,705	-	1,705
Multiple/Unknown			23,916	-	23,916
Wood Recyclers				-	59,158
TOTAL		**11,905**	**98,291**	**16,619,576**	**1,000,333**

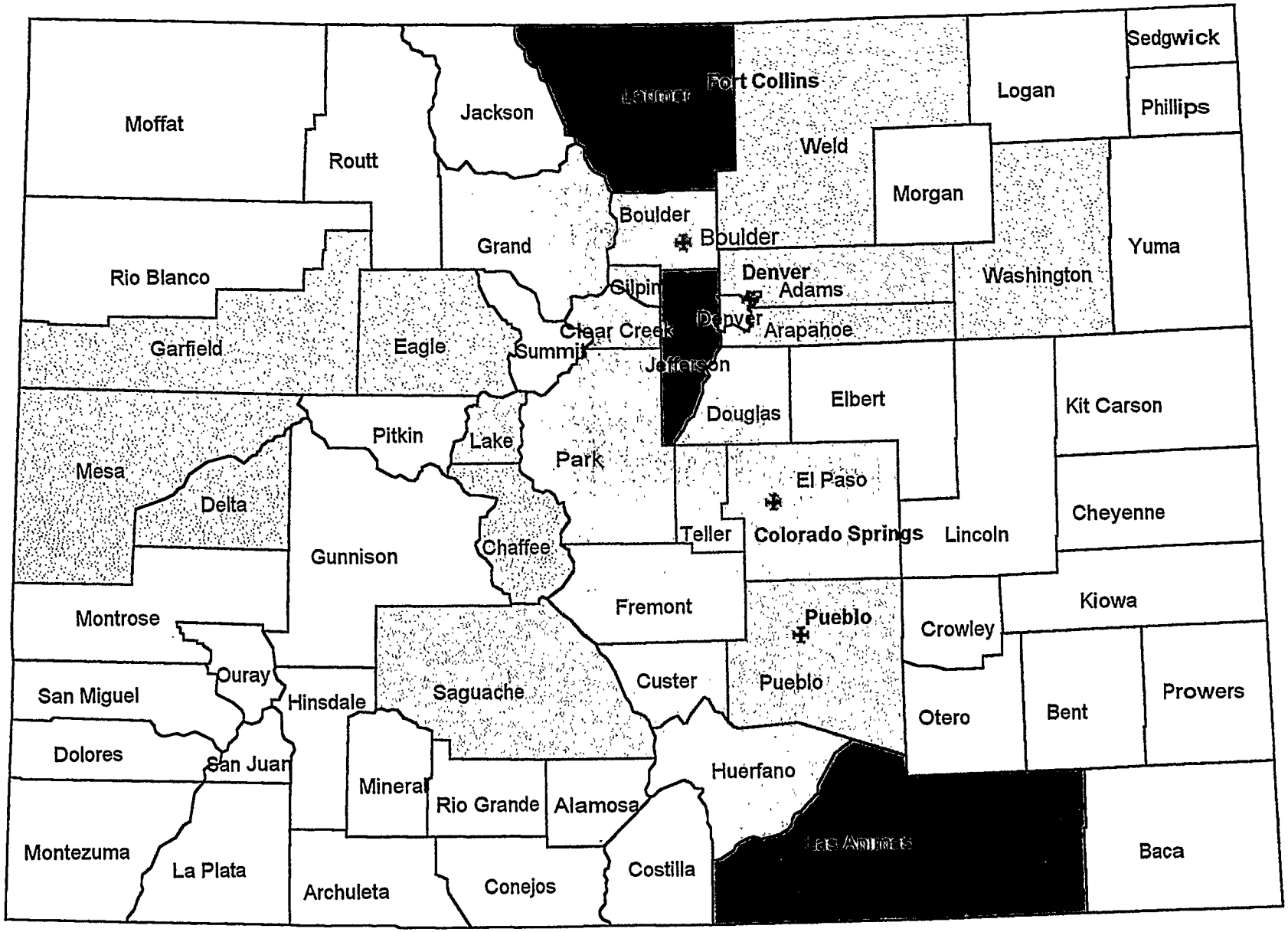
ND = No Data

Table 21. Estimated Annual Biomass Availability for the "Core" Front Range

County Name	Study Class (1=Urban Only; 2=Urban & Forest)	Primary and Secondary Available (bdt/yr)	UTR Available (bdt/yr)	Total Forest Biomass Available (bdt)	Estimated Annual Total (for 20 years) (bdt/yr)
Adams	1	5,480	7,737		13,217
Arapahoe	1	21	6,890		6,911
Boulder	2	1,273	2,019	1,021,024	54,343
Clear Creek	2			663,890	33,195
Denver	1	2,264	18,948		21,212
Douglas	2	2	20	586,859	29,365
El Paso	2	21	3,021	996,570	52,870
Gilpin	2			441,455	22,073
Jefferson	2	250	27,522	1,361,688	95,856
Park	2			1,125,684	56,284
Teller	2	722		1,138,711	57,658
Multiple/Unknown			23,916		23,916
Wood Recyclers					59,158
TOTAL		**10,033**	**90,073**	**7,335,881**	**526,057**

Table 22. Estimated Annual Costs of Biomass for the "Core" Front Range

Product	Total Quantity (bdt/yr)	Cumulative Total (bdt)	Average Cost ($/bdt)	Blended Cost ($/bdt)
Primary/Secondary Manufacturer	10,033	10,033	$15.00	$15.00
UTR	90,073	100,106	$15.00	$15.00
Recycler - Animal Bedding	9,405	109,511	$25.78	$15.93
Recycler - Mulch	12,486	121,997	$26.79	$17.04
Recycler - Compost	26,207	148,204	$39.36	$20.98
"Core" Forest Residues Annual	366,794	514,998	$54.83	$45.09
Recycler - Dyed Mulch	11,059	526,057	$63.35	$45.47
TOTAL		**526,057**		**$45.47**



Major Cities
County Boundaries
Total Biomass
Not included
< 10,000 bdt/year
10,000 - 25,000 bdt/year
25,001 - 75,000 bdt/year
> 75,000 bdt/yeara

Figure 8. Estimated biomass available (bdt/year)

Appendix A. National Forest Data

Assumptions Used for Economic Analysis

ECONOMIC INPUTS AND ASSUMPTIONS		
Mountain haul cost	1.25	per mile
Urban haul cost	1	per mile
Minimum haul cost**	$ 165	roundtrip load
Wood Energy Content*	9,020	Btu/dry lb
Wood Energy Content*	18.0	MMBtu/bone dry ton
Wood Cost at Landing	$39.00	$/bone dry ton
Trailer Capacity	11.25	dry tons
Stumpage	$ 0.25	CCF or cunit @ national forest fund ra
Stumpage	$ 0.45	bdt
Surface road	$0.00	
Slash treatment	$0.00	

** $55 per hour @ 3 hours
*Ponderosa Pine

Ir... an... sum... ns fc... est... ass... ntic...

