



## **Woody Biomass in Colorado:** Quantification, Assessment and Opportunities

Section 6 – Biomass energy and wood utilization technologies



## 6.1 Introduction

Biomass energy production refers to the process of using fuel from natural biotic sources to generate energy (Hohenstein & Wright, 1994). Historically, biomass energy has been used to build fires to cook food and warm houses, and technological advancements have improved this process, making it more efficient and effective while also reducing damage to the environment (Tursi, 2019). A goal of biomass energy production is to reduce reliance on non-renewable energy sources such as fossil fuels, while also reducing the impact of carbon emissions on the environment (Hohenstein & Wright, 1994). In this section we will discuss six mechanisms of woody biomass utilization: Cogeneration (or combined heat and power), co-firing, gasification, pyrolysis, torrefaction and combustion as well as considerations for implementing these technologies in Colorado. Facilities that use woody biomass for energy are often co-located with businesses that manufacture traditional or engineered wood products, and a brief review of those products is included in this section as well.

There are many technologies that can utilize woody biomass to produce energy, but they often have low margins or must receive ongoing assistance to be economically sustainable. This makes it difficult to entice private investment in biomass utilization when there are other investment options with better financial returns. The overall benefits that these technologies provide to society, like wildfire risk mitigation and reduced reliance on fossil fuels, often garner support and capital from both public and private sources. It is important to understand the state of biomass utilization technologies, including available processes and products, their potential applications in Colorado and considerations for site locations.

Biomass can be used to produce energy, traditional wood or engineered wood products, and other miscellaneous products. The scale of operations varies among these technologies from large businesses to the relatively small, with each requiring a correspondingly sized biomass supply. An example of selected biomass utilization technologies is shown in **Table 6.1**.

**Table 6.1** – Examples of biomass technologies

Energy-related	Traditional and/or engineered wood products	Other miscellaneous products
Biomass combined heat and power	Lumber (small, specialty sawmill)	Ground cover/erosion control
Bulk/bundled firewood	Oriented strand board (OSB)	Bark/compost/mulch
Densified fuel bricks/logs	Posts and poles	Biochar
Liquid biofuels	Veneer	Essential oils
Densified fuel (wood pellets, briquettes)	Animal bedding	Wood fiber insulation

**AUTHORS:** Kurt Mackes, Tim Reader and Steve Rudolph with support from the Beck Group

**COVER:** This biomass has been shredded prior to pyrolysis. **Credit:** Biochar Now

## 6.2 Technologies and products

### 6.2.1 Cogeneration or combined heat and power

When discussing biomass utilization, it is common for people to think about combined heat and power (CHP) (also called cogeneration) facilities. These facilities combust biomass, producing steam that can heat facilities and/or generate electricity. While this technology is found throughout the world, it can be difficult to implement due to high capital and operating costs, which generally make biomass power more expensive than other renewable power sources such as wind and solar.

Developing a cogeneration power facility is estimated to cost about \$6 million per megawatt (MW) of capacity but can be lower (on a \$/MW basis) for very large-capacity projects. Most projects considered in the Western U.S. range between 5–50 MW of capacity. For perspective, an average home uses about 10.7 MW hours per year. At a cost of \$6 million per MW of capacity, a significant biomass facility requires a substantial capital investment.

In 2024, there were 159 operational biomass power plants in the U.S., collectively capable of producing up to 5,584 MW of energy. Approximately 51% of these power plants utilized woody biomass as primary feedstock. The woody biomass sources include forest and/or logging residue, mill residuals, chips and wood waste (Acharya et al., 2024). Other biomass facilities utilize agricultural and other wastes for feedstock. Because biomass power is more expensive, most utility companies do not favor biomass power in their portfolio of renewable electric power sources. In some states, such as California, the use of biomass is subsidized for generating electricity.

### 6.2.2 Co-firing

Co-firing is the practice of blending solid fuels with a dissimilar fuel to reduce costs or incorporate renewable fuel sources with nonrenewable sources (Tillman, 2000). This is accomplished via a collection of techniques that involve blending biomass with another fuel (typically coal) and then combusting the combination to power an electricity generating system (Tillman, 2000). In this method, pre-existing infrastructure can accommodate the use of biomass as a fuel source, especially at sites that are currently using coal-burning boilers for the purpose of energy production.

Co-firing has not been widely implemented due to concerns relating to environmental and health risks, biomass supply and related costs, and low impact (relative to the expense) on coal emissions.

Environmental and health concerns are related to the view that harvesting and burning biomass does not reduce emissions. While this view is not universally accepted, it has enough support to create opposition to permitting facilities.

The availability of biomass near coal-fueled facilities is also a concern. Not all coal-fueled facilities are near a forest, so biomass must be transported to the area at extra expense. Stability of supply is also a concern for some areas. In addition, coal-burning facilities tend to be more efficient when biomass is pelletized — another extra expense. Pellets have lower moisture content and are easier to store and transport (Livingston et al., 2016), so they are preferred over less processed forms of biomass.

Co-firing for most coal facilities can be done in small amounts, and thus with little reduction in emissions. If substantial amounts of biomass are to be burned, plants often need expensive modifications. These commonly relate to the means of feeding biomass to the system, dealing with the inorganic components of biomass (which can reduce the efficiency and heat production of the facility) or both.

In 2023 there were six coal-fueled electrical power plants operating in Colorado. Most were scheduled to be completely closed between 2028–2031 except Xcel Energy's Pawnee Station, which will convert to natural gas by 2026. The plants are closing or converting primarily due to regulations concerning natural gas emissions (Jaffe & Booth, 2023).

Currently, co-firing of biomass and coal together for the generation of heat and energy has been successfully implemented in the state of Colorado in two industries: a cement plant and a power plant. At the Holcim cement plant north of Fort Collins, tests have been performed on methods of incorporating wood products as fuel sources for heating cement kilns. The tests indicated that this usage has potential; for it to be feasible the supply of wood must be economical, preferably with low moisture content (for better burning and less expensive transportation), and in the case of salvaged urban wood, free of contaminants such as lead paint or adhesives. The use of salvaged urban wood could benefit landfills by reducing their overall refuse intake (Mackes & Lightburn, 2003).

Forest management in Colorado often involves the removal of small trees to reduce density of overstocked forest stands and mitigate wildfire hazards. These trees, many of which are under nine inches in diameter at breast height (DBH), are of little commercial value due to

their quality and size. The Colorado State Forest Service (CSFS) performed a study to determine the feasibility of co-firing green wood chips (derived from small diameter trees removed for the purpose of fire prevention) with coal in the production of energy (Prokupets et al., 2002). Coal-burning electrical plants typically do not need to modify their existing boiler systems when burning small amounts of biomass with coal.

The W.N. Clark plant located in Cañon City was permitted to burn up to 5% wood by weight with coal. The wood tested was green ponderosa pine chips from nearby thinning projects, with a moisture content between 20–70%. The study provided evidence that green wood chips are a viable fuel source when combined with coal and that a power plant such as the Clark plant in Cañon City can burn up to 25 tons of woody biomass per day (Prokupets et al., 2002). W.N. Clark operated 19 MW and 25 MW coal-fired generators, but the plant was decommissioned in 2013 due to state requirements to reduce emissions from coal-fired power plants. The plant's owner, Black Hills Energy, cited cost and reliability as the reasons for not converting the plant to run on woody biomass (Black Hills Corp., 2010).

### 6.2.3 Gasification

Gasification refers to a suite of techniques that extract gaseous or liquid fuels and hydrocarbons from organic materials. The gasification process occurs when organic or fossil-based carbonaceous materials react with oxygen and water vapor to form carbon monoxide, carbon dioxide, hydrogen and other gases (U.S. Department of Energy [DOE], 2025a). In this reaction, oxygen levels are controlled, which allows little to no combustion to occur. The primary gaseous product is referred to as syngas or synthetic gas, a mixture that can be used as a fuel source to power a boiler. In some processes, a carbon shift reaction is added in which carbon monoxide in the presence of water and a catalyst reacts to form carbon dioxide and additional hydrogen (Corti & Lombardi, 2004). This produces a hydrogen-rich syngas that emits water when burned. In this way, gasification produces less air pollution as well as more marketable byproducts (Safarian et al., 2021).

There are various methods of gasification to produce syngas as well as other types of biofuels (gasoline and diesel). Biomass feedstocks commonly used in gasification include sawmill waste (sawdust and bark), municipal solid waste, agricultural residues and wood pellets. The method selection of biomass gasification depends on the type of feed stock and preferred product. Certain processes are more suited for wood gasification, and others may be better suited to municipal solid waste gasification. Updraft, downdraft and cross draft are commonly used to gasify solid woody materials, and a

fixed or fluidized bed method may be implemented for sawdust or wood pellets. The difference between these processes is the mechanism in which heat and oxygen contact the material that is to be gasified.

A study simulating carbon emissions comparing coal gasification with biomass gasification suggests that the use of biomass in the gasification process can significantly reduce carbon dioxide emissions (Corti & Lombardi, 2004).

The process of wood gasification has been implemented to produce fuel since the 1800s and early 1900s. During World War II, rationing of gasoline led to the conversion of automobiles to run on wood gas that was produced in simple wood gasifiers attached to the cars. Since then, technological advancements have broadened the applications for this process allowing for the development of a viable technique to extract energy from biomass sources.

Several biomass gasification operations have been planned in Colorado but due to technical or financial issues have not yet opened. With a growing need for renewable clean energy, biomass gasification is a key technology that can help reduce dependence on fossil fuels and reduce carbon emissions in large scale energy production.

### 6.2.4 Pyrolysis

Pyrolysis is a chemical reaction that occurs when organic compounds are heated in the absence of oxygen. In this process, biomass products can be heated to high temperatures without combustion due to the lack of oxygen. Organic materials still decompose producing gases and oils (hydrocarbons) that can be purified and used as a fuel source (Mohan et al., 2006). Advantages of pyrolysis are both economic and environmental, including the ability to utilize waste and renewable resources (Clifford, 2020).

Mobile pyrolysis units have been developed to bring the facility to the source material (Flashinski, 2017). The mobile pyrolysis unit can be driven to a site where woody biomass can be processed to produce biochar (described later in this section) and bio-oil.

