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# Emissions tradeoffs associated with cofiring forest biomass with coal: A case study in Colorado, USA

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## HIGHLIGHTS

- Case study using audited fuel consumption and emissions data from a coal mine and power plant.
- Model emissions tradeoffs of cofiring forest biomass with coal up to 20% by heat input value.
- Substituting forest biomass with coal displaces fossil energy with an otherwise waste material.
- Substantially less system emissions overall are generated when cofiring forest biomass.
- Cofiring forest biomass has positive global and local greenhouse gas and human health implications.

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## ABSTRACT

Cofiring forest biomass residues with coal to generate electricity is often cited for its potential to offset fossil fuels and reduce greenhouse gas emissions, but the extent to which cofiring achieves these objectives is highly dependent on case specific variables. This paper uses facility and forest specific data to examine emissions from cofiring forest biomass with coal ranging up to 20% substitution by heat value in southwest Colorado, USA. Calculations for net system emissions include five emissions sources: coal mining, power plant processes, forest biomass processes, boiler emissions, and forest biomass disposal. At the maximum displacement of 20% of heat demand using 120,717 t of forest biomass per year, total system emissions are projected to decrease by 15% for $CO_2$, 95% for $CH_4$, 18% for $NO_X$, 82% for $PM_{10}$, and 27% for $SO_X$. $PM_{10}$ and $CH_4$ emissions benefits are closely tied to reducing open burning for residue disposal. At maximum displacement, 189,240 t of $CO_2$ emissions equivalent to the annual $CO_2$ emissions from 36,200 passenger vehicles, 440,000 barrels of oil, or nearly 990 railcars of coal are avoided. When forest biomass is not cofired, emissions equivalent to144,200 t of $CO_2$ are emitted from open burning. In addition to exploring the details of this case, we provide a methodology for assessing the emissions tradeoffs related to using forest biomass for cogeneration that incorporates the operational aspects of managing forest treatment residues, which are frequently omitted from similar analyses.



## 1. Introduction

Global atmospheric concentrations of $CO_2$ have increased approximately 40% from pre-industrial levels of 240 ppm to about 400 ppm today [1], with the scientific evidence isolating anthropogenic-sourced emissions from fossil fuel combustion as the primary cause [2–5]. Moreover, rigorous debate persists as to which kind of greenhouse gas (GHG) emissions should be characterized as anthropogenic-sourced GHGs, particularly concerning emissions from forest biomass used for bioenergy [6–12]. A number of authors have identified the specific factors that impact the GHG mitigation potential of biomass fuels [13] and some have identified conditions under which biomass fuels may actually be more carbon positive than fossil fuels [14]. Other authors contend that emissions from forest biomass used for bioenergy are generally considered a renewable energy alternative to fossil fuels over long rotations if the harvested land remains as forest cover [15–17]. Currently, policies in many countries, especially in North America and Europe, promote the substitution of forest biomass for fossil fuels to help mitigate climate change associated with GHG emissions [18,19].

In the United States (US), half of all biomass energy is attributable to the forest sector and 61% of biomass electricity is generated from forest biomass [20,21]. Also in the US, Zerbe [22] forecasted that up to 10% of US energy requirements could eventually be

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met with forest biomass and Tilman et al. [23] determined that bioenergy from forests could substantially diminish dependence on fossil fuels. Most of the forest biomass currently used for energy is in the form of mill residues, and residues from logging operations including tree tops, limbs and unmerchantable roundwood. A significant quantity of logging residues (hereafter referred to as forest biomass) are generated annually in the US, yet most of this forest biomass is left onsite to decompose or is burned for disposal [20] to meet state laws for fire hazard reduction, and to open growing space for regeneration. US forest managers continue to search for alternatives to onsite open burning, which is especially prevalent in the interior western US where fire risk is high and markets for forest biomass are limited [24]. An abundance of time, energy, and financial resources have been devoted to researching and demonstrating value-added alternatives to onsite open burning, most notably removal of forest biomass for energy production at facilities close to the harvest site [25]. On a national scale, Gan and Smith [26] estimated that 13.9 million dry tonnes (t) of forest biomass could be used to generate 26 TW h of electricity annually.

For several decades cofiring woody biomass with coal has been evaluated as a near term and low cost option for generating electricity from biomass [27–29], and for reducing fossil fuel GHG emissions [29–35]. Nicholls and Zerbe [36] provide an overview of the status of cofiring in the US and note that cofiring biomass with coal is easily implemented and has the potential to utilize large volumes of biomass. Hughes and Tillman [32] summarize biomass and coal cofiring experiences through the late 1990s – the heyday of industrial cofiring experimentation in the US – and Harding [37] has comprised an extensive list of over 150 worldwide cofiring demonstrations. Additionally, the Electric Power Research Institute houses a significant library containing literature addressing many aspects of cofiring wood with coal [38].