Description	Value	Units	Source	Notes
Biomass, 5 - 11.9"	19.74	wet tons/acre	Lynch	
Biomass moisture conte	50%		Assumed	
Biomass resource	9.87	bone dry tons/	calculation	
Conifer available timberland				
Arapaho - Roosevelt	774,329	acres	1987 USFS Invento	total acres less aspen, bristlecone, limber
Pike - San Isabel	1,280,065	acres	1987 USFS Invento	total acres less aspen, bristlecone, limber
Suitable national forest timberland				
Arapaho - Roosevelt 5	112,783	acres	TRACS	
Arapaho - Roosevelt 6	247,317	acres	TRACS	
Arapaho - Roosevelt T	360,100	acres	calculation	
Pike - San Isabel 500	92,932	acres	TRACS	
Pike - San Isabel 600	488,618	acres	TRACS	
Pike - San Isabel TOTAL	581,550	acres	calculation	
Ratio, Suitable to Available				
Arapaho - Roosevelt	47%		calculation	
Pike - San Isabel	45%		calculation	
Total National Forest Acreage				
Arapaho - Roosevelt	1,264,795	acres	1987 USFS Inventory	
Pike - San Isabel	2,227,120	acres	1987 USFS Inventory	

Arapaho - Roosevelt National Forests Acreage in Red Zone

County	Douglas Fir/ Mix	Lodgepole Pine	Ponderosa Pine	Total Acres	% of Total Forest
High Risk w/Buffer					
Boulder	15,627	15,109	28,268	59,004	5%
Clear Creek	2,732	7,707	1,071	11,509	1%
Gilpin	2,161	11,888	531	14,580	1%
Grand	-	-	-	-	0%
Jefferson	118	1,948	2	2,068	0%
Larimer	12,981	21,508	25,424	59,913	5%
Park	574	277	-	851	0%
TOTAL	34,193	58,437	55,295	147,925	12%
Medium Risk w/Buffer					
Boulder	7,653	7,056	1,134	15,843	1%
Clear Creek	9,195	11,152	408	20,754	2%
Gilpin	6,403	4,420	24	10,847	1%
Grand	-	-	-	-	0%
Jefferson	110	-	-	110	0%
Larimer	7,523	15,458	19,127	42,108	3%
Park	1,210	632	-	1,843	0%
TOTAL	32,095	38,718	20,693	91,506	7%
High and Medium Risk Combined w/ Buffer					
Boulder	23,280	22,165	29,402	74,847	6%
Clear Creek	11,926	18,859	1,479	32,263	3%
Gilpin	8,564	16,307	556	25,427	2%
Grand	-	-	-	-	0%
Jefferson	229	1,948	2	2,178	0%
Larimer	20,504	36,966	44,551	102,021	8%
Park	1,784	910	-	2,693	0%
TOTAL	66,287	97,154	75,989	239,430	19%

Pike - San Isabel National Forests, Acreage in Red Zone

County	Douglas Fir/ Mix	Lodgepole Pine	Ponderosa Pine	Total Acres	% of Total Forest
High Risk w/Buffer					
Custer	7,645	27	484	8,156	0.4%
Douglas	3,286	-	2,120	5,406	0.2%
El Paso	5,152	-	1,842	6,994	0.3%
Fremont	262	-	154	416	0.0%
Huerfano	6,204	644	379	7,226	0.3%
Jefferson	1,318	220	5,886	7,424	0.3%
Las Animas	23	-	-	23	0.0%
Park	1,841	5,690	12,769	20,300	0.9%
Pueblo	6,342	14	1,489	7,845	0.4%
Teller	11,587	-	8,129	19,716	0.9%
TOTAL	43,661	6,595	33,251	83,506	3.7%
Medium Risk w/Buffer					
Custer	22,521	793	2,802	26,115	1.2%
Douglas	15,088	3,587	14,178	32,853	1.5%
El Paso	1,247	270	58	1,576	0.1%
Fremont	2,117	130	520	2,767	0.1%
Huerfano	3,858	-	2,362	6,220	0.3%
Jefferson	10,116	286	19,958	30,360	1.4%
Las Animas	-	-	-	-	0.0%
Park	13,407	2,020	24,474	39,900	1.8%
Pueblo	208	-	-	208	0.0%
Teller	12,601	157	10,196	22,955	1.0%
TOTAL	81,163	7,243	74,548	162,954	7.3%
High and Medium Risk Combined w/ Buffer					
Custer	30,166	820	3,286	34,271	1.5%
Douglas	18,374	3,587	16,298	38,259	1.7%
El Paso	6,399	270	1,900	8,570	0.4%
Fremont	2,379	130	674	3,183	0.1%
Huerfano	10,061	644	2,741	13,446	0.6%
Jefferson	11,433	506	25,845	37,784	1.7%
Las Animas	23	-	-	23	0.0%
Park	15,248	7,710	37,242	60,200	2.7%
Pueblo	6,551	14	1,489	8,053	0.4%
Teller	24,188	157	18,325	42,671	1.9%
TOTAL	124,823	13,837	107,799	246,460	11.1%

Colorado State and Private Timberland (acres)

County	Douglas Fir	Lodgepole	Ponderosa	Total Acres	% of Total Acres	Potential Biomass Removal (BDT)	% of Biomass
Boulder	-	-	28,600	28,600	2%	282,282	2%
Chaffee	1,400	3,900	-	5,300	0%	52,311	0%
Clear Creek	6,500	18,800	9,700	35,000	3%	345,450	3%
Custer	-	-	21,300	21,300	2%	210,231	2%
Douglas	-	-	21,200	21,200	2%	209,244	2%
El Paso	5,900	-	86,500	92,400	8%	911,988	8%
Fremont	21,500	-	58,000	79,500	7%	784,665	7%
Gilpin	-	11,500	7,800	19,300	2%	190,491	2%
Grand	-	70,400	-	70,400	6%	694,848	6%
Huerfano	5,300	9,700	77,300	92,300	8%	911,001	8%
Jefferson	12,700	9,500	75,800	98,000	8%	967,260	8%
Lake	-	19,100	1,900	21,000	2%	207,270	2%
Larimer	31,700	29,900	106,000	167,600	14%	1,654,212	14%
Las Animas	27,200	-	223,700	250,900	21%	2,476,383	21%
Park	7,300	7,400	38,300	53,000	4%	523,110	4%
Pueblo	-	-	24,200	24,200	2%	238,854	2%
Saguach	35,600	2,700	8,800	47,100	4%	464,877	4%
Teller	27,800	-	44,900	72,700	6%	717,549	6%
TOTAL	182,900	182,900	834,000	1,199,800	100%	11,842,026	100%
% of TOTAL	15%	15%	70%	N/A	N/A	N/A	N/A

Source
FIA
Forest land that is producing, or capable of producing, in excess of 20 cubic feet per acre per year of industrial roundwood products, and is not withdrawn fr utilization by statute or administrative regulation.

