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Analysis of Biomass, Converting Wood to Energy: Missouri as a Case Study in Feasibility

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Abstract In 2021, the United States President, Joe Biden, launched an initiative to generate net-zero carbon emissions from the U.S. by 2050. In order to complete this task, commitments must be made to research the most efficient methods in production, transmission, and storage of alternative and renewable energy sources. Foreseen obstacles include capital costs,, environmental, wildlife, economical concerns, political agendas by state, fossil fuel prices, and concerns in greenhouse gas emissions. The development of sustainable, viable systems that promote health, safety, and economic growth must be coordinated with policy changes. The first step of the process at a local level is to baseline the production and consumption of the current energy systems in order to make an educated decision on which system or systems to utilize. If Missouri can expand its biomass energy generation mix, it will be able to drive down the current consumption to production ratio of 8:1, thus, expanding its overall energy mix and ultimately leaving the state in a position to sell energy to neighboring states. To test this hypothesis specifically, this writing investigates process risk, project value, design and building, decommission planning, flexibility, capacity, and adaptability. Journal entries, past issues, and projected issues have been rounded out to provide a projection for current and future success. This will better position Missouri to support the overall agenda of net-zero carbon emissions by 2050 as Missouri appears to be well-positioned to launch a successful wood-to-energy program and well prepared to minimize dependency on energy imports outside their state border.

Keywords: *energy, efficiency, sustainability, transition, biomass to energy, renewable energy, energy systems*

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1. Introduction

As the world looks to move past the global pandemic, known as Covid-19 and return to a new normal, leaders, businesses, and individuals must regain focus as to what is truly important. Now more than ever, the majority of the world realizes the actual value of security, safety, and a healthy future. In support of this, we need to be willing to put in the time, energy, and effort to improve our environment. We must act now to preserve our world for future generations, through pollution reductions, so that the world we handoff is equal to, if not better, than the one we currently live in.

In 2019 to 2020, the world as we knew it changed. Through the many hardships both in health and the economy, almost every individual in the world has been affected, in some way or another. Although hard to see, benefits can be achieved, however, through taking a step back, slowing down, and determining what is important and how to improve. Energy creation and consumption are close to the top of the list.

One source of energy creation that shows promise is biomass, wood-to-energy. Credits have become available for residential biomass heating systems. In Wisconsin, for example, biomass is considered one of the state's largest renewable energy sources. In a state report, wood and biomass produce about ten times as much of the state's electricity as hydro. Wisconsin is suited for biomass production through available timber, paper, and farming sectors. In 2020, a fifth of Wisconsin's renewable electricity generation came from biomass which equates to roughly 1 in 33 homes heated by use of wood.

Proper forest management allows for healthy forests and wildlife, while also preventing wildfires. Through proper forest management, large amounts of wood biomass become available in the form of residue and logs. Many residential households use this wood to heat their homes; however, health risks from the fine particle inhalation of burning off account for around 39-47 % of premature deaths, based on a Harvard study [1].

Wood biomass to energy has a bright future, and it is an incredibly resilient renewable resource. Through proper management, policy, design, and control, benefits will be achieved and negative impacts and risks to our health and the environment will be suppressed.

Wood is composed primarily of the following, which also affect the optimal processing methods.

1. Cellulose: Structural cell wall, 50 % dry weight makeup.
2. Hemicellulose: Cell wall, 30 % dry weight makeup.
3. Lignin: Polymer, 20 % dry weight makeup.
4. Mineral Elements: Nitrogen, Sulfur, Chlorine, and heavy metals [2].

Current state studies show that multi-stage biomass gasification technology may be one way to improve in the energy sector. A 2019 study on the modern state of wood biomass showed that a multi-stage thermal chemical biomass conversion is the most promising gasification technology [3]. There are roughly 160 projects currently within the Organization of Economic Cooperation and Development (OECD) countries, utilizing fluidized bed reactors, and layer gasification, used in 38 projects. Thermal and electrical energies are driving factors for biomass gasification technology. Economic efficiency is shown through the levelized cost of energy. Results show that the cost of electricity produced by wood fuel is 2.5-3 times less than a diesel power plant [3].

The Environmental and Energy Study Institute held conferences on high energy costs, struggling rural communities, low investment in resilience, and the solutions that have been created at the community level. As many smaller farms struggle to remain financially viable against manufacturing or super farms, the overall bio-economy is at risk. Farm income is down by almost 50% from 2013 [4]. Job retention and attraction have been difficult. In the Midwest, trade disputes, flooding, and grant waivers to small refineries have been somewhat crippling. Biofuels can play an important role in the reversal of harmful pollutants from emissions, through renewable fuel standards, blending ethanol into gasoline, low carbon fuel programs, land restoration projects, and utilization of renewable sources for energy [4].

The three major types of pollution that cause harm to our environment are air, water, and land pollution. Examples of water and land pollution include commercial or industrial wastes, such as medical waste or construction materials [5]. An example of air pollution would be exhaust from a vehicle or greenhouse gasses emitting sulfur or carbon dioxide. Data suggests that more than 2 million people are killed each year from air pollution alone [6]. Exposure to pollution also causes lasting effects to our health, such as aging of the lungs and environmental effects such as temperature increase resulting in global warming.

Through the review of journals, current, and past projects, it is apparent that many advancements are happening in the wood-biomass to the energy sector. In Missouri, advancements are being made at the University of Missouri Columbia to support biomass to energy production.

This technical analysis and review aim at utilizing best practices and lessons learned in the industry to prepare Missouri for the transition to self-sufficiency with less reliance on imported energy. The scope of the study is limited to availability of resources within the borders of the state of Missouri, including materials, supply, consumption, transportation, storage, and transmission.

Also, this analysis aims to analyze and evaluate the potential installment of wood-to-energy biomass energy processes within the state of Missouri and determine if it is a viable system in terms of cost and sustainability. We will conclude by logically answering the question: Does biomass wood-to-energy system have a place in Missouri's energy portfolio?

2. Missouri's Energy Profile

Agricultural farms are abundant in rural Southeast Missouri, where the trees are plentiful and green. Missouri can expand their energy systems mix to alternative systems, utilizing available resources to mitigate pollution and carbon emissions. One such alternative system that has been relatively untapped with resources available in Missouri is the conversion of biomass to energy. Many current, past, private and government-funded projects in the biomass sector have advanced the industry and can support Missouri in their endeavor.

Several natural resources such as zinc, copper, limestone, and coal are available in Missouri. Mining each of these resources requires energy together with the residential, commercial, industrial, and transportation industries. In 2019, the transportation sector led energy consumption in Missouri with 567 trillion British thermal units (BTU), closely followed by the residential sector at 530 trillion BTU. The industrial and commercial sectors made up 40% or 707 trillion BTU. The state consumes eight times more energy than it currently produces [7].