Current forest management practices include broadcast burning or burning slash piles (Ramlow et al., 2016). Air quality is a concern with open burning, and prescribed fires need to be staffed by qualified personnel to ensure that they will be safe and effective. Heat generated during slash pile burning can destroy soil structure and kill soil microorganisms (McAvoy et al., 2018). Rather than using open burning methods, mobile pyrolysis is an alternative that can mitigate both carbon dioxide emissions and risks of wildfire in a controlled manner. The



*These kilns at Biochar Now's facility in Berthoud process Colorado timber into biochar via pyrolysis. Credit: Biochar Now*

use of forest biomass as a biomass feedstock is a viable method for sequestering carbon, reducing fire risk and producing biochar. The byproducts of sawmills, or mill residues, are also a viable feedstock for pyrolysis.

### **6.2.5 Torrefaction**

Torrefied pellets made from biomass can be burned for energy and have been suggested as a potential replacement for coal. Like pyrolysis, torrefaction is the process of heating biomass in the absence of oxygen. Torrefaction does not reach the temperature of pyrolysis, but this process transforms the biomass from a fibrous low-quality fuel into a carbon-rich product with excellent fuel characteristics.

After the torrefaction process, the resulting biomass is then densified into pellets that are water resistant and less susceptible to breakup during transportation and storage than non-torrefied pellets. These pellets have energy output similar to that of coal, but with less carbon emissions. Torrefied pellets can be used to generate power, heat structures and in co-firing as discussed previously.

There are some drawbacks to torrefied pellets, the first being expense. It costs more to make torrefied

pellets than other biomass energy sources, which can be a deterrent to their use. There is also the potential that torrefaction can reduce the pellets' combustion potential, which can increase emissions of particulate matter.

### **6.2.6 Combustion**

Combustion is a chemical reaction that occurs when organic compounds and oxygen react to form carbon dioxide and water vapor, releasing heat in the process (Emmons & Atreya, 1982). The process of wood combustion can be divided into three distinct phases: primary, secondary and tertiary.

Primary combustion occurs once wood is heated to a temperature of approximately 540°F. At this point water in the wood has boiled off, releasing volatile compounds that combine with oxygen to form a combustible mixture that then burns (Vogel, 2005). The wood decomposes releasing secondary gases. Once a fire reaches 1100°F, secondary gases can burn; this is referred to as secondary combustion (Vogel, 2005). As the mixture of gases combusts, char forms on the outer layers of the solid wood material (Boonmee & Quintiere, 2005). Third-stage combustion begins after the volatile compounds are released from the wood leaving behind carbon,

cellulose and lignin (charcoal), which will continue to burn at a low temperature for a long time, maintaining the charcoal bed that can be rekindled with more wood and oxygen (Vogel, 2005).

The efficiency of combustion is altered by variations in type and condition of fuel, primarily the moisture content. Higher heating value is a measure of efficiency for the fuel being burned. For biomass it is defined as the total potential heating output in BTU per pound of oven-dried wood (Ince, 1979) — in other words, the maximum thermal output of wood in optimal conditions while not accounting for any heat loss. The recoverable heat energy is the heat output when accounting for energy loss due to moisture content in the wood, hydrogen content and presence of excess air in stack gases and conventional heat loss processes such as thermal radiation, conduction, convection and incomplete combustion. The amount of recoverable heat energy is always less than the higher heating value. The ratio between higher heating value and recoverable heat energy is representative of the efficiency of combustion.

Wood has been used for heat and energy from prehistory to the present day. Wood can be ground or chipped for boiler fuel or used for energy in the form of solid blocks, pellets or densified as bricks or logs. Trees of all sizes can be used to make these products, but where mills exist, it is more profitable to use larger logs for lumber or other forest products. Also, the mills' by-products (sawdust, shavings, etc.) are often less expensive raw materials for making wood pellets and bricks than wood sourced directly from the forest.

According to a survey by the U.S. Energy Information Administration (EIA), as of 2020 200,000 Colorado homes were using wood-burning stoves to heat living spaces (U.S. Energy Information Administration [EIA], 2023). With the proper infrastructure and access to a steady source of fuel, this method can provide a cost-effective method for heating homes and public areas — utilizing a renewable energy source while also promoting forest health through the removal of excess fuels (Lowe, 2006).

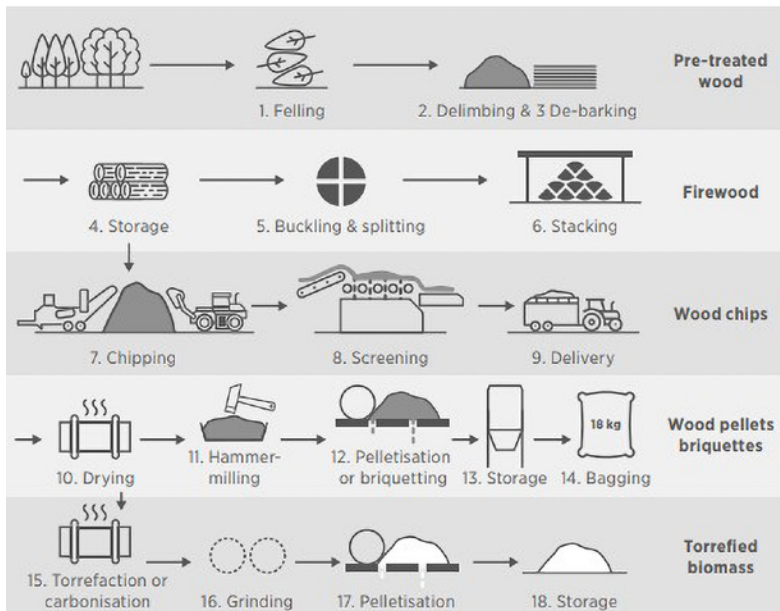
There are some drawbacks to the use of combustion for the purpose of heating or energy production. Burning wood materials to produce heat or energy produces more carbon monoxide (CO) and particulate matter (PM) than burning fossil fuels (Lowe, 2006). When wood burns at insufficient temperature, the resulting incomplete combustion also releases un-combusted volatile compounds. Pollution emissions generated during combustion of wood products pose some of the most significant energy-related risks to human health today and are known to be a major contributing factor to mortality worldwide (Edenhofer et al., 2011). However, the combustion of wood materials in the production of

heat or energy produces less PM and CO than that of an open wildfire or burn piles (Lowe, 2006). Forest fires are common, whether accidental or prescribed. When combustion occurs in the forest, the energy released in the process is lost. In areas with high risk of wildfire, biomass can be utilized for the energy it provides — thus reducing both the need for combustion of fossil fuels and overall emissions.

Furthermore, U.S. Environmental Protection Agency (EPA) regulations as well as recognition of public health risks led to updates — not just to wood-burning stoves but also fuels for stoves. During the 1970s, the use of wood-burning stoves to heat houses grew due to an oil embargo and subsequent increases in fuel prices. The increased use, combined with health-related and heating performance studies, led the EPA to regulate the efficiency and pollution emission production of wood-burning stoves (Fiala & Merola, 2008). As of 2020, EPA standards limit wood-burning stove emissions to 2.0 g PM per hour. This standard limit has changed from 4.0 g of PM per hour since 2015 (U.S. Environmental Protection Agency [EPA], 2015).

Improvements in wood-burning stove designs allow greater burn efficiency. Secondary combustion stoves are designed with channels that allow greater airflow, allowing secondary gases to burn. For fuels to burn optimally, air intake vents on these stoves must remain open; this allows them to achieve the heat necessary to burn secondary gases. Catalytic stove attachments allow secondary gases to burn at a reduced temperature. Once the stove has reached a temperature near 1000°F, secondary gas is directed through a catalytic combustor, a sieve-like device with a catalytic coating. The interaction between the secondary gases and the catalyst reduces the ignition point of the gases, causing them to burn.

Pellet stoves are wood-burning stoves designed to burn compressed pellets made from wood or other sources (DOE, 2023a). These stoves are more efficient and convenient to operate than traditional wood-burning stoves. The small size and shape of pellets allows more complete combustion, translating to higher heating efficiency and lower pollution emissions. Advanced pellet stoves are automated and use a thermostat to control a feed mechanism that loads the stove with pellets. To operate such a stove, the user need only fill a hopper with pellets and set the thermostat; the stove will control the fuel and air mixture rate. In addition, catalytic inserts and reflective wall surfaces in the fire box can increase efficiency by maintaining higher temperatures and an optimal oxygen mix inside the stove, allowing secondary gases to combust.



**Figure 6.1 – Examples of biomass processing.** Image Copied fully from International Renewable Energy Agency [IRENA] (2019)

## 6.2.7 Traditional or engineered wood products

Traditional wood products such as lumber, posts and poles have been produced in forested regions for many years. Engineered wood products are those that combine wood with resins or adhesives to produce wood products for desired applications. In several cases, an advantage of engineered wood products is that they use lower-value and -quality raw materials, breaking them up and reassembling them into engineered wood products using resins and/or adhesives – thus transforming a low-value material into a high-value finished product. These technologies utilize biomass in different forms.

### 6.2.7.1 Lumber

Lumber is usually produced from logs larger than 6” on the small end. There are mills that require one person to operate and those that employ many people. There are many types of lumber produced to meet desired applications in construction. In 2020, 27 mills operated in Colorado (Chung, 2024).

### 6.2.7.2 Veneer

Veneer is made from logs similar to those used for lumber. Depending on species and grade, veneer is used for panel production or laminated veneer lumber. Logs are peeled to produce veneer until the diameter of the remaining log reaches around 3”. Panels with strength requirements must use species with greater strength properties, such as Douglas-fir. Species such as white fir

and ponderosa pine do not have high strength properties and therefore are often used in the cores of plywood panels. There are currently no veneer mills in Colorado.

### 6.2.7.3 Posts and poles

Post-and-pole producers prefer logs with minimal taper from the small end to the large end. Posts and smaller poles are made from smaller logs, usually less than 8” in diameter. Poles used for phone lines and power distribution require straight logs, typically larger than 8” and at least 36’ long. These are usually the most valuable products produced from forest harvests, but are predominantly sourced from trees grown in other regions of the country.