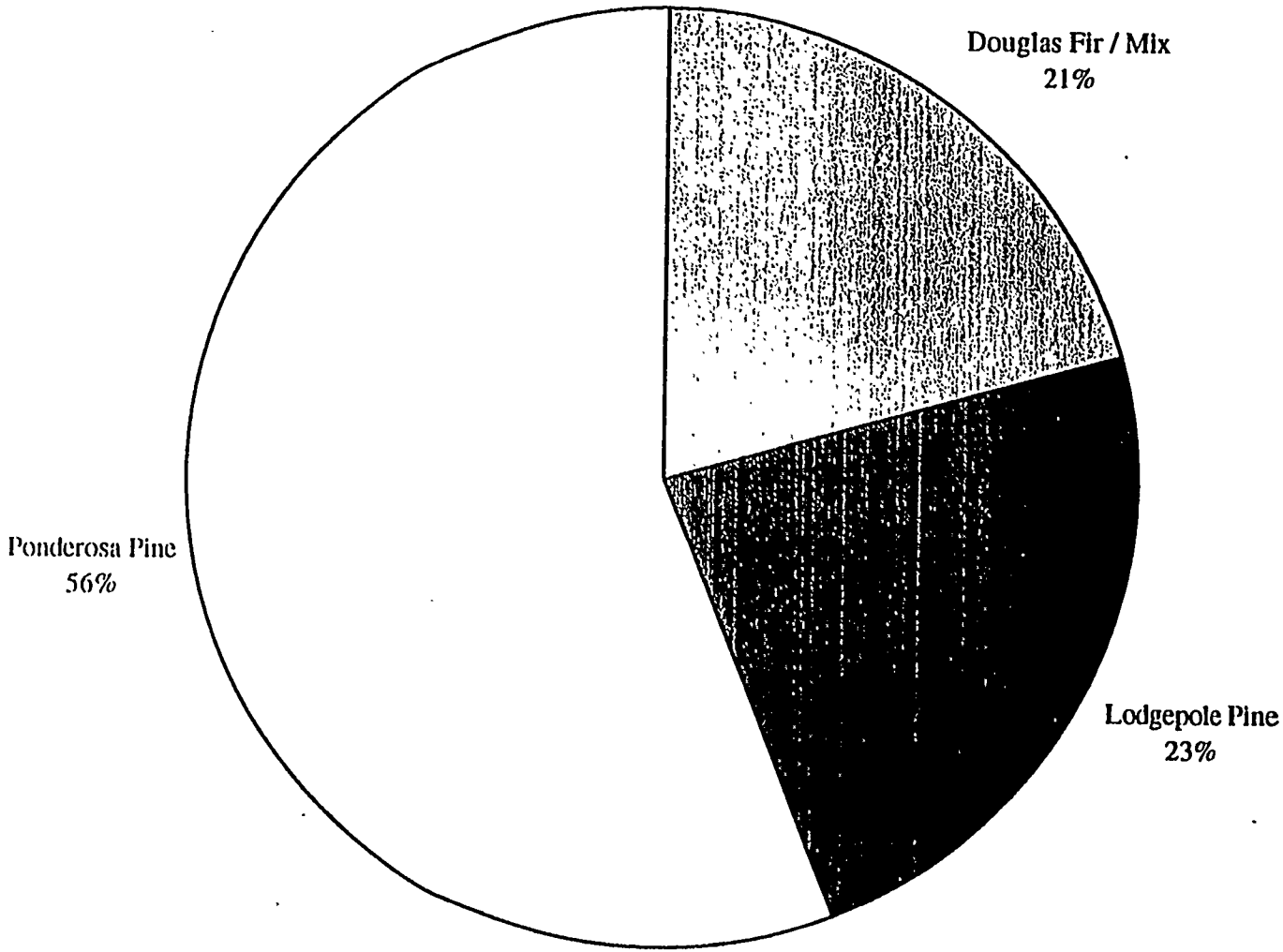
Summary of Federal, State, and Private Biomass Potential (BDT)

County	Arapaho - Roosevelt	Pike - San Isabel	State & Private	Total Biomass	% of Total Biomass
Boulder	738,742		282,282	1,021,024	6%
Chaffee			52,311	52,311	0%
Clear Creek	318,440		345,450	663,890	4%
Custer		338,259	210,231	548,490	3%
Douglas		377,615	209,244	586,859	4%
El Paso		84,582	911,988	996,570	6%
Fremont		31,413	784,665	816,078	5%
Gilpin	250,964		190,491	441,455	3%
Grand	-		694,848	694,848	4%
Huerfano		132,711	911,001	1,043,712	6%
Jefferson	21,497	372,931	967,260	1,361,688	8%
Lake			207,270	207,270	1%
Larimer	1,006,950		1,654,212	2,661,162	16%
Las Animas		225	2,476,383	2,476,608	15%
Park	8,398	594,176	523,110	1,125,684	7%
Pueblo		79,485	238,854	318,339	2%
Saguach			464,877	464,877	3%
Teller		421,162	717,549	1,138,711	7%
TOTAL	2,344,992	2,432,558	11,842,026	16,619,576	100%
% of TOTAL	14%	15%	71%	N/A	N/A

Summary of Biomass Acres by County by Species

County	Douglas Fir / Mix (acres)	Lodgepole Pine (acres)	Ponderosa Pine (acres)	Total Acres	% of Total Acres
Boulder	23,280	22,165	58,002	103,447	5%
Chaffee	1,400	3,900	-	5,300	0%
Clear Creek	18,426	37,659	11,179	67,263	4%
Custer	30,166	820	24,586	55,571	3%
Douglas	18,374	3,587	37,498	59,459	3%
El Paso	12,299	270	88,400	100,970	5%
Fremont	23,879	130	58,674	82,683	4%
Gilpin	8,564	27,807	8,356	44,727	2%
Grand	-	70,400	-	70,400	4%
Huerfano	15,361	10,344	80,041	105,746	6%
Jefferson	24,362	11,954	101,646	137,962	7%
Lake	-	19,100	1,900	21,000	1%
Larimer	67,686	213,939	194,432	476,057	25%
Las Animas	27,223	-	223,700	250,923	13%
Park	24,332	16,020	75,542	115,894	6%
Pueblo	6,551	14	25,689	32,253	2%
Saguach	35,600	2,700	8,800	47,100	2%
Teller	51,988	157	63,225	115,371	6%
TOTAL	389,493	440,964	1,061,669	1,892,126	100%
% of TOTAL	21%	23%	56%	N/A	N/A