Figure 1. Map of the United States with Missouri highlighted [8]

Missouri is considered to be a central transfer point for the United States. It is located at the interchange of the two longest rivers in the United States, theMissouri and the Mississippi. This allows for raw materials to move by the river to transfer points and then to final destinations throughout the country. Missouri's current population is around 6.1 million people as of July 1, 2019 [8]. The largest cities in the state are Kansas City, St. Louis, and Springfield, making up around 1M of the total population.

Figure 1 shows the location of Missouri, highlighted in red, in the United States. As of 2019, Missouri had a low production to consumption ratio, at 8 to 1 as shown in Figure 2.

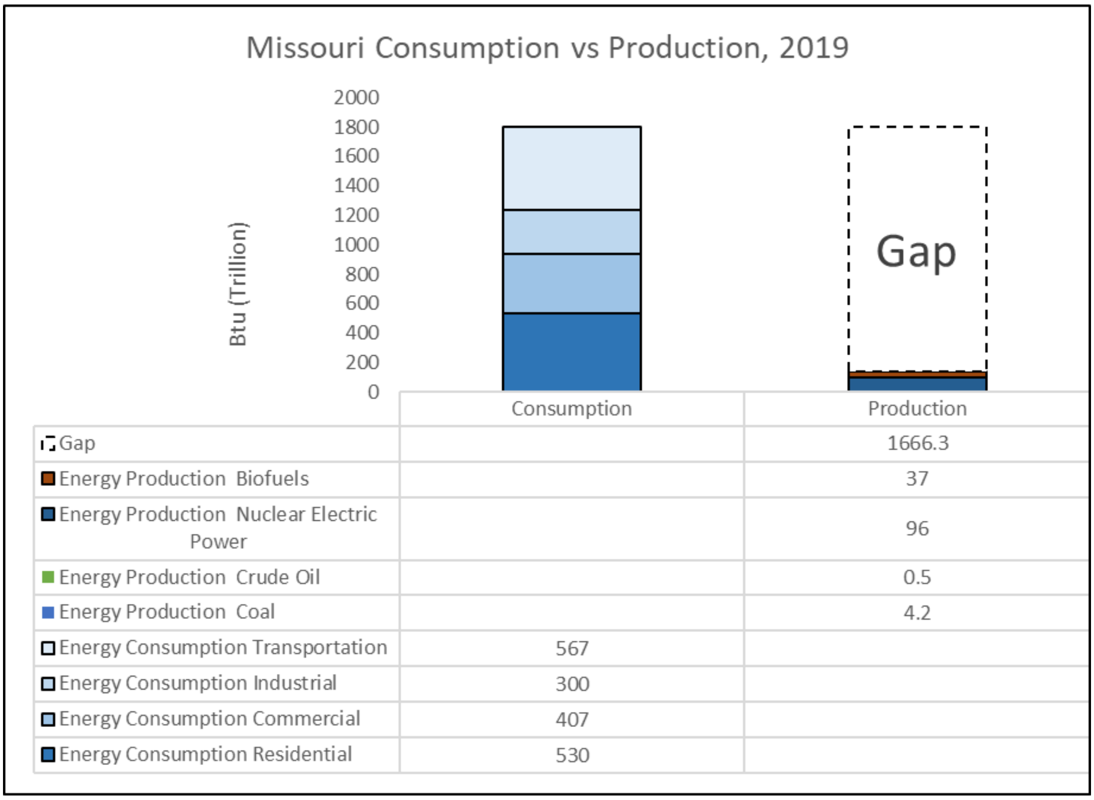

Figure 2. Data showing production versus consumption gap for Missouri in 2019 [7]

This gap, as shown in Figure 2, between production and the consumption rate of energy can be concerning. It could be assumed from this information that the state is not doing enough to promote energy generation and clean energy generation.

3. Energy Consumption in Missouri

Coal and natural gas lead overall consumption by sector, while biomass is in the bottom 25% [7].

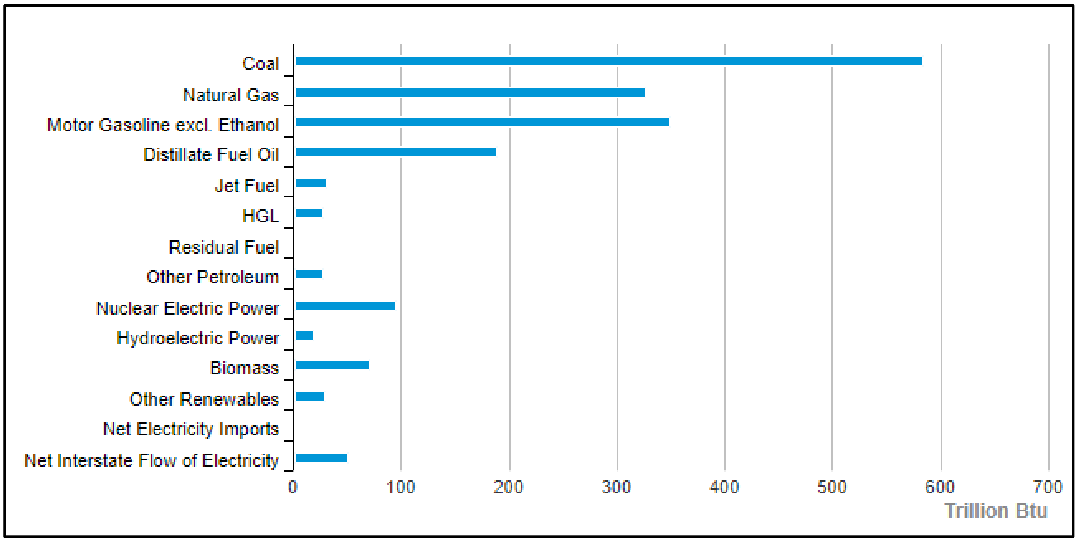

Figure 3. Missouri Energy Consumption Estimates, 2019 [7]

Table 1. Missouri Energy Indicators [7]

Demography	**Missouri**	**Share of U.S.**	**Period**
Population	6.2 million	1.9 %	2020
Civilian Labor Force	3.1 million	1.9 %	May 2021
Economy	**Missouri**	**U.S. Rank**	**Period**
Gross Domestic Product	$321.7 billion	22	2020
Gross Domestic Product for the Manufacturing Sector	$37,972 million	22	2020
Per Capita Personal Income	$51,177	37	2020
Vehicle Miles Travelled	79,168 million miles	14	2019
Land in Farms	27.8 million acres	12	2017
Climate	**Missouri**	**U.S. Rank**	**Period**
Average Temperature (^{o}F)	5.8	19	2021
Precipitation (in)	46.3	16	2020

There is a relatively large expansion window for renewables and biomass to operate in Missouri. Strategically increasing the proportion of the bottom 25% of the product mix, shown in Figure 3, will increase energy production internally, while decreasing the state's carbon footprint. Energy indicators show stability and progression within the state rankings, in relation to the United States.