### 6.2.7.4 Oriented strand board

Oriented strand board (OSB) can utilize small trees and tops to make strands typically 4-1/2” to 6” long, 1/2” wide and approximately 1/40” thick. These strands are dried, mixed with resin and wax, then oriented perpendicularly to each other until the desired width is met. The common use for OSB is sheathing and underlayment in homes. While OSB appears to have great potential for using non-merchantable biomass, plants need to be large enough to produce OSB cost-efficiently enough to be competitive. That requires a major capital investment, an assured supply of biomass and significant due diligence about market demand for structural panels.

### 6.2.7.5 Animal bedding

Animal bedding in the form of shavings or pellets is a common use of mill residuals. Being a by-product of milling makes these forms of biomass less expensive than capturing them from forest operations. There are some shavings facilities in the West using forest-derived biomass. An issue affecting the market for bedding materials is that the finished product occupies a large unit of volume but has low weight. This makes it expensive to transport, as the transportation reaches its space limit before reaching a weight limit. To be economically feasible, markets for these products need to be relatively near the manufacturing site.

## 6.2.8 Other miscellaneous products

The other potential forest products are a mix of technologies, most of which use chipped or ground biomass as the raw material. Biomass can be derived from the forest or as urban woody debris. Residuals from other forest products businesses are the common supply for many of these technologies, as they are less expensive than forest-derived biomass. Ground cover



*The Colorado Building Workshop partnered with the Colorado State Land Board to construct this outdoor classroom, made of mass timber from Colorado spruce, at Chico Basin Ranch. Credit: CU Denver*

applications for erosion control and bark or mulch for landscaping require larger populations for adequate market depth. The Front Range in Colorado might be an opportunity for these technologies, as approximately 84% of the state's population resides along or near the Rockies' eastern foothills (Colorado Department of Local Affairs, 2024).

### **6.2.8.1 Biochar**

One potential use of biomass is conversion to biochar, a carbon-rich, charcoal-like material made by pyrolyzing biomass. Biochar is used as a soil amendment to improve moisture retention and increase nutrient availability, and its high carbon concentration makes it a viable way to store carbon for the long term, thus reducing carbon emissions. This contribution to mitigating climate change allows producers to sell carbon credits based on the volume of biochar distributed. Biochar can last for hundreds or thousands of years (Power, 2021). Biochar can also be used in reclamation of soils that have been damaged by mining operations by absorbing organic pollutants and increasing soil pH (Ramlow et al., 2016).

One limitation of biochar as a soil amendment is the time it takes to show improvement in plant growth. Also, there is a lack of standardization as different feed stocks,

processing temperatures and processing times lead to products with different properties. Business owners need to develop markets suitable for the specific biochar that they can produce. Additionally, there are existing operations (such as biomass power plants) that can create biochar by adjusting how their boilers operate, which creates a higher percentage of a type of ash that is considered biochar. Such operations have a much lower cost of production relative to a producer that has invested in equipment and purchased raw material for the sole purpose of producing biochar.

### **6.2.8.2 Mulch/compost**

Many municipalities accept urban wood waste such as trees, portions of trees and untreated lumber. Often this material is chipped or ground into mulch for landscaping, and it can be used as compost for soil enhancement. These products can also be made from biomass derived from forest operations.

### **6.2.8.3 Emerging technologies**

Biomass is used for products in Europe that have not yet become popular in the U.S. One example is wood fiber insulation. TimberHP began producing this product in Maine in 2024 after it had been used in Europe for more than 20 years. This product uses chips and wood waste that can be made from small logs not

considered merchantable for other applications. Wood fiber insulation can be substituted for fiberglass and other current forms of insulation while being made of sustainable raw materials.

Another European technology that has not been used in the U.S. is wood wool cement. This product is made from a combination of cement and wood excelsior that can be made from small logs. Large wall elements can be made from wood wool cement and used in prefabricated housing. This mixture of wood and concrete is expected to be more flame-resistant than traditional wood structures, making them desirable for construction in areas at risk of wildfire.

### 6.3 Technology comparisons .....

Each of the biomass conversion technologies presented thus far has a broad range of configurations depending on scale, location and feedstock types available. Each category has characteristics that make it more appealing for one type of project over another or makes it more economically competitive. **Table 6.3** illustrates the comparison between combustion, co-firing, pyrolysis and gasification to provide a starting point for evaluating which technology makes the most sense for a desired project with a focus on industrial-scale plants. Since the outcomes and technological requirements within these categories are heavily dependent on the characteristics of the feedstocks entering each system, **Table 6.2** provides a comparison of the qualities of potential feedstocks.

An important consideration with all these technologies, and especially those aimed at retrofitting existing facilities, is that the material handling system for a biomass plant is a major part of its capital costs (EPA, 2007). By comparison with fossil fuels such as coal, woody biomass requires significant storage and processing areas before it is ready to be converted into a more usable form. This means that careful considerations of material handling space and proximity to biomass sources should be given to all potential projects. This factor gives mobile conversion units an advantage.

Mass timber is another technology that continues to grow in popularity. Mass timber refers to a family of engineered wood products that are made by taking smaller pieces of wood and bonding them with adhesives, nails, or dowels to create larger building components. The benefits of building with mass timber include lower embodied carbon compared to steel or concrete, ease of on-site construction by using prefabricated materials and a connection with the natural environment that can improve the mood and well-being of occupants (Naturally: wood, 2025).

Permitting will be an important consideration for any woody biomass energy project. The scopes and types of permits will vary broadly between different technologies, feedstocks used and locations.

Any sizable woody biomass processing plant will require a significant amount of land area for storage and processing of biomass, which will mean permitting for a larger area than most existing fossil fuel plants.

- There are also still significant air quality and greenhouse gas emissions from many biomass energy technologies, and while they may be less than those from a coal- or natural gas-fired plant, they will still require a similar permitting process.
- The emissions and waste products from a biomass conversion process can change significantly depending on the quality and characteristics of its feedstock. This means that close attention should be paid to what type of woody biomass is being used within a project and whether it produces waste or by-products that will require special permits to emit or dispose of.

**Table 6.2 – Feedstock comparison**

Feedstock type	Transportation cost effectiveness	Bulk density (kg/m <sup>3</sup> )	Moisture levels	Lower heating value (LHV) (MJ/kg)	Energy density (MJ/m <sup>3</sup> )
Solid wood (air-dried)	Comparable to logging industry	310-550 [a2][a5]	20% [a2]	15 [a2]	6,350-8,000 [a5][a2]
Forest residue	Transport over relatively short distances is most effective since low-density, high-moisture content and lack of uniformity make distance transportation costly.	150-250 [a2][a5]	30-40% [a1]	17.5-20.8 [a1]	2,735 [a5]
Wood chips (air-dried)	Delivery cost is most competitive when transportation costs are below ~45 USD/ton. [a2]	150-230 [a2][a4]	20-30% [a2][a4]	15 [a2]	2,693-3,244 [a5][a2]
Wood pellets	Delivery cost only outcompetes wood chips at transportation costs above 60 USD/ton and torrefied wood pellets at transportation costs below 90 USD/ton.[a2]	450-700 [a2][a3][a5]	8-8.5% [a2][a3]	15.9-17 [a2][a3]	8,200-12,700 [a5][a2]
Torrefied biomass pellets	Delivery cost becomes competitive with wood chips at transportation costs around 60-75 USD/ton and with wood pellets around 85-95 USD/ton. [a2]	700-850 [a2][a3][a5]	1-5% [a2][a3]	20-21 [a2][a3]	13,600-15,500 [a5][a2]
Industrial wood waste	Transportation depends on proximity to industrial source. Ideal to co-locate with industrial complex.	Sawdust: 160 [a2]	5-25% [a1][a2]	15-19.9 [a1][a2]	2,400 [a2]
Coal	Consistently cheaper than any woody biomass transportation. However, woody biomass is more competitive at low transportation costs. [a2]	750-850 [a2][a3][a5]	12% [a2]	20-30 [a2][a3]	13,600-21,000 [a5][a2]

**Feedstock comparison table citations:**

[a1] IRENA, 2012

[a2] IRENA, 2019

[a3] Basu, 2018a

[a4] Gendek et al., 2016

[a5] Manandhar & Shah, 2021

**Table 6.3 – Technology comparison**

Technology category	Biomass storage requirements	Feedstock type	Output type	Heat output of product	Levelized cost of energy (USD/kWh based on 2010 USD)	Advantages and disadvantages
Combustion	Woody biomass storage requires an area between 12,500 and 93,750 square feet for systems operating at 100 tons/day and 680 tons/day respectively. [b7]	Wide range of sources from direct forest residues and wood waste products to wood chips and pellets. Minimizing moisture content will increase efficiency. However, combustion can generally accept higher moisture levels than pyrolysis or gasification. [b5] [b2]	Power and heat	Output product is heat and electricity	Stoker boiler: 0.062–0.21  Bubbling fluidized bed and Circulating fluidized bed boiler: ~0.07–0.22 [b2][b3]	<b>Advantages</b> Ability to handle a wide variety and quality of feedstocks Reliance on a well-developed technology; can be combined with industrial facilities for heat and power  <b>Disadvantages</b> Combustions emissions often similar to those from fossil fuels even if quantity is somewhat reduced [b5]
Co-firing	Biomass requires more space than coal and may need to be covered to keep dry or go through drying process. [b6]	Feedstock uniformity and grindability is preferable making biomass pellets appealing, especially torrefied pellets. Use of wood chips will require construction of a separate material handling system. [b6] Small particle sizes and low-moisture content are needed to avoid efficiency losses. [b2]	Power and heat	Output product is heat and electricity	Generally: 0.044–0.13  10% co-firing of 250 MW plant: 0.031  100% biomass repowering of 100 MW plant: 0.088 [b2][b3]	<b>Advantages</b> Use with existing coal fired infrastructure and a focus on minimizing cost of initial investment Reducing carbon emissions over a fully coal powered plant  <b>Disadvantages</b> Economics may be challenging if retrofit cost is high and payment for reduced emissions is not available. Fly ash from plant may no longer qualify for cement production [b7]