Distribution of Species, All Colorado Front Range Post-Zone Counti

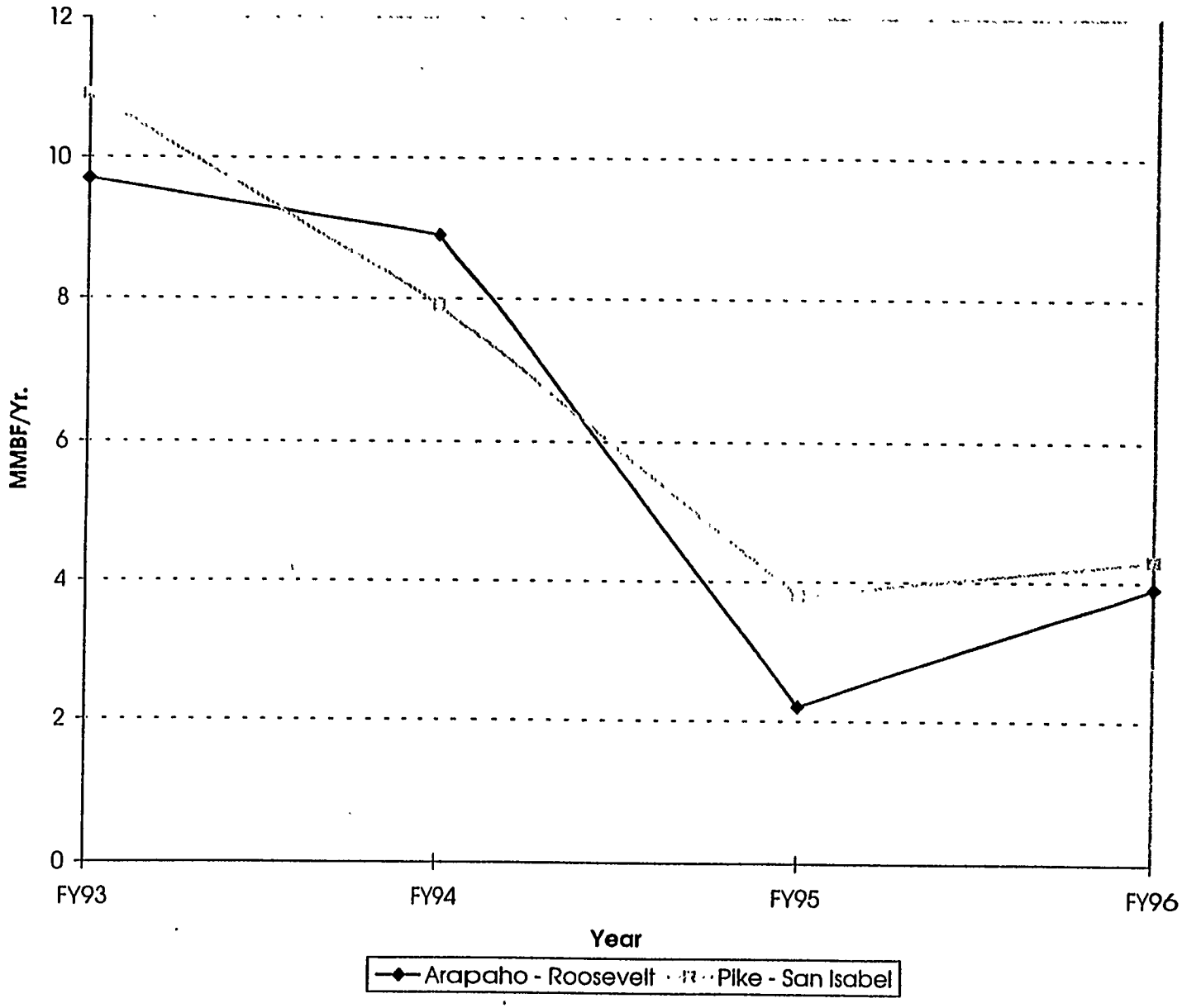


Biomass Delivered Costs, by County

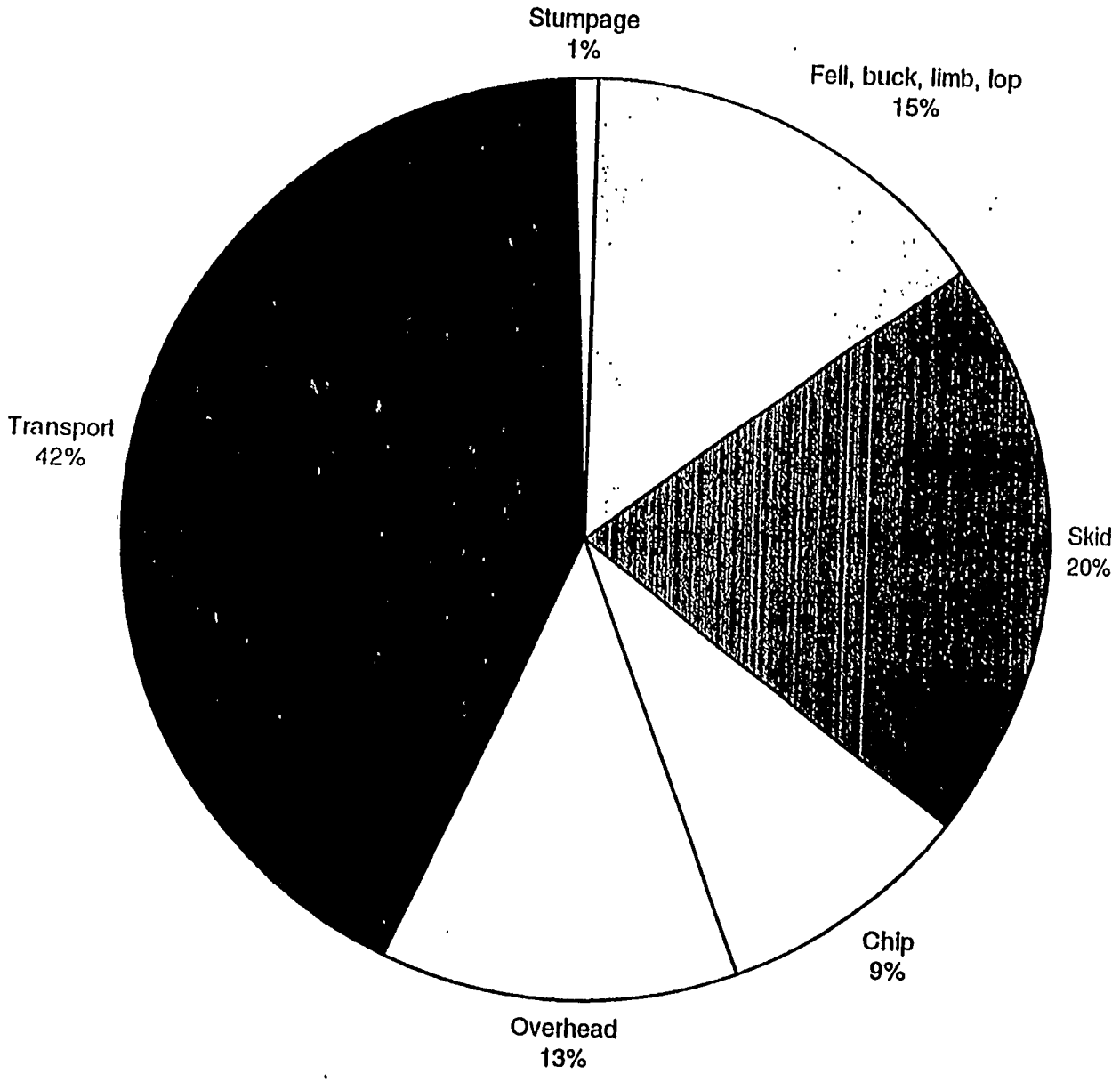
County	Distance to Denver (miles)	Haul Cost ($)	Haul Cost ($/BDT)	Total Cost** ($BDT)	Total Cost ($/MMBtu)
Boulder	50	$165.00	$14.67	$54.12	$3.00
Chaffee	140	$350.00	$31.11	$70.56	$3.91
Clear Creek	50	$165.00	$14.67	$54.12	$3.00
Custer	180	$450.00	$40.00	$79.45	$4.40
Douglas	50	$165.00	$14.67	$54.12	$3.00
El Paso	75	$187.50	$16.67	$56.12	$3.11
Fremont	130	$325.00	$28.89	$68.34	$3.79
Gilpin	50	$165.00	$14.67	$54.12	$3.00
Grand	150	$375.00	$33.33	$72.78	$4.03
Huerfano	180	$450.00	$40.00	$79.45	$4.40
Jefferson	50	$165.00	$14.67	$54.12	$3.00
Lake	150	$375.00	$33.33	$72.78	$4.03
Larimer	150	$375.00	$33.33	$72.78	$4.03
Las Animas	220	$550.00	$48.89	$88.34	$4.90
Park	75	$187.50	$16.67	$56.12	$3.11
Pueblo	160	$400.00	$35.56	$75.00	$4.16
Saguach	200	$500.00	$44.44	$83.89	$4.65
Teller	70	$175.00	$15.56	$55.00	$3.05
Average		$306.94	$27.28	$66.73	$3.70
Minimum		$165.00	$14.67	$54.12	$3.00
Maximum		$550.00	$48.89	$88.34	$4.90