Missouri makes up 1.9 % of the United States population, as shown in Table 1, with a matching labor force. The economy in Missouri is strong, and the climate shifts from hot summers to cold winters. Below are the key metrics of Missouri.

1. Missouri is ranked 22 in the United States for GDP, at $321.7 billion.
2. The average temperature is around 55.8 ^{o}F.
3. Farmland makes up around 27.8 million acres of land.
4. Six major crude oil pipelines pass through Missouri.
5. Missouri ranks 3^{rd} in the nation in biodiesel production.
6. Missouri is one of two states that require 10 % ethanol in gas.
7. Missouri's single plant accounts for 11 % of electricity generation.

Table 2 shows the environmental energy indicators in Missouri. As coal-fired capacity has decreased since 2011, natural gas in the power sector has increased. Coal, fuels about 70 % of electricity generation, and 80 % of the top power plants in the state are coal-fired [9]. Some have started to switch to natural gas, whiles other areas of generation include hydropower and wind farms. There are only three hydroelectric power plants with storage in the state of Missouri. These include the Taum Sauk, Clarence Cannon and Harry Truman plants. The rivers in Missouri offer expansion potential for future hydropower projects beyond those listed. Investor-owned companies supply power to major urban areas while electric cooperatives supply most of the remainder. Electricity pricing per kilo-watt hour (kWh) in Missouri falls in the lowest 20 % of all states within the United States.

Missouri ranks within the top one-third of states in ethanol consumption and has the third largest biodiesel production capacity in the nation due to robust policy initiatives [9]. However, key areas need to be considered for analysis and improvement. Renewable energy production is high within ethanol at 1.8 %, and energy consumption is low within biomass at 0.2 %. Missouri's ethanol consumption is ranked high at 16 in the U.S. and emissions in carbon dioxide equate to 3.3 % of the U.S. Each of these metrics shows the need and potential for improvements.

Table 2. Missouri Environmental Energy Indicators [7]

Renewable Energy Capacity	**Missouri**	**Share of U.S.**	**Period**
Total Renewable Energy Electricity Net Summery Capacity (Utility Scale Units)	2.856 MWh	1.1 %	As of April 2021
Ethanol Plant Nameplate Capacity	297 million gal/year	1.7 %	2020
Renewable Energy Production	**Missouri**	**Share of U.S.**	**Period**
Utility-Scale Hydroelectric Net Electricity Generation	191,000 MWh	1.0 %	Apr-21
Utility-Scale Solar, Wind, and Geothermal Net Electricity Generation	655,000 MWh	1.4 %	Apr-21
Utility-Scale Biomass Net Electricity Generation	7,000 MWh	0.2 %	Apr-21
Small-Scale Solar Photovoltaic Generation	38,000 MWh	0.8 %	Apr-21
Fuel Ethanol Production	6,597,000 barrels	1.8 %	2019
Renewable Energy Consumption	**Missouri**	**U.S. Rank**	**Period**
Renewable Energy Consumption as a Share of State Total	6.7%	37	2019
Fuel Ethanol Consumption	7,378,000 barrels	16	2019
Total Emissions	**Missouri**	**Share of U.S.**	**Period**
Carbon Dioxide	123.9 million metric tons	2.3%	2018
Electric Power Industry Emissions	**Missouri**	**Share of U.S.**	**Period**
Carbon Dioxide	57,516,000 metric tons	3.3%	2019
Sulfur Dioxide	81 thousand metric tons	6.4%	2019
Nitrogen Dioxide	42 thousand metric tons	3.1%	2019

Through emerging countries and advanced technology, energy consumption is happening at a rapid pace. Pollution and emissions are causing irreparable damage to our environment, and our society based on traditional sources is exhausting resources faster than they are capable of being replenished. The need to expand our energy mix and the resulting immediate need for action is not always apparent.

Missourimust expand energy sources to mitigate energy security risk and become self-sustaining through areas they are capable of, such as wood-to-energy and biomass. If the state of Missouri decides not to continue on its quest of efficiently and sustainably expanding potential renewable resources into energy, many scenarios may take effect. These can include damage to the atmosphere through increased carbon emission, and purchasing versus producing energy, causing an increased risk of energy security. Another possibility that may happen if Missouri does not choose to expand their energy resources, is that climate change may happen more rapidly, which could cause damage to plants, animals, flooding, and ultimately putting human life at risk.

Funding studies in biomass for Missouri allows for potential benefits to the state, the renewable energy sector, and the future of wood-to-energy conversions. Benefits that may be yielded through funding include, supporting the U.S. initiative to become net zero in carbon emissions. Creating education opportunities for colleges, and research institutes, which will support future grant and funding opportunities. Other benefits that may be realized are reduction in landfill, improving land value, water resources and the wildlife habitat, while minimizing dependence on other energy-producing states.

Through the appropriate funding channels and efficient use of those funds, wood-to-energy biomass in Missouri has the potential of adding value to the state. With proper analysis and research, the benefits and having an optimistic attitude will allow for an efficient energy system approach to take place. Ultimately, this may yield setting new industry standards.

4. Wood-to-Energy Biomass

Biomass is a renewable organic material that is generated from plants or animals. In Missouri, biomass is primarily used to provide energy using biodiesel and ethanol fuels from soybeans, corn, and other crops. Missouri is ranked fourth in the nation in biodiesel production capacity and second in production in the US, with eight biodiesel plants in operation [11]. Missouri's biomass energy systems can be expanded by utilizing other biomass materials [9].

Wood biomass to the world and Missourians is not a new concept. Wood is utilized in heating homes in many countries through wood stoves or fireplaces [12]. It is common to see smoke exiting the chimneys of residential homes in the winter months..

5. Conventional Wood-Biomass Processing Methods

Several methods are utilized to turn wood biomass into energy. These methods include the following.

1. Thermal

(i) Combustion – burning biomass to produce heat

(ii) Gasification – heating organic materials with free oxygen to produce hydrogen-rich gas

(iii) Pyrolysis – heating organic materials without free oxygen

2. Thermochemical – decomposition of organic matter for biofuel production.

3. Chemical

(i) Hydrothermal liquefaction – a process in which the biomass molecules are hydrolyzed by water.