Technology category	Biomass storage requirements	Feedstock type	Output type	Heat output of product	Levelized cost of energy (USD/kWh based on 2010 USD)	Advantages and disadvantages
Pyrolysis	Storage similar to combustion.	Fast pyrolysis (~500 C): Ideal feedstock is low-moisture content <10% by weight and particle size 5mm or less. [b5]	Bio-oil Biochar Pyrolysis gas	Bio-oil: 13-18 MJ/kg Biochar: 20-25 MJ/kg Pyrolysis gas: 11-20 MJ/Nm <sup>3</sup> [b1]	Combustion of fast-pyrolysis bio-oil: 0.087 [b4]	<b>Advantages</b> Ability to produce a variety of different products depending on pyrolysis pathway Production of alternative transportation fuels Creating Biochar as a marketable product <b>Disadvantages</b> Production costs of Bio-oil struggle to compete with cost of comparable fossil fuels [b8]
Gasification	Storage similar to combustion	Feedstocks need to be tightly controlled for moisture content, particle size, bulk density, ash content and homogeneity, making feedstock sourcing challenging. [b5] Feedstock drying typically required. [b7]	Producer gas  Syngas	Producer gas: 5-6 MJ/m <sup>3</sup>  Syngas: 9-19 MJ/m <sup>3</sup> [b2]	Generally: 0.065-0.24 [b2]	<b>Advantages</b> Production of a gaseous product that can be used with adaptations to existing technologies developed for natural gas electricity production. Shows promise for high electrical efficiency rate Low emissions from burning cleaned syngas <b>Disadvantages</b> Largely emerging technologies which have seen limited commercialization. Syngas often needs to be cleaned of contaminants before use

## Technology comparison technology table citations:

- [b1] Basu, 2018b
- [b2] IRENA, 2012
- [b3] Electric Power Research Institute, 2010
- [b4] Perkins, 2018
- [b5] Adams et al., 2018
- [b6] Basu, 2018c
- [b7] EPA, 2007
- [b8] Lewandowski et al., 2020

## 6.4 Biomass energy applications comparisons .....

There is a broad range of applications for energy generated from biomass:

- Residential heating
- Recreational firewood
- Dedicated central power facilities
- Semi-mobile power plants
- Co-location at existing facilities
- Heating and cooling
- Co-generation of heat and power

Residential heating and recreational uses for biomass energy were discussed previously in Section 5.3.1. The other applications listed are discussed subsequently.

### 6.4.1 Dedicated central power plant

Biomass power plants use processes such as combustion, gasification and pyrolysis to convert organic matter into energy. Equipment used to convert woody biomass into usable energy includes combustion chambers, boilers, turbines and power generators. Plant efficiency varies considerably depending on factors such as type and quality of biomass fuel, the conversion process used and power plant design. Benefits of biomass power plants include production of renewable energy and dispatchability; this last allows biomass to be stored and converted to energy as required to meet demand. Disadvantages can include harmful emissions, potential supply concerns and overharvesting forestland to provide fuel for power generation.

The World Resources Institute (2023) maintains a global biomass power plant database. Based on this database, there are 153 biomass power plants operating in the U.S. that have capacity to generate 5,123.2 MW of electric power. In 2023, woody biomass plants generated 31 billion kWh of electricity or 0.8% of U.S. power demand, which was 4.18 trillion kWh (EIA, 2024).

### 6.4.2 Semi-mobile biomass plant

Forest management activities in Colorado generate large quantities of woody biomass in the form of logging slash and residues. It is often not cost-effective to transport biomass from the logging site to a facility for utilization. There has been considerable interest in developing semi-mobile plants to process biomass on-site into a form for economical transport to either a stand-alone biomass power plant or for co-firing at large coal-fired power plants.

Semi-mobile biomass plants are containerized processing facilities that can be relocated with changes in supply and demand (Zimmer et al., 2018). Multiple units can be redeployed as necessary to optimize transportation costs. A 2018 economic analysis by Zimmer et al. showed that intermodal transportation was required to deliver biomass to facilities at a price competitive with fossil fuels. Although there are currently no semi-mobile biomass plants operating in Colorado, of all conversion technologies evaluated, torrefaction might be the most promising for this application.

Biomass torrefaction subjects biomass to moderate heat. The resulting torrefied biomass is both energy- and volume-dense, which effectively reduces transportation costs (van der Stelt et al., 2011). While conventional torrefaction systems tend to be large-scale centralized facilities, small-scale systems are being developed. In 2018, Severy et al. constructed a semi-mobile torrefaction pilot plant to determine optimal operating conditions and throughput requirements using forest residuals as feedstock. Torrefied material was then densified to evaluate briquette quality.

Although results from this pilot study were promising, it showed that further optimization of the torrefaction system was required for a commercial facility. Kirchstetter (2021) investigated a small-scale biomass torrefaction reactor design and its economic feasibility, which resulted in the scale-up of its throughput capacity. This advancement could allow for greater deployment of this system with broader application to biomass markets than conventional torrefaction technologies.

### 6.4.3 Co-location at an existing facility

Co-location of biomass facilities involves placing plants near each other to share resources such as land, buildings, equipment and other infrastructure to utilize biomass feedstock more effectively. There are numerous examples of co-location associated with the forest products industry. For example, of the 159 biomass power plants located in the U.S., many are co-located with mills that produce lumber, veneer, pulp and paper, or other wood products. Other scenarios for co-location also exist. A study by the Green Power Institute (2002) for the National Renewable Energy Laboratory found that co-locating ethanol production facilities with existing biomass power plants could reduce production costs for both facilities. A similar study by BBI International (2002) concluded that co-locating a cellulosic ethanol plant with existing coal-fired power plants would have similar benefits.

Because there is currently no capacity to produce pulp and paper products in Colorado, other forest products facilities such as sawmills are the best option for co-location with a biomass facility. These facilities generally have the electrical infrastructure to connect to the power grid, which can reduce the cost of developing a biomass facility. Sawmills generate substantial quantities of residuals that include bark, sawdust, wood chips, wood shavings and cull logs. Since they are also major electricity consumers, their interconnecting systems tend to be robust. This can help reduce the cost of tying a biomass power project to the grid.

Although these residuals can be used for a variety of applications in Colorado (such as landscape mulch, compost and animal bedding), finding profitable markets for residuals continues to be a challenge for some Colorado sawmills. A biomass facility owned and operated by Montrose Forest Products recently went online and is co-located at its sawmill in Montrose (Henseler, 2023). The plant required \$15 million to build and will provide heat and power to the sawmill. It also created five new jobs. The primary source of biomass for the plant is approximately 15 daily truckloads of wood and bark residuals generated by the sawmill operation.

### 6.4.4 Heating and cooling

In addition to heating, biomass systems can also be used to cool spaces (EPA, 2021). Renewable technologies for cooling spaces generally involve chilling water or refrigerant fluids. Using hot water or refrigerant fluids for cooling is not new technology; the first use of this technology dates to 1850. Adsorption refrigeration cooling involves four primary pathways (steps) for cooling spaces using energy from biomass: evaporation, absorption, separation and condensation.

1. Evaporation of a refrigerant removes heat from surrounding air as it occurs.
2. Adsorption of vapor into another liquid (absorber) improves the speed and efficiency of evaporation.
3. Separation involves heating a mixture of refrigerant and absorber to evaporate the refrigerant out of the absorber.
4. During the condensation process, heat is released as evaporated refrigerant is forced through a condenser, converting it back to liquid form. Released heat is vented from the system.

Chilled water or refrigerant fluid is usually distributed to a building or complex of buildings through insulated pipes. After circulating through the system, the water or liquid refrigerant can be reused by returning to Step 1.

A review of small-scale biomass-fired combined cooling, heat and power systems (CCHP) was conducted in 2018 by Wegener et al. Larger-scale district energy CCHP systems comprise a central cooling and heating plant that distributes hot water, steam or chilled water to a nearby cluster of buildings through a network of insulated pipes. District energy systems can be designed for many locations, such as educational institutions and healthcare facilities. The primary benefits of district energy systems are reduced energy cost and increased opportunity to use high-efficiency technologies such as combined heat and power (CHP).

An example of a district energy CCHP system that uses wood chips as fuel is located on the campus of Chadron State College (CSC) in northwest Nebraska. Two wood-fired boilers, installed on campus at the Sheaman Plant, were first used to heat buildings in 1991. By 2005, they were providing about 90% of CSC's heating requirements, distributing heat to 20 buildings on campus, representing a total area of about 1.1 million square feet (Williams, 2005). In 2004 a 700-ton steam adsorption chiller was installed at the Sheaman Plant. The system utilizes up to 9,000 tons of wood chips annually that are generated from forest management projects ongoing in the surrounding hills of the Pine Ridge Reservation (Hurst Boiler, 2008).

## 6.4.5 Cogeneration of heat and power

Biomass cogeneration of heat and power (CHP) involves technologies that simultaneously produce heat and electricity using biomass as the fuel source. In 2007, a catalog of biomass CHP technologies was published by the EPA and the Combined Heat and Power Partnership, showing that simultaneous heat and power production enhances operational efficiency that can lower overhead costs. Other benefits include distributed generation of power, reduced reliance on the power grid and recovery of heat that would otherwise be vented from the system. The result is reduced energy waste, which corresponds to increased energy efficiency.

## 6.5 Opportunities for bioenergy utilization

The DOE conducted research on the sustainable utilization of biomass and published findings in the 2023 *Billion Ton Report* (DOE, 2023b). According to their findings, the U.S. can produce from 1.1 to 1.5 billion tons of biomass from wastes, agricultural residues and logging residues annually in a future mature market, with potential to provide renewable liquid fuels for hard-to-electrify sectors while meeting demands for food and environmental services. From this report, the timber products industry harvests an estimated 200 million tons per year for timber products. Residues, which include both logging and mill residuals, are created during that process. The report estimates 20 million tons could be available within economic and environmental constraints. Another estimated 35 million tons of small diameter (<11") trees could also be produced while meeting demands for sustained yield of timber products and retaining current forestland area.

Considering that greenhouse gas emissions from fossil fuels are expected to exceed 36.8 billion metric tons in 2023 (Kiest, 2023), increased biomass utilization may play a role in achieving net-zero emission goals for a sustainable future. Net-zero emission goals are achieved when carbon emissions released by human activity are counterbalanced by carbon removed from the atmosphere. This can happen either by reducing emissions or neutralizing them by removing equivalent amounts, often in the form of carbon offsets (Axelsson et al., 2024).