** Total Cost includes felling, bucking, skidding, chipping, and transportatic and stumpage

Cut on National Forest Lands, FY 93 - FY96, Arapaho - Roosevelt and Pike - San Isabel



Distribution of Costs Associated with Biomass Harvest



Appendix B. FIA Database Retrieval System Results, Colorado State and Private Forests

Table Generator Results:
- Date of retrieval : 22-SEP-98
- Data requested by : 206.156.104.49
- Identification No.: 174937
- Retrieval type: County
- Number of forested plots 93
- Number of sample trees 1642
- States with date of inventory:
  Colorado 1983
- Plot selection criteria:
  Ownership (all)
  Stand age (all)
  Volume class (all)
  Slope (specific)
    0-5 %
    6-10%
    11-20%
    21-30%
  Forest type group (specific)
    Lodgepole pine
  Past forest type group (all)
  Stand origin (all)
  Past stand origin (all)
  Physiographic class (all)
  Site class (all)
- Tree selection criteria:
  Size of tree (specific by tree size)
    Poletimber
    Sawtimber
  Species (all)
  Damage (all)

The following table is available in a comma delimited file for convenience in downloading to a spreadsheet or data base.

Table 1--Area by county and land class

County	All land	Forest land				Nonfor lan
		Total	Timberland	Other forest land	Reserved timberland	
	thousand acres					
Colorado						
Chaffee	3.9	3.9	3.9	0.0	0.0	
Clear Creek	18.8	18.8	18.8	0.0	0.0	
Costilla	9.7	9.7	9.7	0.0	0.0	
Eagle	9.2	9.2	9.2	0.0	0.0	
Gilpin	17.3	17.3	11.5	5.8	0.0	
Grand	70.4	70.4	70.4	0.0	0.0	
Gunnison	13.6	13.6	13.6	0.0	0.0	
Huerfano	9.7	9.7	9.7	0.0	0.0	
Jackson	65.1	65.1	63.7	1.4	0.0	
Jefferson	9.5	9.5	9.5	0.0	0.0	
Lake	21.0	21.0	19.1	1.9	0.0	
Larimer	29.9	29.9	29.9	0.0	0.0	
Moffat	10.7	10.7	10.7	0.0	0.0	
Park	7.4	7.4	7.4	0.0	0.0	
Routt	33.4	33.4	33.4	0.0	0.0	
Saguache	2.7	2.7	2.7	0.0	0.0	
Summit	17.4	17.4	17.4	0.0	0.0	
All counties	349.9	349.9	340.9	9.0	0.0	

|FIA Database Retrieval System Results|

Table Generator Results:
- Description : Douglas Fir
Date of retrieval : 15-FEB-97
Data requested by : 206.156.104.165
- Identification No.: 115950
Retrieval type: County
Number of forested plots 74
- Number of sample trees 958
- States with date of inventory:
Colorado 1983
Plot selection criteria:
Ownership (all)
Stand age (all)
Volume class (all)
Slope (specific)
0-5 %
6-10%
11-20%
21-30%
Forest type group (specific)
Douglas-fir
Past forest type group (all)
Stand origin (all)
Past stand origin (all)
Physiographic class (all)
Site class (all)

- Tree selection criteria:
Size of tree (specific by tree size)
Poletimber
Sawtimber
Species (all)
Damage (all)

The following table is available in a comma delimited file for convenience in downloading to a spreadsheet or data base.

Table 1--Area by county and land class

County	All land	Forest land: Total	Forest land: Timberland	Forest land: Other forest land	Forest land: Reserved timberland	Nonforest land
	thousand acres					
Colorado						
Archuleta	12.0	12.0	12.0	0.0	0.0	0.0
Chaffee	1.4	1.4	1.4	0.0	0.0	0.0
Clear Creek	6.5	6.5	6.5	0.0	0.0	0.0
Conejos	2.7	2.7	2.7	0.0	0.0	0.0
Costilla	18.0	18.0	18.0	0.0	0.0	0.0
El Paso	5.9	5.9	5.9	0.0	0.0	0.0
Fremont	21.5	21.5	21.5	0.0	0.0	0.0
Garfield	14.1	14.1	14.1	0.0	0.0	0.0
Gunnison	22.9	22.9	22.9	0.0	0.0	0.0
Hinsdale	0.7	0.7	0.7	0.0	0.0	0.0
Huerfano	5.3	5.3	5.3	0.0	0.0	0.0
Jackson	1.4	1.4	1.4	0.0	0.0	0.0
Jefferson	12.7	12.7	12.7	0.0	0.0	0.0
Larimer	31.7	31.7	31.7	0.0	0.0	0.0
Las Animas	27.2	27.2	27.2	0.0	0.0	0.0
Montrose	4.7	4.7	0.0	4.7	0.0	0.0
Park	7.3	7.3	7.3	0.0	0.0	0.0
Rio Blanco	21.5	21.5	21.5	0.0	0.0	0.0
Rio Grande	1.0	1.0	1.0	0.0	0.0	0.0

Saguache	35.6	35.6	35.6	0.0	0.0	0.0
Teller	27.8	27.8	27.8	0.0	0.0	0.0
All counties	282.2	282.2	277.6	4.7	0.0	0.0

- Numbers in rows and columns may not add to totals due to rounding.
- The data are derived by sampling and are subject to statistical error.
- Source Intermountain FIA : Ogden, UT
  States:(AZ,CO,ID,MT,NV,NM,UT,WY)
  For assistance contact: Sharon Woudenberg 801-625-5379
  homepage http://www.xmission.com/~int
- All columns except timberland are zeroed when a circle or plot selection retrieval is

!FIA Database Retrieval System Results!