(ii) Carbonation – a process of heating in an oxygen-free environment in which biomass is converted into a charcoal type material

4. Biochemical – using bacteria, microorganisms, and enzymes to breakdown biomass

5. Physical processes – burning oil [13].

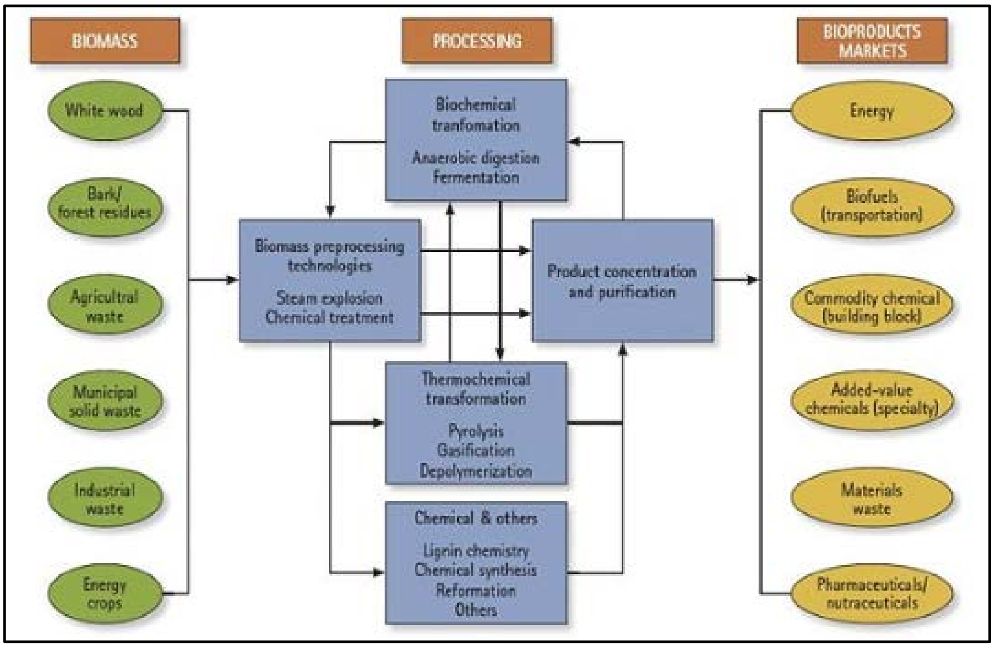

Figure 4. Biomass Processes [14]

Figure 4 shows a schematic representation of biomass to energy conversion through standard processing methods.

In simple form, the process can be grouped into four main steps.

1. Feedstock – Raw materials used for processing which are converted into another product or fuel. In biomass these resources are renewable, and examples would be crop waste, woody materials and forest residues. These materials are categorized as those that are not favorable to be sold or the residues that are left after logging timber.
2. Pre-processing – There are several applicable, efficient biomass preprocessing controls such as drying, sizing, shredding and chemically treating the feedstock for optimal processing. The greater consistency and repeatability in the feedstock, the greater the chance of running high efficiency in the conversion step or downstream process. Biomass feedstock consistency and variability has a direct effect on the cost and approach to pre-processing. Improving the pre-processing system to manage variation, improve quality control and remain cost effective is equally important [15].
3. Conversion – Wood-to-energy biomass can be converted through a direct combustion, chemical, physical, biochemical, thermochemical, and biological conversions. Each of these processes has its own advantages and disadvantages based on the application and energy end use. For example, chemical or biological conversion is most suitable to convert biomass to liquid fuel whilst direct combustion is the most appropriate conversion method to covert wood biomass for heating purposes.
4. End-user consumption – Wood has been used as a source of heating and energy for centuries. In 2020, wood and wood waste accounted for 5.5 % of industrial end-use energy consumption [16]. Wood biomass will continue to be utilized as a fuel for residential and commercial heating, providing electricity, and chemicals such as biodiesel.

6. Missouri's Transition Challenges

Missouri is heavily reliant on receiving energy from outside sources, as shown in Figure 2. Missouri can transition from a top consumer of energy to a top producer. In order to do so, Missouri can target industries that are within the scope of available resources. Biomass is one such resource that Missouri has successfully tapped into, mainly through crops. Innovations within wood biomass are suited well for the resources available in the region. Missouri has 15 million wooded acres that provide an abundance of resources for biomass. This woody biomass consists of trees, limbs, needles, wastes, and other residues. Although this wood is being used to drive the economy through logging, milling, and building materials, it can also provide opportunities for energy.

In order to increase the energy production rate against the consumption rate, while maintaining a clean profile, Missouri can adapt and traverse into alternate methods and materials such as wood-to-energy biomass. It has the ability to support increasing energy production. It is a relatively new innovation, and materials are largely available in Missouri. Research and studies have been done at various levels, however, the system has not been brought to market. This technical analysis on the proposed introduction of wood-to-energy biomass system will challenge, and countermeasure some of the current issues in the process chain of biomass production as shown in Table 3, and challenges that Missouri as a state face, as shown in Table 4.

Table 3. Challenges for Missouri

Challenges for Missouri
1. Production ratio against consumption ratio is low.
2. Security at risk due to dependence on imported energy.
3. Alternative / renewable energy programs lacking.
4. Long-term plan not in place to promote clean energy production.

Table 4. Challenges for Biomass

Challenges for Biomass
1. Emission of pollutants, example: volatile organic compound (VOCs), CO_2
2. Deforestation potential
3. High costs
4. Supply constraints

Transitioning into a clean biomass process using the wood-to-energy process can benefit not only Missouri, but other states similar in geography. When utilizing the wood-to-energy technology, each state can contribute to the realization of the United States achieving net-zero emissions by 2050.

7. Case Studies

7.1. Case Study by U.S. Department of Energy

The U.S. Department of Energy's research center in Bioenergy is composed of 5 research areas. These areas focus on supply and sustainability, development, deconstruction and separation, conversion of biomass to biofuels, and enabling technologies.

The Great Lakes Bioenergy Research Center is focused on supply and sustainability. They reported that the development and breakdown of nitrogen and carbon cycling are essential for creating sustainable biofuel landscapes through research and testing. Using the latest tools in chemical engineering, the Joint Bioenergy Institute transformed biomass sugars into energy-rich fuels. These microbes can quickly ferment complex sugars, which can be used as biofuels. Farmland degradation, economic impacts, and variability into feedstock were all considered in each study.

In development, high-yield perennials were analyzed as domestic feedstock while advances were made in studies of populus and switch-grass. Genetic engineering was identified as an improvement to plant processing through augmentation. In deconstruction and separation, an innovative pretreatment method that reduces enzyme loadings and increases yields were developed.

Next-generation deconstruction was developed by avoiding chemicals and instead utilizing organic solvents from plants to break down biomass into cellulose and lignin.

Benefits discovered through the bioenergy research project had an impact on other sectors as well, including human health and sustainable agriculture. One example is higher value forage plants through lignin control, making them easier to break down and convert into biofuel [17].

7.2. Case Study by the University of Missouri Columbia

In 2008, the University of Missouri-Columbia decided to decommission a coal-fired boiler for a more carbon-friendly alternative. Through research and analysis, the University opted for a biomass-fed boiler. Researchers evaluated the available renewable resources in the region, ranging from debris from natural disasters and mill waste to logging residues and opportunity forest management to grow and harvest small trees. Careful analysis and consideration were taken to launch the project without harming future forest stabilization as well as protecting local landowner interests. The project was officially launched in 2012, and the 75-million-dollar plant came online [10].