Concerns about global climate change and air quality have increased interest in biomass and other renewable energy sources that are potentially less polluting; even so, large-scale biomass development involving immense land and biomass requirements must proceed responsibly to maximize ecological benefit

Cogeneration strategies can use any of the pathways discussed in Section 6.1.1; thermochemical or biochemical are more commonly used, but chemical and physical conversion technologies have also been developed (Tursi, 2019). The U.S. Department of Energy (DOE) maintains a database of CHP facilities operating in the United States (DOE, 2025b). Although there are 24 CHP plants operating in Colorado currently listed in the DOE database, none use wood as a fuel source following the closure of Eagle Valley Clean Energy.

and minimize potential environmental damage. During 2023, 8% of all energy consumed in the U.S. came from renewable sources, and 21% of electricity generation came from renewables (EIA, 2024). Solid biofuels including firewood and wood pellets were the dominant feedstocks in the early 2000s. Although still dominant in Colorado, nationally the usage levels of solid biofuels have remained stable, with liquid biofuel production accounting for most of the increased use of biofuels over the past two decades. Heat production in the U.S. is currently dominated by fossil fuels, particularly natural gas. About 10% of heat consumed in the U.S. is produced using biomass, which is the most important renewable heat source (International Energy Agency, 2021). The percentage of electricity and liquid fuels produced nationally from forest biomass is much more modest.

A subsequent discussion of opportunities and benefits for increased biomass utilization is given for various stakeholder groups.

### 6.5.1 Cottage industry

Cottage industries are small manufacturing businesses owned and operated by individuals or families (Kenton, 2023). They are often operated out of a home rather than a separate business location and are defined by the relatively small amount of investment required to start one. In Colorado, cottage industries have developed to produce a variety of forest-related products including furniture, bulk firewood sales and delivery, cabinet and millwork manufacturing, and wood art and novelties. These products constitute an important source of employment and income throughout Colorado, especially in more rural areas of the state.

Cottage industries can benefit from biomass energy in several ways. Biomass can be used to produce energy for both heating and cooling buildings, provide heat for industrial processes and fuel electric generators and other machinery. For cottage industries that have access to an economical source of biomass fuel, such as residues from woodworking, these technologies can be used to reduce their energy costs (Prasad, 2020). In addition, by using a renewable fuel source such as biomass they can reduce their reliance on fossil fuels and the electric power grid, while reducing their carbon footprint.

## 6.5.2 Community

Utilizing biomass to generate energy can provide an opportunity for sustainable and eco-friendly development in Colorado communities, particularly in rural areas of the state that have access to wood biomass resources. The development of efficient biomass handling technology and establishment of facilities that utilize biomass from forest treatments can promote good stewardship of Colorado's forest resources.

Increased use of firewood in Colorado is an example of how biomass utilization can benefit its communities. With the availability of high-efficiency EPA-approved wood-burning appliances (Colorado Department of Public Health & Environment, 2025), individuals and communities can be actively engaged in biomass utilization, helping to utilize a resource that would otherwise likely go unused. Because most of this biomass is locally harvested and processed, increased use of it promotes economic development that leads to local job creation and perpetuation. Also, dollars spent on locally sourced biomass tend to stay in the local economy more than dollars spent on fossil fuels (Biomass Thermal Energy Council, 2017).

Past community-based projects that involved building biomass plants in Colorado have had various levels of success. Some have failed, such as a biomass boiler installed in Nederland (Hayes, 2005). Other more successful projects such as the Boulder County Open Space Facility and the Gilpin County Road and Bridge Facility biomass plants can be found in the publication *Where Wood Works* (Colorado State Forest Service [CSFS], 2011). Both facilities have boilers that utilize wood chips to heat the facilities.

## 6.5.3 Local industry

Biomass energy utilization can provide a sustainable and cost-effective alternative to traditional fossil fuels

for entities located near forest resources. Potential applications for bioenergy in local industry include power (electricity) generation, heat and cooling, and production of a range of biofuels and bioproducts. Companies that provide biomass for use as energy are often very important to small rural communities.

Bulk firewood sales are a good example of how local forest products businesses can benefit from biomass energy utilization. Because a high percentage of bulk firewood used in Colorado is sourced and used locally, bulk firewood suppliers are found across the state, especially in rural areas. These suppliers are primarily classified as small businesses employing fewer than 20 people, with most employing fewer than five. Collectively, these local businesses provide an important source of employment and economic development in rural areas of Colorado.

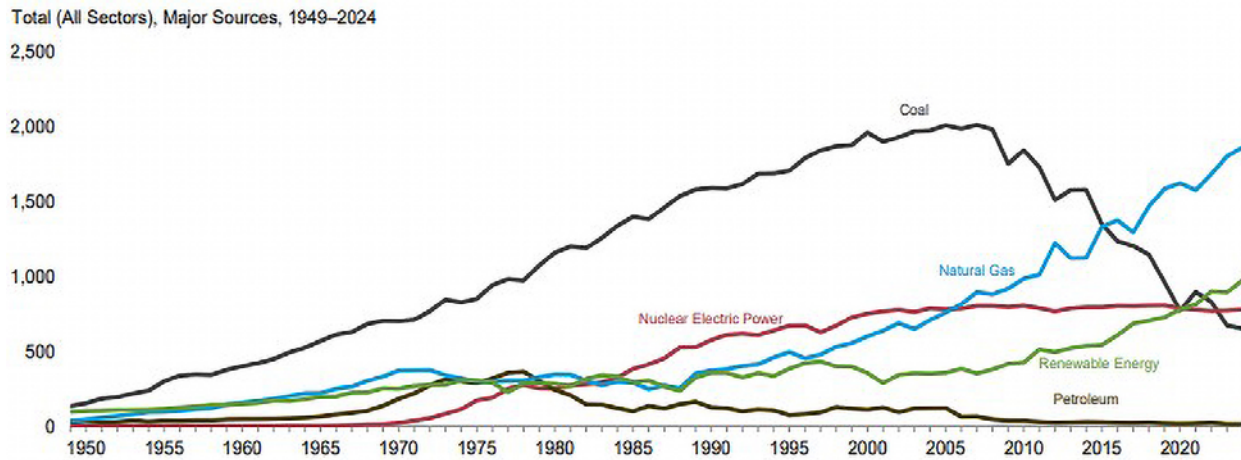
## 6.5.4 Regional industry

Development of a regional biomass industry can promote economic growth within communities, providing benefits like those of other local industries. Initiatives such as Regional Biomass Resource Hub from the DOE are designed to promote regional biomass utilization (DOE, 2025c). Although this initiative promotes utilization of purpose-grown energy crops, sustainably harvested forest biomass for bioenergy is an important aspect of forest management, and guidelines have been established to ensure ecological sustainability (Titus et al., 2021).

Biomass energy products produced locally but frequently marketed outside the state include bundled firewood and wood pellets. Several Colorado companies produce bundled firewood, which is a value-added product. Bulk firewood typically sells for \$100 to \$300 per cord. Bundled firewood (0.75–1.00 cubic foot) sells for \$6 to \$18 per bundle, or \$1,100 to \$3,500 per cord. Heat treatment in a kiln can be a requirement to ship firewood across state lines for commercial sale. Nonetheless, bundled firewood is sold throughout the region.

## 6.5.5 Electric grid

While the share of renewable electricity has increased significantly in the U.S. over the past decade, power production is still dominated by electricity produced from fossil-based and nuclear fuels (EIA, 2025). About 60% of electricity currently consumed in the U.S. is generated with fossil fuels and 20% with nuclear fuels (EIA, 2024). While electricity generated with coal was reduced by half, there was a corresponding increase in electricity produced using natural gas. However, in 2023



**Figure 6.2** – Net electricity generation (billion kilowatt-hours). Figure from EIA (2025).

about 86% of new electric generation capacity in the United States would be fueled with non-fossil sources (DOE, 2023c).

Wind, solar and hydroelectric power account for most of the renewable electricity generated in the U.S. Only about 2% of the electricity consumed during 2020 in the U.S. was generated from biomass (EIA, 2023). Based on data published by the EIA in 2023 for Colorado, the electrical energy generation mix for the state was 37.6% coal, 26.7% natural gas, 28.6% wind, 2.9% hydroelectric, 4.2% solar and 0.3% biomass in 2022. Nonetheless, a study by Jorgenson et al. (2011), Colorado has an estimated 1.5 million tons of biomass available annually that could be used to sustainably fuel more than 200 MW of electric generation capacity.

In 2022, the U.S. Department of Agriculture awarded a grant to researchers at Rutgers University to determine the potential for decarbonizing the electric grid and its implications for U.S. agriculture (Rutgers, 2026). The objectives of this study included quantifying existing biomass feedstocks, assessing how much electricity could be sustainably produced from renewable sources, evaluating the economic and environmental impacts, and determining their impact on agricultural and local rural communities. XCEL Energy announced plans to develop a new 19-megawatt biomass power plant in Hayden as part of its Clean Energy Plan to double the supply of renewable energy across the state (Voegelé, 2023).

## 6.6 Site identification and location

Many biomass facilities have been proposed for Colorado. Proper site location is critical to facility profitability and success, providing several benefits including reduced feedstock transportation costs and environmental impacts. The EPA publishes a guide that outlines how to identify sites for renewable energy development, including biomass (EPA, 2025). Site selection involves considering factors that include access to existing suppliers and customers, available land and buildings, tax incentives and grants, reliable cost-competitive utilities, environmental constraints, quality of life and workforce availability (Perez, 2023). Access to feedstock, land use and availability, utilities and infrastructure, and economic, environmental and social criteria are all factors that influence facility location that are presented subsequently.

### 6.6.1 Access to feedstock

Biomass facilities must have sufficient feedstock to meet production capacity. When evaluating potential sites, it is important to determine feedstock costs and any competing regional uses for that biomass. Generally, the closer a facility is to the source of biomass, the lower its feedstock costs should be because of lower transportation costs. Bioenergy facilities that utilize forest biomass usually evaluate biomass availability within 75 miles of the facility site. In Colorado, haul distances can easily exceed 75 miles, and longer hauls normally require a transportation subsidy for economic viability. Proximity of the plant to biomass will also lower emissions associated with transportation.