Table Generator Results:
- Date of retrieval : 22-SEP-98
- Data requested by : 206.156.104.49
- Identification No.: 175621
- Retrieval type: County
- Number of forested plots 173
- Number of sample trees 1299
- States with date of inventory:
  Colorado 1983
- Plot selection criteria:
  Ownership (all)
  Stand age (all)
  Volume class (all)
  Slope (specific)
    0-5 %
    6-10%
    11-20%
    21-30%
  Forest type group (specific)
    Ponderosa pine
  Past forest type group (all)
  Stand origin (all)
  Past stand origin (all)
  Physiographic class (all)
  Site class (all)
- Tree selection criteria:
  Size of tree (specific by tree size)
    Poletimber
    Sawtimber
  Species (all)
  Damage (all)

The following table is available in a comma delimited file for convenience in downloading to a spreadsheet or data base.

Table 1--Area by county and land class

County	All land	Forest land: Total	Forest land: Timberland	Forest land: Other forest land	Forest land: Reserved timberland	Nonfor lan
	thousand acres					
Colorado						
Archuleta	76.5	76.5	76.5	0.0	0.0	
Boulder	28.6	28.6	28.6	0.0	0.0	
Clear Creek	9.7	9.7	9.7	0.0	0.0	
Conejos	5.8	5.8	5.8	0.0	0.0	
Costilla	3.9	3.9	3.9	0.0	0.0	
Custer	21.3	21.3	21.3	0.0	0.0	
Dolores	12.0	12.0	12.0	0.0	0.0	
Douglas	21.2	21.2	21.2	0.0	0.0	
El Paso	86.5	86.5	86.5	0.0	0.0	
Elbert	38.2	38.2	38.2	0.0	0.0	
Fremont	58.0	58.0	58.0	0.0	0.0	
Gilpin	7.8	7.8	7.8	0.0	0.0	
Gunnison	33.1	33.1	33.1	0.0	0.0	
Hinsdale	1.0	1.0	1.0	0.0	0.0	
Huerfano	77.3	77.3	77.3	0.0	0.0	
Jefferson	75.8	75.8	75.8	0.0	0.0	
La Plata	148.0	148.0	148.0	0.0	0.0	
Lake	3.7	3.7	1.9	1.9	0.0	
Larimer	106.0	106.0	106.0	0.0	0.0	
Las Animas	226.1	226.1	223.7	2.3	0.0	
Mesa	9.4	9.4	9.4	0.0	0.0	
Moffat	42.2	42.2	28.1	14.1	0.0	
Montezuma	42.8	42.8	42.8	0.0	0.0	
Montrose	4.7	4.7	4.7	0.0	0.0	
Park	38.3	38.3	38.3	0.0	0.0	

Pueblo	24.2	24.2	24.2	0.0	0.0
Routt	1.2	1.2	0.0	1.2	0.0
Saguache	8.8	8.8	8.8	0.0	0.0
San Miguel	12.7	12.7	12.7	0.0	0.0
Teller	49.3	49.3	44.9	4.4	0.0
All counties	1273.9	1273.9	1250.1	23.8	0.0

|FIA Database Retrieval System Results|

Appendix C. Survey Forms

Primary and Secondary Manufacturers

ID Number: _____

Company: «COMPANY» Contact: «CONTACT» Type: «CODE»

Address1: «ADD1» Address2: «ADD2»

City: «CITY», State: «ST» Zip Code: «ZIP» County: «COUNTY»

Phone: «PHONE» Fax: «FAX»

Annual Production: «ANNPROD» Unit Production: «UNITPROD»

Products: «PROD1», «PROD2», «PROD3», «PROD4», «PROD5»

Species: «SP1», «SP2», «SP3», «SP4», «SP5»

****

Hello, my name is _____. I'm calling on behalf of NEOS Corporation. We are under contract to the US Forest Service to determine the amount of wood residue located along the Colorado Front Range. As part of this effort, we are calling select firms to identify the quantity of wood residues that might be available on an annual basis. Do you have a few minutes to answer several quick questions? All the information that you provide will be kept confidential.

Q-1 How would you characterize your business type? (check appropriate entry)

1. _____ Sawmill, annual production (board feet per year)
2. _____ Secondary Processor (describe operation) _____
3. _____ Pallets
4. _____ Construction
5. _____ Demolition
6. _____ Reels
7. _____ Other (please describe) _____

Q-2 What type of wood?

1. _____ % Hardwood
2. _____ % Softwood

Q-3 What is the total quantity of wood residue your facility generates on an annual basis?

1. _____ Number or Quantity
2. _____ Units (e.g., wet or dry tons, cubic yards, truck load, dumpster, specify sizes)
3. _____ Time (e.g., week, month)

Q-4 What are the major forms of wood residue your facility generates?

1. _____ %/yr. Sawdust
2. _____ %/yr. Chips
3. _____ %/yr. Shavings
4. _____ %/yr. Sander dust
5. _____ %/yr. Whole / construction wood (eg., cut ends, slabs)
6. _____ %/yr. Other, please specify _____

Q-5 How do you presently dispose of your wood residue?

1. _____ % Landfill, at what cost? _____ ($/unit)
2. _____ % Sell, for what purpose and price _____ (units)
3. _____ % Give away, for what purpose? _____
4. _____ % Use on site, please explain: _____

Q-6 What is the moisture content of the wood residues?

1. _____ % moisture
2.

Q-7 Are there any impurities (e.g., metal, varnish, paint, etc.) in the wood residue?

1. No
2. Yes please describe. _____

Q-8 Of the total residue generated by your organization, what percentage is generated during each season?

Spring (Mar, Apr, May)	_____%	Fall (Sep, Oct, Nov)	_____%
Summer (Jun, Jul, Aug)	_____%	Winter (Dec, Jan, Feb)	_____%

Q-9 Do you have a current stockpile of wood waste you wish to dispose?

1. No
2. Yes, how much (location, quantity & type). _____

Q-10 Would you like to be included on the mailing list for a copy of the survey results?

1. No
2. Yes

Thank you for your time and consideration

Urban Tree Residues

Company Name: _____

Street and/or P.O. Box: _____

City: _____ County: _____ Zip: _____

Contact Name: _____

Phone #: _____ SIC Code: _____

Hello, my name is _____. I'm calling on behalf of NEOS Corporation. We are under contract to the US Forest Service to determine the amount of wood residue located along the Colorado Front Range. As part of this effort, we are calling select firms to identify the quantity of wood residues that might be available on an annual basis. Do you have a few minutes to answer several quick questions? All the information that you provide will be kept confidential.

Q-1 How would you characterize your business type? (check appropriate entry)

1. _____ Commercial tree care
2. _____ Utility
3. _____ Municipal
4. _____ Park & Recreation Dept.
5. _____ Land clearance contractor
6. _____ Lawn/garden/maintenance
7. _____ Other (please describe) _____

Q-2 What is the total quantity of wood residue your organization generates on an annual basis?