Credited with being the biggest sustainable energy project on an American university campus at the time, the boiler accounted for 25 % of the total electrical and thermal energy used on campus [17]. The boiler consumes around 100,000 tons of biomass a year through semi-truck delivery with covered silo storage. The biomass consumed ranges from switch-grass, corn stover, and sustainably sourced wood. This project has been deemed a success, which has allowed for on-going project goals to be created to utilize biomass in adjacent boilers and further decrease greenhouse gas emissions, up to 50 %, while utilizing up to 100 % biomass. Other benefits are the reduction of coal usage by 25 % and the creation of similar projects that will create even more local jobs [18].

7.3. Case Study by Manomet

A study conducted by Manomet for the Massachusetts Department of Energy Resources aimed to study biomass and its complexities in sustainability and the effectiveness on carbon policy. Researchers in this study examined the wood biomass available from Massachusetts forests and potential ecological impacts, and greenhouse gas implications. Data and results showed feasibility, and greenhouse gas implications provided relevant information that ultimately reformed biomass policies. Recommendations include harvesting improvements and forest creations to encourage ecological value, retention of standing dead trees and developing guidelines to make them easy to follow and practice [19].

7.4. Significance / Scientific Merits

Wood biomass is a renewable resource that has played an important role in the environment, energy, and economy. World dependence on conventional non-finite resources, such as petroleum and oil, has caused constraints in our economy and national security. Military and farm vehicles run on diesel fuels, which support our food supply. As the United States moves towards net-zero carbon emissions, it is important to capitalize on three key areas shown in phases in Table 5.

Table 5. Key Areas and Phases for Clean Energy Transition

Key Area	Phase timing	Focus and Improvements
Enhancing the environment - Reducing current energy source emissions	Short-Term	1. Forest management, health, and habitat.
		2. CO_2 offset and greenhouse gas reductions
		3. Reduce forest fire risk by removing excess biomass [20].
Enhancing the economy - Utilize renewable resources to diversity or hybrid the energy system mix	Mid-Term	1. Jobs created by the state and for the state.
		2. Ability to set pricing internally.
		3. Landowner value through forest excess biomass reduction
Enhancing the economy - Transition out of conventional resources into carbon-free energy sources	Long-Term	1. Developing sustainable energy systems that can be benchmarked.
		2. Improved efficient processing.
		3. Forest management and wood utilization.

Each of these areas is important as to why we should study wood-to-energy biomass in-depth to move both the technology and policy forward to create a relevant energy system.

7.5. Wood-to-Energy Biomass Expansion in Missouri

Through prior research, case studies, and benchmarking Missouri's resource and energy portfolio, it is acceptable to analyze biomass facilities in order to increase the percentage of this renewable resource in the Missouri's renewable energy product mix. There are 15 million acres of forest in Missouri, covering 34 % of the state. The breakdown for forestland by ownership is shown in Figure 5.

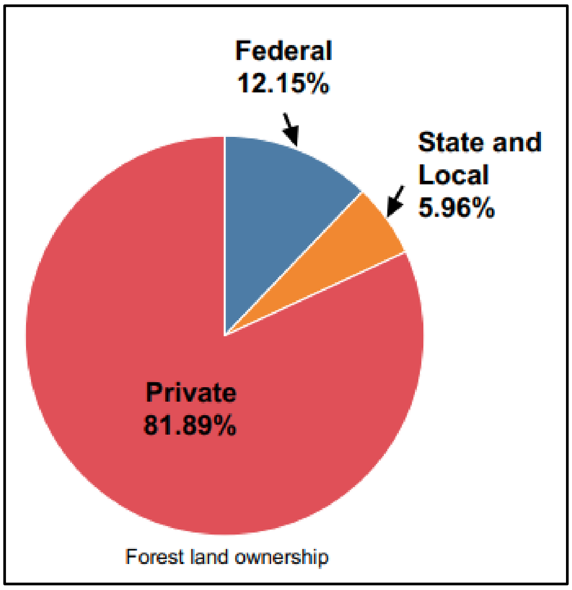

Figure 5. Forestland distribution in Missouri [21]

Figure 6 illustrates the number of live trees on forestland in Missouri as of 2019. As shown, live trees have decreased marginally between 2014 and 2019.

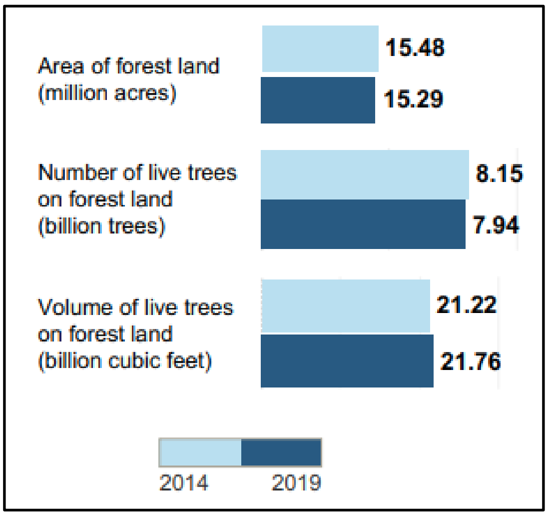

Figure 6. Number of live trees, 2014 - 2019 [21]

According to a similar study titled Biomass Potential [22], it is assumed that each acre of forestland can produce a cord of wood annually. Each cord weighs roughly 1.5 tons dry and 2.5 - 3 tons green. Heat values per pound of wood are at 6,429 BTU based on the heat density in dry wood. Through analysis and research, we must determine how much wood is available for harvesting in Missouri to support the state's energy demand.

7.6. Wood Type Availability

Missouri's 15 million acres of forest are concentrated heavily in the central and southeastern part of the state, as shown in Figure 7.

These forests are home to 89 species of trees. Most of these are hardwoods, primarily red oak, white oak, black walnut, and hickory. Each of these types of woods are processed through about 400 primary processors comprised of sawmills, cooperage mills, post mills, and charcoal plants. There are over 1000 secondary processing shops, such as furniture, cabinet, and flooring producers [23]. Table 6 shows examples of Missouri's top 10 wood export products by rank and dollar value.