Based on this logic, forest biomass should flow to the nearest facility. In practice, this is often not the case. A spatial analysis conducted by Richardson in 2016, evaluated the flow of biomass from forest management projects in Colorado to facilities (sawmills) for utilization. They found no significant relationships between working haul distance and proximity to treatments, feedstock origin or species being processed. In other words, biomass frequently traveled far greater distances than necessary for utilization due to market forces other than transportation costs.

Nonetheless, when evaluating alternative site locations, adequate biomass feedstock supply and cost – including transportation costs – are important factors to consider.

### **6.6.2 Land use and availability**

When selecting a site for a biomass facility, land use (permitting) and availability are important considerations. Generally, site selection involves evaluating available land or buildings that meet project requirements. The goal is to identify sites that accommodate all aspects of the operation, maximizing its efficiency. Any potential impediments such as permits, easements and environmental concerns associated with a potential site should be considered.

Most permits are issued by state, county or city government. Local jurisdictions may have zoning or covenants that restrict land use. Restrictions may include allowable uses, setback requirements, building height restrictions and landscaping. The sites being considered should be zoned for the intended use and allow for future expansion. The regulatory environment associated with a site can dramatically affect the time required for startup and ultimate operation of the facility.

Facilities should be in areas that are not prone to natural disasters such as floods, hurricanes, earthquakes and wildfires. While most of Colorado is at low to moderate risk for natural disasters (FEMA, 2025), there are elevated risks of flooding in some areas, particularly along the Front Range. Wildfire is a danger throughout the state, with many areas at high risk. More than 1 million homes and businesses in Colorado are currently threatened by wildfire, and over the next 30 years the number of threatened structures across the state is expected to grow by 19% (Jaffe, 2022). The CSFS maintains a wildfire risk map that shows the level of wildfire risks across Colorado (CSFS, 2023). Selecting a facility location in less fire-prone areas will help minimize wildfire risks.

### **6.6.3 Utilities and infrastructure**

Evaluating alternative site locations for a biomass facility must consider utilities and infrastructure requirements, such as the transportation network. The availability of utilities to support a facility, such as electricity, sewer and water, is an important factor in determining site suitability. In addition to availability, utility cost may also be a consideration, particularly in terms of price stability over the life of the facility.

If the facility is generating electricity, access to the grid or nearby customers will be necessary to sell electricity. Selling power to the grid continues to be a challenge for both proposed and existing biomass power plants in Colorado. There are several reasons for this, including high capital costs, low efficiency, high feedstock costs and procuring power purchase agreements with electric utility distribution companies, as experienced by Eagle Valley Clean Energy (Greenbacker Renewable Energy, 2019). Grid accessibility was an important driver for the proposed XCEL biomass power plant at Hayden (Voegele, 2023).

Proximity to the transportation network for moving biomass to a facility and finished product to market is also essential. In Colorado, most biomass feedstock is transported by truck; therefore, potential sites must have adequate access for trucks. The volume of truck traffic may also be a consideration. Rail service is available in many areas of the state, but accessing it has proven to be a challenge for biomass facilities in Colorado. One of the most pressing concerns with rail transportation is the poor service provided by freight railroads (Marsh, 2022). Locating sidings for rail access can also be difficult. Other forms of transportation, including air and ship transportation, are less important for biomass facilities located in Colorado, although opportunities exist for pellet manufacturers in the state to export pellets via ship to European or Asian markets.

### **6.6.4 Economic, environmental and social criteria**

Site identification and selection should consider costs and benefits of economic, environmental and social criteria that include factors such as job creation, air quality, greenhouse gas emission reduction and public acceptance.

Titus et al. evaluated biomass harvesting guidelines in 2021, emphasizing their importance for ensuring that harvesting forest biomass for bioenergy and bio-based products is ecologically sustainable. Within the context

of sustainable forest management (SFM), guidelines were considered for environmental concerns that included soil, site productivity, biodiversity, water quality and carbon storage. Social concerns such as visual aesthetics, recreation and preservation of cultural, historical and archeological sites were also considered. Although guidelines are usually voluntary, governance measures such as SFM policies, trade regulations and certification systems were also discussed. The intent of considering all these factors when selecting a site is to minimize environmental impacts and promote social acceptance for the facility, and ultimately for a growing bioeconomy (Titus et al., 2021).

### **6.6.5 Analytical tools and methods for site selection**

Many analytical tools and methods exist that can assist with site selection and evaluation. In addition to Section 3 of this assessment, other resources exist for identifying potential sources of biomass. The EPA has a website that helps identify sites for renewable energy facilities that includes biomass (EPA, 2025). The EPA also provides county-level biomass resource maps that can be used to identify potential sources of feedstock including forest and mill residuals (EPA, 2024).

The Bio-Based Energy Analysis Group (BEAG) housed in the University of Tennessee's Institute of Agriculture conducts bio-based energy research and outreach. It supports sustainable bio-based markets using holistic modeling and quantitative analysis approaches (Boyer et al., n.d.). Among other services, the BEAG can perform both supply and demand assessments. And closer to home, the CSFS maintains the Timber Availability Science & Data Byte, which analyzes timber supply and

processing availability based on USFS FIA data (Marucci & Clements, 2022).

Several models have been developed to assist with locating viable sites for biomass facilities. Hogland et al. (2018) used spatial analysis and logistics software to model variables such as feedstock availability within an economically viable distance of the biomass facility and the logistic cost of moving biomass there. Hartley (2014) developed a mixed integer linear programming model that optimized harvest, extraction, transport, storage and preprocessing, providing the lowest possible feedstock cost. Based on this analysis, optimal locations were identified along with their respective supply chains for delivery of feedstock.

Another study by Young et al. (2017) developed a regression model combined with Bayesian inference to predict potential locations for biomass facilities. Analyses were done for two groups of facilities that use biomass; Group I comprised sawmill-sized facilities and Group II consisted of larger facilities similar in size to pulp and paper mills. For Group I median family income, road density, slope of harvest area, annual growth-to-drain ratio and forest land: area ratio significantly influenced location. For Group II, slope of harvest area, urban land: area ratio and number of primary processing facilities in proximity were highly significant.

Woo et al. (2018) integrated multi-criteria analysis and a GIS model, including a supply chain analysis to identify optimal locations for biomass facilities that balanced economic, environmental and social criteria considered in the supply chain analysis. These are discussed further in Section 7 of this assessment.



*A stack of spruce logs waits to be milled. Credit: CSFS*

## 6.7 Summary .....

Colorado’s forests, many of which are at high or very high fire risk, have the potential to produce large quantities of usable biomass through forest thinning treatments. In most cases, this usage leads to energy: either combustion of biomass to produce energy or its processing into fuel for others to transform into energy.

There is no perfect solution to the issues involved in burning biomass for energy. Distance from source to plant is always a factor. Biomass combustion can pollute less than a wildfire, but this can also depend on the scale and intensity of the wildfire. The public perception (which is not without foundation) is that burning biomass for energy contributes to climate change, and this in turn contributes to permitting opposition. This perception often does not factor in the impact to climate change represented by large-scale wildfire with intensities and severities worsened by the lack of forest management in some areas of Colorado.

Biomass processing options, such as firewood and pellet production, are most restricted by distances to markets. Simply put, most Coloradans (and thus most markets, including that of nearby Cheyenne, Wyoming) reside along or near the I-25 corridor from Fort Collins to Pueblo. Only a fraction of Colorado’s forestland lies

within economic reach of those markets. Pellet and firewood facilities farther from those markets might encounter less public resistance, but they also have smaller markets that place practical ceilings on their production. Other options, such as shavings and landscaping bark, have value but encounter limitations imposed by market size and distance.

All biomass utilization options large enough to make an impact in Colorado would require assured supplies of biomass to begin with, high likelihood of approval and confidence in market acceptance. If the purpose is combustion for power, users must be able to afford it. If the biomass is to be processed for others to combust for power or heating/cooling, it must be affordable in those markets. A promising method is co-location, in which biomass facilities share space and equipment with sawmills, post-and-pole operations and other industries that have already located near sources of feedstock.

While renewable energy is on the national rise, it has room to expand. Its increase in Colorado in the form of biomass utilization will depend upon supply/distances/terrain, facilities and markets – and quite possibly, efforts by the state government to facilitate the connections between these.