1. _____ Number or Quantity
2. _____ Units (e.g., wet or dry tons, cubic yards, truck load, dumpster, specify sizes)
3. _____ Time (e.g., week, month)

Q-3 What are the major forms of wood residue your organization generates?

1. _____ %/yr. Chips
2. _____ %/yr. Unchipped logs (generally greater than 12 inches in diameter)
3. _____ %/yr. Unchipped tops and brush
4. _____ %/yr. Unchipped mixed wood (combination of logs, tops and brush)
5. _____ %/yr. Fall leaves
6. _____ %/yr. Lawn clippings
7. _____ %/yr. Whole stumps
8. _____ %/yr. Other, please specify _____

Q-4 How do you presently dispose of your wood residue?

1. _____ % Landfill, at what cost? _____ ($/unit)
2. _____ % Sell, for what purpose and price _____ (units)
3. _____ % Give away, for what purpose? _____
4. _____ % Use on site, please explain: _____

Q-5 What is the moisture content of the wood residues?

1. _____ % moisture

Q-6 Are there any impurities (e.g., metal, varnish, paint, etc.) in the wood residue?

1. No
2. Yes please describe. _____

Q-7 Of the total residue generated by your organization, what percentage is generated during each season?

Spring (Mar, Apr, May) _____% Fall (Sep, Oct, Nov) _____%

Summer (Jun, Jul, Aug) _____% Winter (Dec, Jan, Feb) _____%

Q-8 Do you have a current stockpile of wood waste you wish to dispose?

1. No
2. Yes, how much (location, quantity & type). _____

Q-9 Would you like to be included on the mailing list for a copy of the survey results?

1. No
2. Yes

Thank you for your time and consideration

Wood Processors Survey

Company Name: «Company» IDNO: «IDNO»

Address: «ADDRESS1»

City: «CITY» County:_____ Zip: «ZIP»

Phone #: «Phone»

Contact Name: «CONTACT»

Hello, my name is _____. I'm calling on behalf of NEOS Corporation. We are under contract to the US Forest Service to determine the amount of wood residue located along the Colorado Front Range. As part of this effort, we are calling select firms to identify the quantity of wood residues that might be available on an annual basis. Do you have a few minutes to answer several quick questions? All the information that you provide will be kept confidential.

Q-1 How would you characterize your business type? (check appropriate entry)

1. _____ Wood Processor
2. _____ Composting
3. _____ Other: Describe_____

Q-2 What source does your raw material come from?

1. _____ % Construction
2. _____ % Pallets
3. _____ % Demolition
4. _____ % Primary Processors
5. _____ % Secondary Processors
6. _____ % UTR
7. _____ % Other, Describe:_____

Q-3 What is the total quantity of wood residue your organization processes per year?

1. _____ Number or Quantity
2. _____ Units (e.g., wet or dry tons, cubic yards, truck load, dumpster, specify sizes)
3. _____ Time (e.g., week, month)

Q-4 What are your major products?

1. _____ %/yr. Mulch
2. _____ %/yr. Boiler fuel
3. _____ %/yr. Compost
4. _____ %/yr. Animal Bedding
5. _____ %/yr. Other, please specify _____

Q-5 Do you charge a tip fee?

1. NO
2. YES. If YES, How Much_____

Q-6 What is the moisture content of the wood residues?

1. _____ % moisture

Q-7 What is the approximate selling price of your products?

1. _____. Mulch
2. _____. Boiler fuel
3. _____ Compost
4. _____ Animal Bedding
5. _____ Other, please specify _____

Q-8 Of the total residue processed by your organization, what percentage is generated during each season?

Spring (Mar, Apr, May) _____% Fall (Sep, Oct, Nov) _____%

Summer (Jun, Jul, Aug) _____% Winter (Dec, Jan, Feb) _____%

Q-9 Would you like to be included on the mailing list for a copy of the survey results?

1. No
2. Yes

Thank you for your time and consideration

Landfill Operator Survey

Company Name:_____ IDNO: _____

Address: _____

City: _____ County:_____ Zip: _____

Phone #: _____

Contact Name:_____

Hello, my name is_____. I'm calling on behalf of NEOS Corporation. We are under contract to the US Forest Service to determine the amount of wood residue located along the Colorado Front Range. As part of this effort, we are calling select firms to identify the quantity of wood residues that might be available on an annual basis. Do you have a few minutes to answer several quick questions? All the information that you provide will be kept confidential.

Q-1 How would you characterize your business type? (check appropriate entry)

1. _____ Landfill
2. _____ Transfer Station
3. _____ Other: Describe_____

Q-2 Do you separate your wood waste from the rest of the solid waste stream?

1. NO
2. YES

Q-3 What is the estimated total quantity of wood residue your facility takes-in per year?

1. _____ Number or Quantity
2. _____ Units (e.g., wet or dry tons, cubic yards, truck load, dumpster, specify sizes)
3. _____ Time (e.g., week, month)
4. _____ % of _____ Total Amount (give units)

Q-4 Do you charge a tip fee for wood waste?

1. NO
2. YES. If YES, How Much_____

Q-5 Would you like to be included on the mailing list for a copy of the survey results?