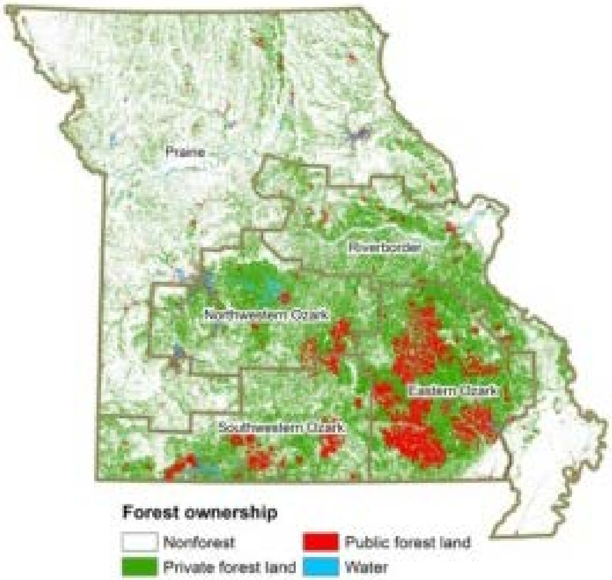

Figure 7. Missouri forests layout [23]

Table 6. Top 10 Missouri forest export products [23]

Renewable Energy Capacity	Forest Products	Year 2016
1	Hardwood Lumber	$61,819,000
2	Hardwood Logs	$31,800,000
3	Wooden Casks/Barrels	$29,779,000
4	Ties	$11,777,000
5	Wood Charcoal	$6,418,000
6	Softwood Logs	$5,432,000
7	Wood Chips	$3,678,000
8	Densified Wood	$2,657,000
9	Builders Joinery	$1,971,000
10	Wooden Cases	$1,665,000

From each of these processes, waste is generated, which can be turned into fuel to provide energy.

7.7. Energy Supply Validation

The residential, commercial, industrial, and transportation sectors consume nearly 1,804 trillion BTU of energy annually. The potential 15 million acres of forest converted to heat values is 289,305 trillion BTU.

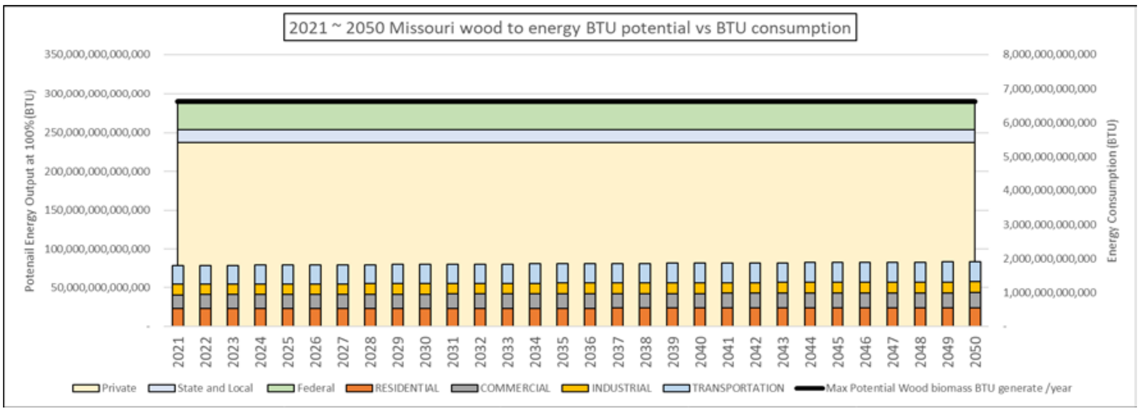

Figure 8. Missouri Consumption against forest potential heat value at 100 % efficiency

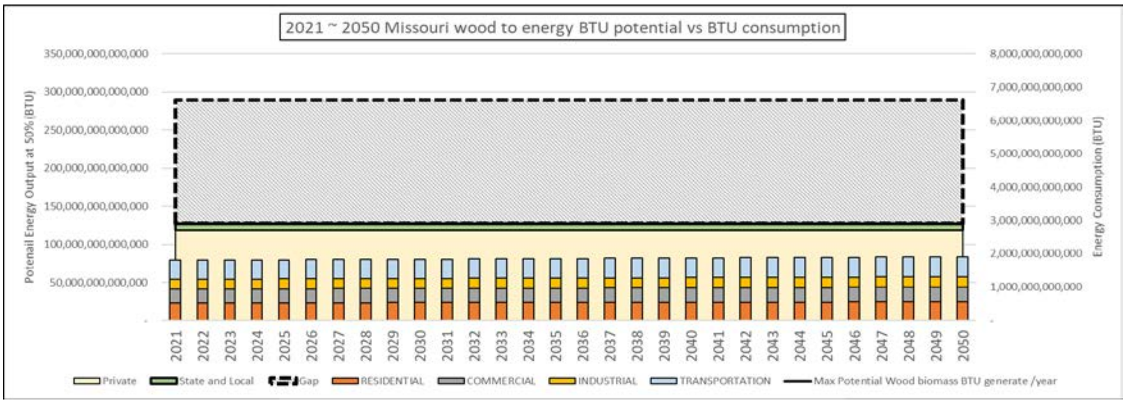

Figure 9. Missouri Consumption against forest potential heat value adjusted

7.8. Probable Land Availability

Figure 8 assumes that 100 % of all Missouri forest acreage can be harvested into energy. Assuming 100 % conversion of this available forest acreage to energy is not realistic though, as there are other end-uses to forest wood that are beneficial to Missouri. These include hardwood lumber for building both locally and exporting. We must start by utilizing what is within the state's control. This includes the 6 % state-owned forestlands. Gaining confidence in residential landowners to take part in the program is essential. It is assumed within this writing that 50 % of all residential landowners will participate in allowing their land to be harvested, as incentives to do so would outweigh any potential detriment to their property value or environment. It is also assumed that all state and local land would be 50 % utilized for the program, as other programs still utilize forest wood. Total BTU potential is at 127,077 trillion BTUs. This allows for less economic impact from current programs that contribute to around 9.7 billion in Missouri's economy. These programs include exports to China, Canada, France, and many other countries. End-uses range from flavoring wines to furniture and hardwood flooring worldwide [23].

Figure 9 shows conservative assumptions adjusted from the maximum available wood-to-energy conversion. These include a 50 % contribution of forest acreage in the private sector, 50 % in the state sector, and 0 % of acreage from the federal sector. This allows for minimizing risks during the program launch.

7.9. Wood-to-Biomass Methods Analysis

Based on the wood resources in Missouri,the energy needs of the state, and adjacent projects, wood-to-biomass has great potential. Consideration should be taken as to which conversion method is the most efficient for wood-to-biomass conversion, based on the application.

After compiling research and developing a matrix of the core processes of wood-to-energy conversion, it is reasonable to conclude that each process has both unique advantages and purpose as displayed in Table 7. For example, if gas prices continue to climb, pyrolysis can make economic sense as fuel alternatives become attractive.