## 6.8 References

- Acharya, B. S., Saud, P., Sharma, S., Perez-Verdin, G., Grebner, D. L., & Joshi, O. (2024). Wood-based bioenergy in North America: An overview of current knowledge. *Forests*, 15(9), 1669. <https://doi.org/10.3390/f15091669>
- Adams, P., Bridgwater, T., Lea-Langton, A., Ross, A., & Watson, I. (2018). Chapter 8: Biomass conversion technologies. In P. Thornley & P. Adams (Eds.), *Greenhouse gas balances of bioenergy systems* (pp. 107-139). Academic Press. <https://doi.org/10.1016/B978-0-08-101036-5.00008-2>
- Axelsson, K., Wagner, A., Johnstone, I., Allen, M., Caldecott, B., Eyre, N., Fankhauser, S., Hale, T., Hepburn, C., Hickey, C., Khosla, R., Lezak, S., Mitchell-Larson, E., Malhi, Y., Seddon, N., Smith, A., & Smith, S. M. (2024). *Oxford Principles for Net Zero Aligned Carbon Offsetting* (revised 2024). Oxford: Smith School of Enterprise and the Environment, University of Oxford. <https://www.smithschool.ox.ac.uk/sites/default/files/2024-02/Oxford-Principles-for-Net-Zero-Aligned-Carbon-Offsetting-revised-2024.pdf>
- Basu, P. (2018a). Chapter 4: Torrefaction. In P. Basu (Ed.), *Biomass gasification, pyrolysis and torrefaction (third edition)* (pp. 93-154). Academic Press. <https://doi.org/10.1016/B978-0-12-812992-0.00004-2>
- Basu, P. (2018b). Chapter 5: Pyrolysis. In P. Basu (Ed.), *Biomass gasification, pyrolysis and torrefaction (third edition)* (pp. 155-187). Academic Press. <https://doi.org/10.1016/B978-0-12-812992-0.00005-4>
- Basu, P. (2018c). Chapter 11: Biomass combustion and cofiring. In P. Basu (Ed.), *Biomass gasification, pyrolysis and torrefaction (third edition)* (pp. 393-413). Academic Press. <https://doi.org/10.1016/B978-0-12-812992-0.00011-X>
- BBI International. (2002). *Feasibility study for bioethanol co-location with a coal fired power plant*. National Renewable Energy Laboratory. <https://docs.nrel.gov/docs/fy03osti/32999.pdf>
- Biomass Thermal Energy Council. (2017). *Why use biomass for heating?* <https://files.dnr.state.mn.us/forestry/biomass/swet/WhyUseWoodFactSheet.pdf>
- Black Hills Corp. (2010, December 16). Colorado public utilities commission approves retirement of W.N. Clark to comply with clean air, clean jobs act. *PR Newswire*. <https://www.prnewswire.com/news-releases/colorado-public-utilities-commission-approves-retirement-of-wn-clark-to-comply-with-clean-air-clean-jobs-act-112036254.html>
- Boonmee, N., & Quintiere, J. G. (2005). Glowing ignition of wood: The onset of surface combustion. *Proceedings of the Combustion Institute*, 30(2), 2303-2310. <https://doi.org/10.1016/j.proci.2004.07.022>
- Boyer, C., Clark, C., English, B., Hellwinckel, C., Jensen, K., Larson J., Menard, J., Trejo-Pech, C., & Yu, E. (n.d.). *Bio-based energy analysis group*. University of Tennessee Department of Agricultural and Resource Economics. <https://arec.tennessee.edu/research/beag/>
- Chung, N. (2024). *Economic and community contributions of the forest product industry in Colorado*. Colorado State University. [https://csuredi.org/wp-content/uploads/2024/11/Final-report\\_to\\_post.pdf](https://csuredi.org/wp-content/uploads/2024/11/Final-report_to_post.pdf)
- Clifford, C. B. (2020). *Alternative Fuels from Biomass Sources* [Class Website]. Penn State University. <https://www.e-education.psu.edu/egee439/node/537>
- Colorado Department of Local Affairs. (2024). *State and regional population and housing data lookup*. [https://demography.dola.colorado.gov/assets/lookups/region\\_pop\\_lookup.html](https://demography.dola.colorado.gov/assets/lookups/region_pop_lookup.html)
- Colorado Department of Public Health & Environment. (2025). *Approved indoor burning devices*. <https://cdphe.colorado.gov/indoor-air-quality/approved-indoor-burning-devices>
- Colorado State Forest Service. (2011). *Where wood works: Harnessing the energy of woody biomass in Colorado*. <https://static.colostate.edu/client-files/csfs/pdfs/Where-Wood-Works-2011.pdf>
- Colorado State Forest Service. (2023). *Colorado wildfire risk viewer*. <https://co-pub.coloradoforestatlas.org/>
- Corti, A., & Lombardi, L. (2004). Biomass integrated gasification combined cycle with reduced CO2 emissions: Performance analysis and life cycle assessment (LCA). *Energy*, 29(12-15), 2109-2124. <https://doi.org/10.1016/j.energy.2004.03.015>
- Edenhofer, O., Pichs Madruga, R., & Sokona, Y. (2011). *Renewable energy sources and climate change mitigation: Summary for policymakers and technical summary*. International Panel on Climate Change. [https://archive.ipcc.ch/pdf/special-reports/srren/SRREN\\_FD\\_SPM\\_final.pdf](https://archive.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf)
- Emmons, H. W., & Atreya, A. (1982). *The science of wood combustion*. Proceedings of the Indian Academy of Sciences Section C: Engineering Sciences.

- Electric Power Research Institute. (2010). *Engineering and economic evaluation of biomass power plants*. <https://www.epri.com/research/products/000000000001019762>
- FEMA. (2025). *The national risk index*. <https://hazards.fema.gov/nri/>
- Fiala, B. J., & Merola, S. (2008). *Wood burning and its impacts on human health and ambient air quality*. Broome County Environmental Management Council. <https://www.gobroomecounty.com/sites/default/files/dept/planning/pdfs/WoodBurningWhitePaperAdopted5-1-08Lthd.pdf>
- Flashinski, J. (2017, November 2). Mobile pyrolysis draws diverse crowd in Colorado. *Utah Forest Newsletter*, 21(2), 7.
- Gendek, A., Aniszewska, M., & Chwedoruk, K. (2016). Bulk density of forest energy chips. *Annals of Warsaw University of Life Sciences, SGGW*, 67, 101–111.
- Green Power Institute. (2002). *Bioethanol co-location study*. National Renewable Energy Laboratory. <https://docs.nrel.gov/docs/fy03osti/33000.pdf>
- Greenbacker Renewable Energy. (2019, May 5). Greenbacker acquires Colorado biomass project. *Biomass Magazine*. <https://biomassmagazine.com/articles/greenbacker-acquires-colorado-biomass-project-16134>
- Hartley, D. S. (2014). *Modeling and optimization of woody biomass harvest and logistics in the Northeastern United States*. [Doctoral dissertation, Davis College of Agriculture]. <https://doi.org/10.33915/etd.5775>
- Hayes, D. (2005, October 18). Nederland's bio-mess. *Vail Daily*. <https://www.vaildaily.com/news/nederlands-bio-mess/>
- Henseler, K. (2023, October 25). Montrose Forest Products \$15 million investment is a win for the company and environment. *Montrose Press*. [https://www.montrosepress.com/free\\_access/montrose-forest-products-15-million-investment-is-a-win-for-the-company-and-environment/article\\_02f2da4a-7297-11ee-8532-b7b31e3e521e.html](https://www.montrosepress.com/free_access/montrose-forest-products-15-million-investment-is-a-win-for-the-company-and-environment/article_02f2da4a-7297-11ee-8532-b7b31e3e521e.html)
- Hogland, J., Anderson, N., & Chung, W. (2018). New geospatial approaches for efficiently mapping forest biomass logistics at high resolution over large areas. *ISPRS International Journal of Geo-Information*, 7(4). <https://doi.org/10.3390/ijgi7040156>
- Hohenstein, W. G., & Wright, L. L. (1994). Biomass energy production in the United States: An overview. *Biomass and Bioenergy*, 6(3), 161–173. [https://doi.org/10.1016/0961-9534\(94\)90073-6](https://doi.org/10.1016/0961-9534(94)90073-6)
- Hurst Boiler. (2008, August 8). Chadron State College. *Hurst Boiler News*. [https://www.hurstboiler.com/news/chadron\\_state\\_college](https://www.hurstboiler.com/news/chadron_state_college)
- Ince, P. J. (1979). *How to estimate recoverable heat energy in wood or bark fuels*. U.S. Department of Agriculture, Forest Service. <https://www.fs.usda.gov/research/treesearch/5783>
- International Energy Agency. (2021). *Implementation of bioenergy in the United States - 2021 update*. [https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021\\_USA\\_final.pdf](https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_USA_final.pdf)
- International Renewable Energy Agency. (2012). *Renewable energy cost analysis - biomass for power generation*. <https://www.irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis---Biomass-for-Power-Generation>
- International Renewable Energy Agency. (2019). *Solid biomass supply for heat and power. Technology brief*. [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA\\_Solid\\_biomass\\_supply\\_2019.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Solid_biomass_supply_2019.pdf)
- Jaffe, M. (2022, May 19). 1 million Colorado buildings are threatened by wildfire. The risk is highest in suburban counties. *The Colorado Sun*. <https://coloradosun.com/2022/05/19/wildfire-risk-colorado-first-street-foundation/>
- Jaffe, M., & Booth, M. (2023, May 15). How is Colorado doing in shutting down coal power plants? *The Colorado Sun*. <https://coloradosun.com/2023/05/15/colorado-coal-shut-down-new-epa-rules/>
- Jorgenson, J., Gilman, P., & Dobos, A. (2011). *Technical manual for the SAM biomass power generation model*. U.S. Department of Energy, Office of Scientific and Technical Information. <https://www.osti.gov/biblio/1026561>
- Kenton, W. (2023). *Cottage industry. Definition, impact on developing economies, and examples*. Investopedia. <https://www.investopedia.com/terms/c/cottage-industry.asp>
- Kiest, K. (2023, December 5). *Record carbon dioxide emissions impeding progress on meeting climate goals*. NOAA Research. <https://research.noaa.gov/2023/12/05/record-fossil-carbon-dioxide-emissions-impeding-progress-on-meeting-climate-goals-report/>
- Kirchstetter, T. (2021). *Decentralized and mobile biomass torrefaction to upgrade the biomass supply chain*. U.S. Department of Energy, Office of Scientific and Technical Information. <https://doi.org/10.2172/1773475>