Tillman [33] describes the combustion consequences of cofiring biomass with coal as primarily based upon each fuel's volatility, ash composition and reactivity, all of which are functions of fuel chemical and physical properties. Though published details of the kinetics and chemistry of co-combustion are limited [39,40], some studies have been conducted examining the chemistry of cofiring biomass with coal, and cofiring has been shown to have both advantages and problems compared to boilers fueled entirely with coal. Cofiring wood in coal power plants achieves higher efficiency for converting wood to electric power when compared to firing wood alone [29], and cofiring can result in reduced sulfur emissions [32,41]. Mixing wood with coal also reduces the temperature for initiation of pyrolysis, an indirect measure for the ease of ignition of the fuel blend [39]. Laursen and Grace [42] conducted bench scale experiments of cofiring coal with hog fuel and sludge from a paper mill to determine coal ignition properties and limestone requirements for sulfur emission suppression. Robinson et al. [27,30] conducted ash deposition experiments from cofiring a variety of biomass materials with different coals over a range of energy equivalency blends, and found that red oak has a lesser ash deposition rate than switch grass, wheat straw, and all the US coals examined. Robinson et al. [43] found that cofiring wood with high fouling coals mitigates some fouling difficulties, and Duong and Tillman [44] and Tillman [45] reviewed literature regarding the deposition and corrosion effects from varying chlorine contents of biomass materials and coals with the intention of identifying acceptable concentrations of chlorine to reduce corrosion.

In addition to evaluating the operational characteristics of biomass cofiring, several studies have examined the impacts of cofiring biomass with coal on emissions of $CO_2$ and other GHGs. Froese et al. [46] assessed the $CO_2$ emission mitigation potential of cofiring biomass with coal for electricity generation in the mid-western US and found that $CO_2$ stack emissions are reduced and the fossil fuel energy requirements to produce a unit of electricity are lowered for cofiring than for coal alone. Similarly, Tillman et al. [34] found that cofiring sawdust with coal in a cyclone boiler directly reduces fossil $CO_2$ emissions by one tonne for each tonne of sawdust burned plus an additional 1.8 t of $CO_2$ equivalent emissions from avoided landfill emissions. Savolainen [47] measured reductions of $CO_2$, $SO_2$, and $NO_X$ emissions when cofiring sawdust with coal in a combined heat and power pulverized coal boiler. Galik and Abt [48] analyzed woody biomass cofiring with coal as a baseline to quantify GHG emissions resulting from various scales of forest management that generate biomass for energy based upon demand for biomass under maximum cofiring capacity. Results generally show that larger management units generate greater emissions reduction benefits.

In this paper, we draw from previous cofiring research and use facility specific data collected from the electric power production and utility industries, and other sources, to model emissions from cofiring bituminous coal with forest biomass from forest restoration treatments. The objective is to quantify and understand the emissions tradeoffs of cofiring compared to open burning of forest biomass at the individual facility scale in the context of local forest management. While many aspects of cofiring wood have been evaluated, there is little research that compares the disposal of forest biomass by open burning to utilization for energy. The new information presented here will help individual forest managers and energy providers weigh the emissions tradeoffs of cofiring at local and regional scales. As forest managers consider options for using forest biomass from forest restoration treatments, emissions from utilization alternatives are an important aspect of the decision. Results are also intended to assist decision makers when evaluating renewable energy portfolios and policies, as many individual States in the US have proposed Climate Change Action Plans to reduce GHG emissions [49].

## 2. Study area

To study the tradeoffs associated with emissions from cofiring forest biomass, we focused on the Uncompahgre Plateau (UP) in the western US state of Colorado (Fig. 1) because silvicultural treatments in this area produce large volumes of forest biomass that could potentially be available for cofiring at a nearby power plant. The UP faces significant land management challenges related to severe effects from fire, insects, disease, and invasive species. Approximately 70% of the 607,000 hectares (ha) of the UP are at risk of high to mixed severity fire that would result in stand replacement, alter the current vegetation mosaics, and increase the risk of permanent physical changes due to direct effects to soils and water, as well as accelerated introduction of invasive species [50–52]. Ranging in elevation from 1400 to 3100 m, forests affected by these conditions include several distinct ecosystems. Ponderosa pine (*Pinus ponderosa*) and mixed conifer forests are the primary vegetation type where wildfire is likely to result in undesirable severe crown fires accompanied by high mortality in both understory and dominant trees [53,54]. In addition, many mature aspen (*Populus tremuloides*) stands are experiencing aspen decline with associated high mortality [55] and the pinyon-juniper (*Juniperus* spp., *Pinus edulis*, and *Pinus monophylla*) woodlands that dominate lower elevations are prone to severe fire compared to historical conditions [56]. Also, the spruce fir vegetation type (*Picea* spp. and *Abies* spp.) is experiencing heavy spruce budworm infestation with increasing mortality in infected stands [57,58], and widespread forest mortality is expected to result in uncharacteristically heavy surface fuels over the next several decades [59].

Management of insect, disease, and wildfire threats on these lands often requires restoration treatments to improve ecosystem