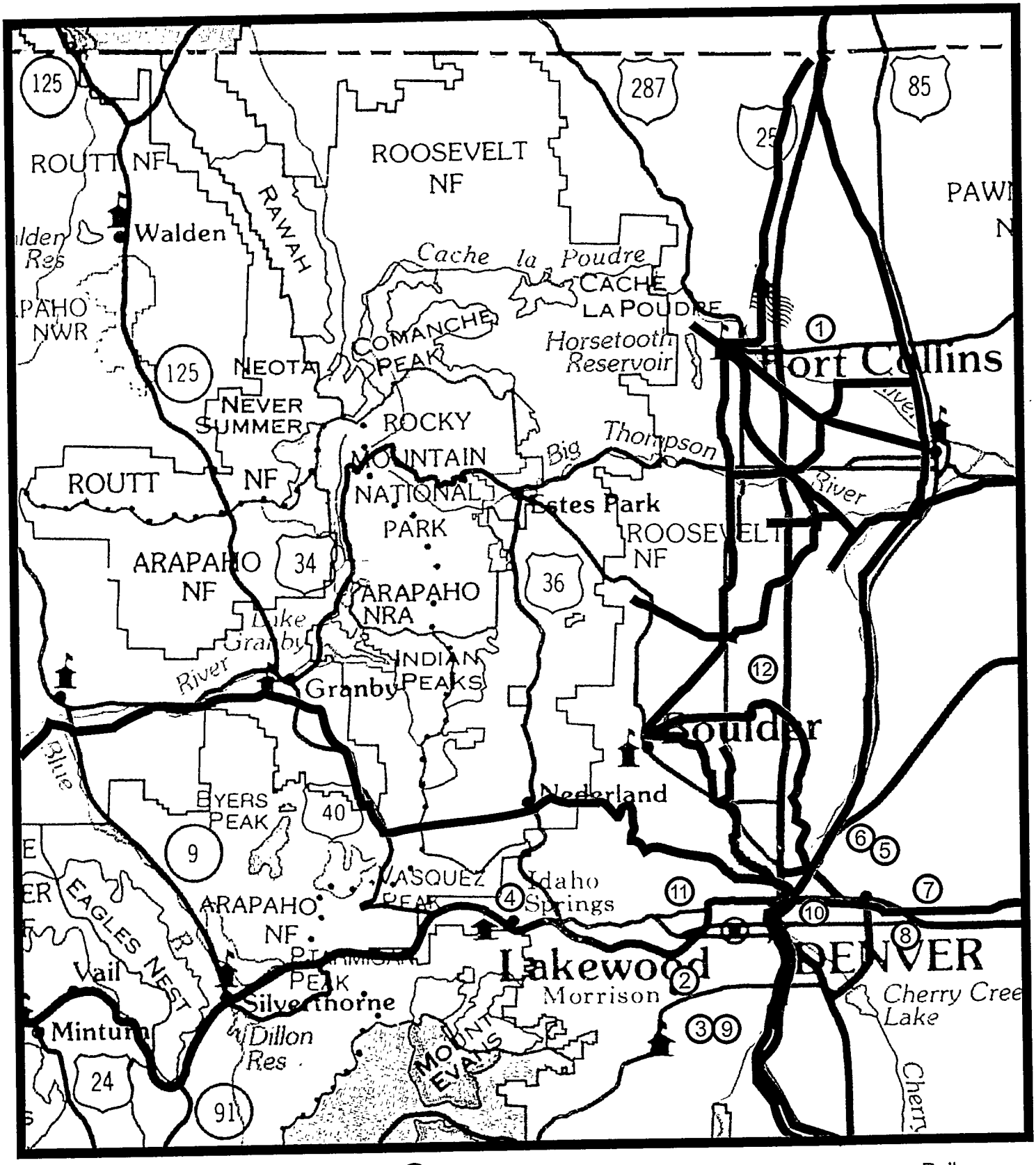
1. No
2. Yes

Thank you for your time and consideration

APPENDIX E

Potential Site Locations
Potential Southern Colorado Sites

Potential Site Locations

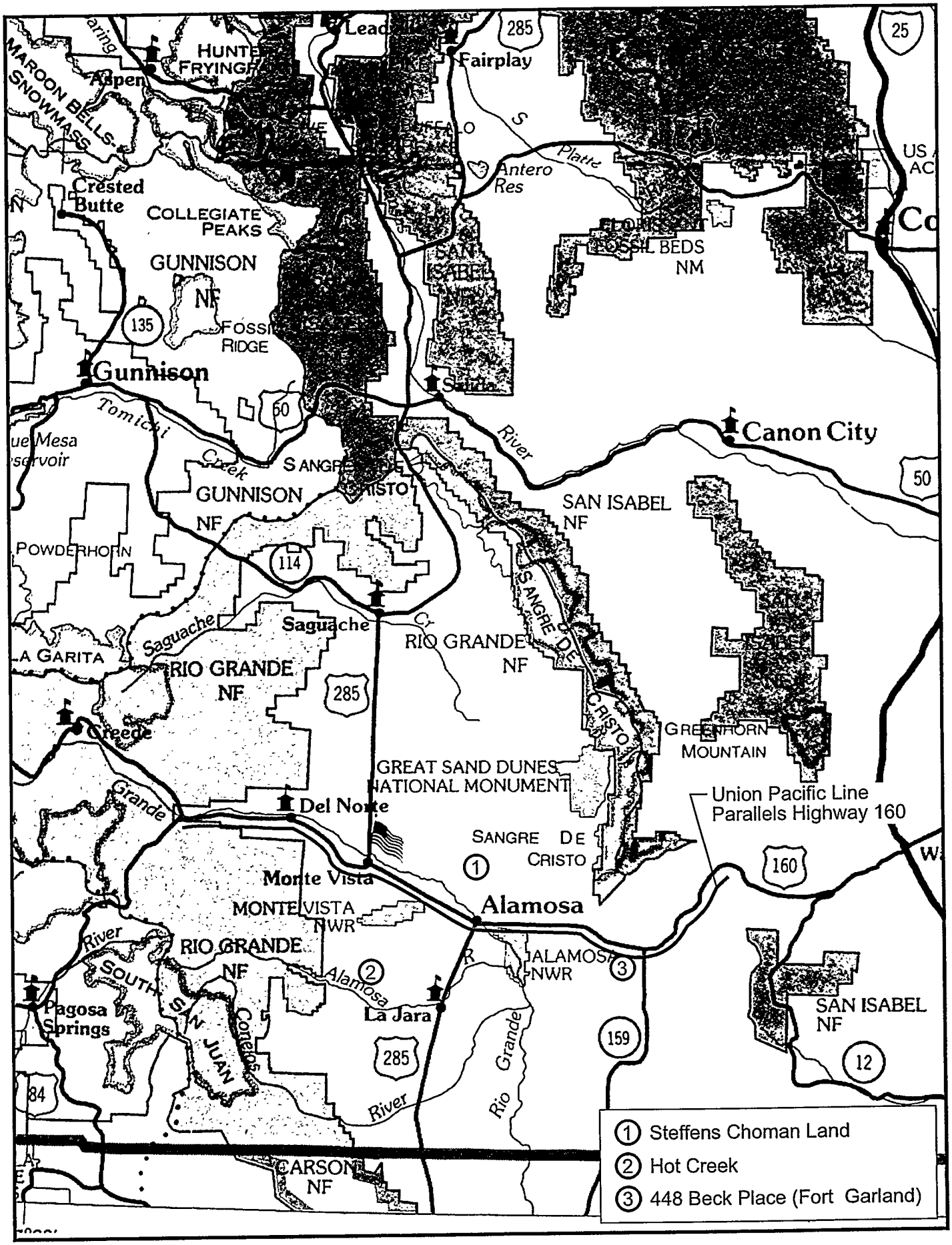


1. Weld County Landfill
2. Morrison Area
3. Elias Property @ Moore Road
4. Idaho Springs
5. 120th and E-470
6. Brighton, I-76 and Baseline
7. Watkins Property
8. Gun Club/Jewell/E-470
9. Titan Road West of South Santa Fe
10. Stapleton Redevelopment
11. Coors
12. I-25 @ Erie Exit, Purevision

Rail

Highways

Potential Southern Colorado Sites.



REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

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13. ABSTRACT *(Maximum 200 words)* The Front Range Forest Health Partnership is an alliance of individuals,citizen groups, federal, state, private, and nonprofit organizaitons that formed to promote forest health restoration and reduce fire risks on Colorado's Front Range. The partnership promotes selective thinning to restore forest health and supports econically feasible end uses for wood waste materials. The Phase I study was initiated to determine the environmental and economic feasibility of using wood wastes from forested and urban areas for the production of fuel-grade ethanol.

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