- Lewandowski, W. M., Ryms, M., & Kosakowski, W. (2020, April 26). Thermal biomass conversion: A review. *Processes*, 8(5). <https://doi.org/10.3390/pr8050516>
- Livingston, W. R., Middelkamp, J., Willeboer, W., Tosney, S., Sander, B., Madrali, S., & Hansen, M. T. (2016). *The status of large scale biomass firing*. IEA Bioenergy. [https://www.ieabioenergy.com/wp-content/uploads/2016/03/IEA\\_Bioenergy\\_T32\\_cofiring\\_2016.pdf](https://www.ieabioenergy.com/wp-content/uploads/2016/03/IEA_Bioenergy_T32_cofiring_2016.pdf)
- Lowe, L. L. (2006). *Potential for using woody biomass for heat and/or power in Utah's institutions and industries*. Utah Department of Natural Resources. <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=b408e694185f4bd1f61b02684a78c719c2e07f9a>
- Mackes, K. H., & Lightburn, C. R. (2003). Evaluating the use of green wood chips processed from small-diameter trees as an alternate fuel for making cement. *Forest Products Journal*, 53, 42–47.
- Manandhar, A., & Shah, A. (2021, July 28). *Improving biomass properties via densification and upgrading*. Ohio State University Extension. <https://ohioline.osu.edu/factsheet/fabe-6605>
- Marsh, J. (2022, May 4). Commodity giants and unions are slamming railroads as performance tanks. *FreightWaves*. <https://www.freightwaves.com/news/should-the-freight-rail-industry-be-overhauled>
- Marucci, C., & Clements, D. (2022, May 18). *Accessible timber volume, 2010–2019*. Colorado State Forest Service. <https://csfs.colostate.edu/2022/05/16/accessible-timber-volume-2010-2019/>
- McAvoy, D., Dettenmaier, M., & Kuhns, M. (2018). Mobile pyrolysis for hazardous fuels reduction and biochar production in western forests. *Journal of Extension*, 56(1). <https://doi.org/10.34068/joe.56.01.14>
- Mohan, D., Pittman, Jr., C. U., & Steele, P. H. (2006). Pyrolysis of wood/biomass for bio-oil: A critical review. *Energy & Fuels*, 20(3), 848–889. <https://doi.org/10.1021/ef0502397>
- Naturally: wood. (2025). *What is mass timber?* <https://www.naturallywood.com/design-and-construction/mass-timber/>
- Pérez, R. (2023). *5 workforce factors to consider in site selection*. The workforce 2023 guide. Site Selection. <https://www.abq.org/wp-content/uploads/2023/06/5-Workforce-Factors-to-Consider-in-Site-Selection.pdf>
- Perkins, G. (2018). Techno-economic comparison of the levelised cost of electricity generation from solar PV and battery storage with solar PV and combustion of bio-crude using fast pyrolysis of biomass. *Energy Conversion and Management*, 171, 1573–1588. <https://doi.org/10.1016/j.enconman.2018.06.090>
- Power, N. (2021). *The pros and cons of biochar in horticulture*. North Carolina Cooperative Extension. <https://richmond.ces.ncsu.edu/2021/07/biochar-2/>
- Prasad, M. N. V. (2020). Biomass energy sources and conversion technologies for production of biofuels. In P. Pathak & R. R. Srivastava (Eds.), *Alternative energy resources. The handbook of environmental chemistry*, vol 99. Springer. [https://doi.org/10.1007/698\\_2020\\_613](https://doi.org/10.1007/698_2020_613)
- Prokupets, D., Mackes, K. H., & Smith, S. (2002). Co-firing wood biomass with coal at the Cañon City power plant. *Fire, fuel treatments, and ecological restoration: Conference proceedings*. RMRS-P-29, 203–206. [https://www.fs.usda.gov/rm/pubs\\_exp\\_forests/tenderfoot/rmrs\\_2003\\_mccaughey\\_w001.pdf](https://www.fs.usda.gov/rm/pubs_exp_forests/tenderfoot/rmrs_2003_mccaughey_w001.pdf)
- Ramlow, M., Keske, C., & Cotrufo, M. F. (2016). *Biochar in Colorado*. Colorado State University Extension. <https://extension.colostate.edu/topic-areas/agriculture/biochar-in-colorado-0-509/>
- Richardson, E. A. (2016). *Spatial component for the decision support systems of Colorado's forest products industry- Industry cluster analysis on sawmills in Northern Colorado*. Colorado State University. <https://api.mountainscholar.org/server/api/core/bitstreams/945b5713-72b6-4cf1-9059-94163504bfb0/content>
- Rutgers, The State University of New Jersey. (2026). *Decarbonizing the electricity grid and its implications for U.S. agriculture: Challenges and opportunities*. U.S. Department of Agriculture, National Institute of Food and Agriculture. <https://www.researchwithrutgers.com/en/projects/decarbonizing-the-electricity-grid-and-its-implications-for-us-ag/#:~:text=The%20increasing%20utilization%20of%20renewable%20energy%20systems,an%20increase%20in%20the%20share%20of%20renewables%2C>
- Safarian, S., Ebrahimi Saryazdi, S. M., Unnthorsson, R., & Richter, C. (2021). Gasification of woody biomasses and forestry residues: Simulation, performance analysis, and environmental impact. *Fermentation*, 7(2). <https://doi.org/10.3390/fermentation7020061>

- Severy, M. A., Chamberlin, C. E., Eggink, A. J., & Jacobsen, A. E. (2018). Demonstration of a pilot-scale plant for biomass torrefaction and briquetting. *Applied Engineering in Agriculture*, 34(1): 85–98. <https://doi.org/10.13031/aea.12376>
- Tillman, D. A. (2000). Biomass cofiring: The technology, the experience, the combustion consequences. *Biomass and Bioenergy*, 19(6), 365–384.
- Titus, B. D., Brown, K., Helmisaari, H. S., Vanguelova, E., Stupak, I., Evans, A., Clarke, N., Guidi, C., Bruckman, V. J., Varnagiryte-Kabasinskiene, I., Armolaitis, K., de Vries, W., Hirai, K., Kaarakka, L., Hogg, K., & Reece, P. (2021). Sustainable forest biomass: a review of current residue harvesting guidelines. *Energy, Sustainability and Society*, 11(10). <https://doi.org/10.1186/s13705-021-00281-w>
- Tursi, A. (2019). A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Research Journal*, 6(2), 962. <https://doi.org/10.18331/BRJ2019.6.2.3>
- U.S. Department of Energy. (2023a). Wood and pellet heating: Choosing and installing wood- and pellet-burning appliances. <https://www.energy.gov/energysaver/wood-and-pellet-heating>
- U.S. Department of Energy. (2023b). 2023 billion-ton report: An assessment of U.S. renewable carbon resources. <https://www.energy.gov/eere/bioenergy/2023-billion-ton-report-assessment-us-renewable-carbon-resources>
- U.S. Department of Energy. (2023c). FOTW #1304, August 21, 2023: In 2023, non-fossil fuel sources will account for 86% of new electric utility generation capacity in the United States. <https://www.energy.gov/eere/vehicles/articles/fotw-1304-august-21-2023-2023-non-fossil-fuel-sources-will-account-86-new>
- U.S. Department of Energy. (2025a) *Hydrogen production: Biomass gasification*. <https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification>
- U.S. Department of Energy. (2025b). Onsite energy installation database. <https://doe.icfwebservices.com/chp>
- U.S. Department of Energy. (2025c). *Regional biomass resource hub initiative*. <https://www.energy.gov/eere/bioenergy/regional-biomass-resource-hub-initiative>
- U.S. Energy Information Administration. (2023). *Residential energy consumption survey*. <https://www.eia.gov/consumption/residential/data/2020/index.php?view=state>
- U.S. Energy Information Administration. (2024). *Frequently Asked Questions: What is U.S. electricity generation by energy source?* <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>
- U.S. Energy Information Administration. (2025). *June 2025 monthly energy review*. <https://www.eia.gov/totalenergy/data/monthly/archive/00352506.pdf>
- U.S. Environmental Protection Agency. (2007). Biomass combined heat and power catalog of technologies. [https://www.epa.gov/sites/default/files/2015-07/documents/biomass\\_combined\\_heat\\_and\\_power\\_catalog\\_of\\_technologies\\_v.1.1.pdf](https://www.epa.gov/sites/default/files/2015-07/documents/biomass_combined_heat_and_power_catalog_of_technologies_v.1.1.pdf)
- U.S. Environmental Protection Agency. (2015). *Standards of performance for new residential wood heaters, new residential hydronic heaters and forced-air furnaces (2060-AP93; Final)*. <https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and>
- U.S. Environmental Protection Agency. (2021). *Biomass heating and cooling technologies*. [https://19january2021snapshot.epa.gov/rhc/biomass-heating-and-cooling-technologies\\_.html](https://19january2021snapshot.epa.gov/rhc/biomass-heating-and-cooling-technologies_.html)
- U.S. Environmental Protection Agency. (2024). *State renewable energy: Biomass/biogas*. <https://www.epa.gov/statelocalenergy/state-renewable-energy-biomassbiogas>
- U.S. Environmental Protection Agency. (2025). *How to identify sites*. <https://www.epa.gov/re-powering/how-identify-sites>
- van der Stelt, M. J. C., Gerhauser, H., Kiel, J. H. A., & Ptaskinski, K.J. (2011). Biomass upgrading by torrefaction for the production of biofuels: A review. *Biomass and Bioenergy*, 35(9), 3748–3762. <https://doi.org/10.1016/j.biombioe.2011.06.023>
- Voegelé, E. (2023, September 28). Xcel Energy—Colorado to develop 19 MW biomass plant. *Biomass Magazine*. <https://biomassmagazine.com//articles/xcel-energycolorado-to-develop-19-mw-biomass-plant>
- Vogel, M. (2005). *Heating with Wood: Principles of Combustion*. Montana State University Extension. <https://woodlandinfo.org/wp-content/uploads/sites/383/2017/09/mt198405hr.pdf>

- Wegener, M., Malmquist, A., Isalqué, A., & Martin, A. (2018). Biomass-fires combined cooling, heating, and power for small scale applications – A review. *Renewable and Sustainable Energy Reviews*, 96, 392-410. <https://doi.org/10.1016/j.rser.2018.07.044>
- Williams, J. (2005). *Biomass in the Black Hills*. U.S. Department of Agriculture, Forest Service. <https://danr.sd.gov/Conservation/docs/Biomass/Biomass-Briefing-Paper.pdf>
- Woo, H. Acuna, M., Moroni, M., Taskhiri, M. S., & Turner, P. (2018). Optimizing the location of biomass energy facilities by integrating multi-criteria analysis (MCA) and geographical information systems (GIS). *Forests*, 9(10), 585. <https://www.mdpi.com/1999-4907/9/10/585>
- World Resources Institute. (2023). *Global power plant database*. <https://datasets.wri.org/datasets/global-power-plant-database>
- Young, T. M., Perdue, J. H., & Huang, X. (2017). *Predicting site locations for biomass using facilities with Bayesian methods*. WSEAS Transactions on Environment and Development. [https://www.srs.fs.usda.gov/pubs/ja/2017/ja\\_2017\\_perdue\\_002.pdf](https://www.srs.fs.usda.gov/pubs/ja/2017/ja_2017_perdue_002.pdf)
- Zimmer, T., Breun, P., & Schultmann, F. (2018). Deployment and relocation of semi-mobile facilities in a thermal power plant supply chain. In A. Fink, A. Fugenschuh, & M. Geiger (Eds.), *Operations Research Proceedings 2016*. [https://doi.org/10.1007/978-3-319-55702-1\\_26](https://doi.org/10.1007/978-3-319-55702-1_26)