Table 7. Conversion process decision matrix [24]

Type	Process	Life Cycle Efficiency	CO_2 Emissions	Market Options	Current Availability	Cost (LCOE $/kWh)	Applicable Rating
Thermochemical	Combustion Combined Heat and power (CHP)	High	Medium	Heat	Yes	0.23	1
	Gasification	Medium	Medium Low	Fuel gas	Yes	0.45	2
	Pyrolysis	High	Medium	Ethanol, aerosol	Yes	0.35	3
Biochemical	Biological	High	Medium	Biodiesel	Yes	0.3	4
	Physical	Medium	Low	Methane	Yes	0.25	5
Mechanical	Mechanical	Medium	Medium	Transport Fuel	Yes	0.42	6

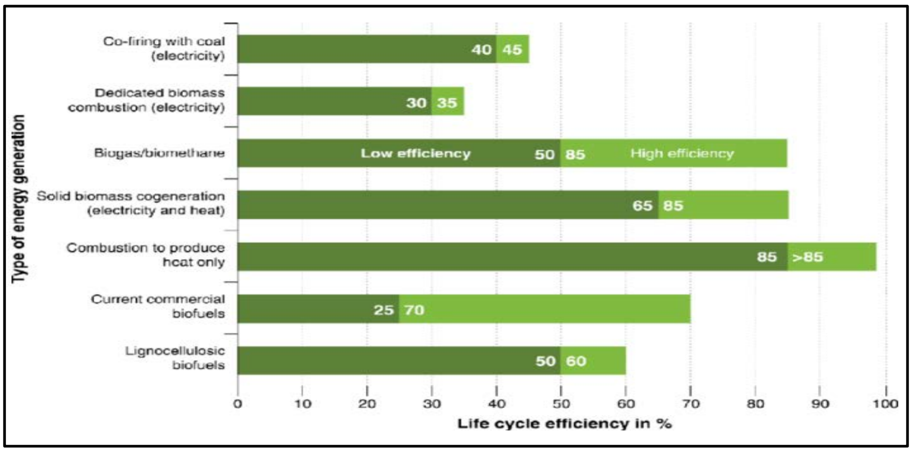

Figure 10. Net efficiency range biomass to energy pathways [15]

Currently, the most widely used system would be a combustion type system, which also has a high life cycle efficiency, as shown in Figure 10. Each technology is gaining traction, and expanding the process mix will be vital to remaining flexible and sustainable. Consideration of needs and wants is most important.

In order to yield the maximum efficiency in the shortest time, we must consider proposing the systems approach in phases.

Phase 1: (2021-2030)

The primary targeted system that needs to be considered is a combined heat and power system. This type of energy system allows for high-efficiency gains as the waste heat is converted into energy [25]. In order to yield success in this stage, confidence must be instilled by being thorough and responsible through the following steps.

1. Demonstrate and display positive impact and gain public buy-in.
2. Immediate reduction of emission potential.
3. Utilization of current space, no additional land consumed.
4. Improve efficiency gains of existing plants.
5. Utilize current waste, mill, debris, and logging.
6. New Plant analysis and design phase (determine how many plants are for capacity).
7. Benchmark best practices.
8. Continue to monitor water quality, wildlife, and economy.

Phase 2: (2030-2040)

Develop policy and programs with landowners, local businesses and develop new harvesting systems. Create new adaptable plants by utilizing the levelized cost of energy and life cycle efficiency. Flexibility, commissioning, and decommissioning are key. Action items applicable in phase 2 consist of the following.

1. Harvesting system for small tree quick turnaround.
2. Hybrid systems.
3. Landowner incentives (pricing per acre).
4. Forest management program.
5. Optimize capture and reduction strategies.
6. Installation of a new plant.
7. Continue to monitor water quality, wildlife, and economy.

Phase 3: (2040-2050)

The goal is to get to net-zero carbon emissions while being self-sufficient. Policy changes must take shape to support buy-in at all levels, from consumer to state officials. In order to achieve sustained success in the future, the following actions can be employed.

1. Benchmark best practices
2. Set sell prices to other states
3. Continue to monitor water quality, wildlife, and economy

7.10. Step Approach to Succeed

1. Research and development: Initial phase complete, proceed with tracking changes, availability, pricing.
2. Information: Continue to track data, develop a knowledge base, and target sectors.
3. Assessments: Further assess economics, resource availability, and technical requirements.
4. Strategic Analysis: Follow market, develop a sustainability plan, review and deploy portfolio, track costing.
5. Interface: Align policy, educate the population, and transfer technology to adjacent sectors.

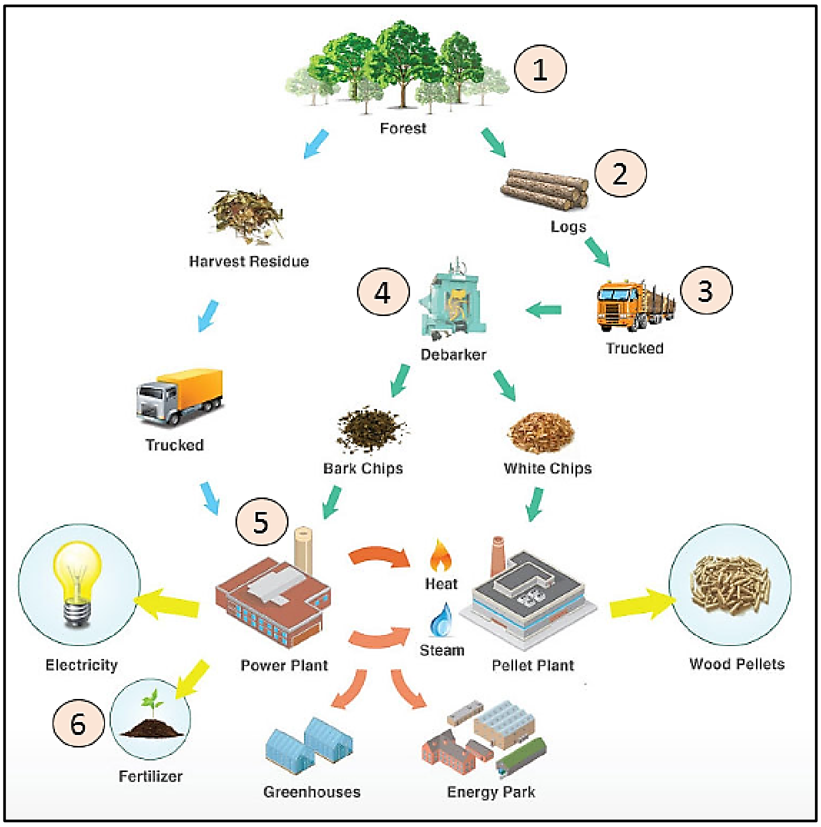

Figure 11. Biomass Process, Wood to energy [26]

Figure 11 represents a sample biomass-to-energy process Missouri could adopt to minimize carbon output from conventional energy processes while enhancing its renewable energy mix.

Table 8. Biomass wood-to-energy processing steps

Steps	Process	Pros	Risk
1. Forest harvesting management	Missouri has programs and policies in place to harvest, forests safely.	• Good forest management - Value added land - Less risk of forest fire	• Without proper forest management risk increases. - Wildlife - Drinking water - Land preservation
2. Harvest residue and logs	Wood residue and logs are collected	• Renewable resources can improve forest health	• Processing should be done with care to avoid damage and loss of restoration.
3. Transportation	Moving wood residue and logs to the processing site	• Seamless production • Easy to manage	• Some transportation methods are unsafe to handle and can harm the environment.
4. De-barker	Sizes the logs down to a management size	• Makes the processing simpler, can use smaller equipment as the logs are smaller.	• Adds a step to the process, utilizes more energy.
5. Power Plant	CHP plants allow for up to 80 % or greater efficiency.	• Existing coal-fired plants can be co-fired. - Reduce loss of efficiency and energy. - CHP technology is around 8.3 cents/kWh - Emissions can be reduced by up to 50 % [28].	• Capital intensive • Levelized Cost of Energy (LCOE) can be higher than running a coal-fired plant.
6. End-use energy	How the energy is consumed by the end customer.	• Provides energy to humans to support their daily lives. - Power - Fuels - Chemicals - Heating processes	• If not processed properly can cause risk to humans and wildlife.

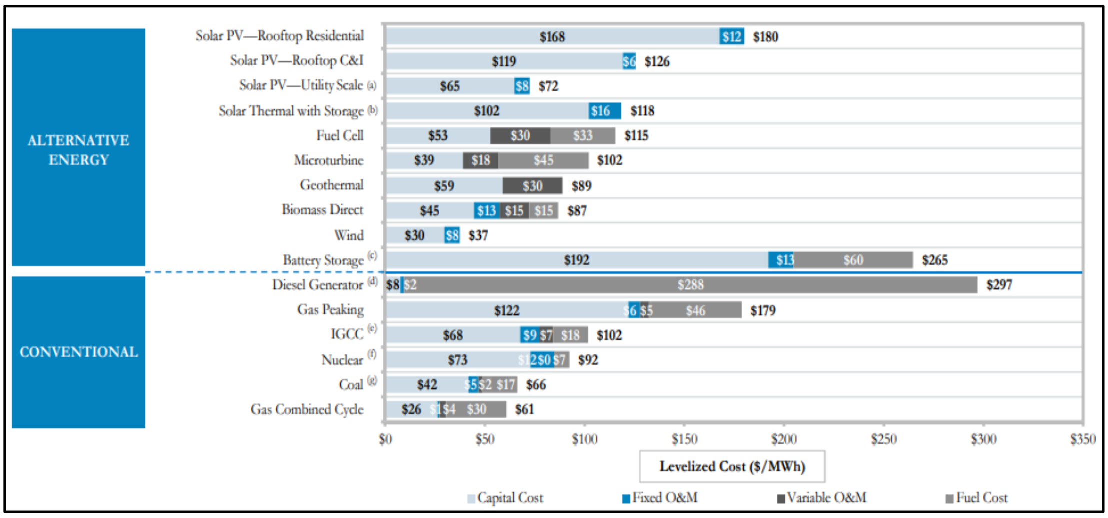

Figure 12. Levelized Cost of Energy comparison low-end [26]

Levelized cost of electricity (LCOE) is an important metric that measures the net present cost of electricity of a plant's lifetime. It is calculated by dividing the operating expenditures by the energy production and the result is then added to the capital expenditures. This metric allows comparison and investment analysis across various methods, as shown in Figure 12.

As shown in Figure 12, the levelized cost of energy of biomass, an alternative energy source, is comparable to that of nuclear, a conventional source.

7.11. Policy Reform

Short-term: Allow changes to occur at the local level, control and launch value added activities today to protect tomorrow. Develop phases of policy that align with phases of transition. Allow for credits to be increased to gain buy-in at the local level.

Long-term: Full transition into clean, renewable, safe energy practices, such as wood-to-energy at market scale. Continuous research and development will allow for technology to match policy and regulations in the future. Increased supply of biomass, through the utilization of all available resources, federal, private and state, will promote the development of more renewable energy opportunities. Funding and tax credit opportunities will increase as policy expands to allow all biomass feedstock to be included. Policies need to align with safe and healthy forest harvesting practices to reduce risk potential.

7.12. Risk Potential

Safety/Health/Environmental: There are always risks with any process. Wood-to-energy risks present just the same. Safety is the most important priority. Regulations must be in place to safely harvest wood from the tree state to the energy state. Other risks are de-valuing land, adverse environmental impacts, and higher costs than traditional energy. If process control is not in place, pollution will result in deforestation, causing wildlife and existing water resources to be jeopardized. Policy change will help to countermeasure these risks.

7.13. Long-term Outlook

Emission reduction: Biomass wood-to-energy can support emission reductions over time, the theory of one tree taken and one tree planted if at the same pace allows for a net-zero carbon impact. Theoretically, burning biomass will not have more carbon impact than processing crops. Proper planting programs will allow carbon dioxide to be captured by the trees.

Economy: Incentives to landowners, tax credits to companies and the creation of new jobs will allow the economy to thrive over time. Good policy initiatives will allow for expansion instead of harming the local economies.

8. Conclusion

Wood-to-energy biomass has the potential to be a significant renewable energy source for Missouri. With proper implementation, wood-to-energy biomass will support sustainable, efficient opportunities for the state to reduce the energy consumption to production ratio of 8 to 1 while supporting the 2050 directive of net-zero carbon emissions. Ultimately, this can leave Missouri in a position to become a benchmark for the sector with future options of selling to adjacent consumers.

Learning from concerns in previous studies, and harnessing the benefits, will allow for greater acceptance and yield in the sector. It is more important than ever to develop clean, efficient methods to power our future in today's high-paced, technologically advanced world. With 15 million acres of renewable forest, this project is ideal for the state. Sustainable forest management and policy will allow for mitigated risk. There are many processes to consider when processing wood biomass, and through research, development, and technological advancement, these processes will allow for reduced costs of processing the wood into energy. Ultimately, this will drive down the levelized cost of energy of biomass to energy, which is now very comparable to that of traditional energy sources, such as nuclear energy, as shown in Figure 12. Wood-to-biomass processing, however, may not be applicable in all areas based on transmission and transportation issues which add additional costs to the supply chain. These plants and initiatives must be strategically located and carried out in order to yield the highest efficiencies.

The takeaways of this analysis are that Missouri can further explore its resources. The developments from the Bioenergy research project are great examples of pilot programs under the government's control. By enlisting research centers to research and advance technology and capability, public and private companies will benefit from the findings. In combined heat and power plant conversions, carbon emission reductions can equal 50 % or greater over standard coal-fired plants. Missouri has the ability over time to become self-sufficient and non-reliant on energy imports. Other improvement steps include co-generation and a mix of renewables and traditional energy resources. One such method in emissions reductions is improved storage and dissipation of carbon through sequestration. Missouri can consider at all areas of improvement in both current emissions reductions, energy consumption, transportation, and processing. Reducing wasted steps, and streamlining the process, will allow for quicker efficiency gains. We will be able to over achieve the goal of reducing emissions at a local level while supporting national goals. The next step is to design the overall process, followed by a design review.

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Author Contributions

All authors contributed to the study conception and design. Alec Ernst performed material preparation, data collection and analysis. Alec Ernst wrote the first draft of the manuscript and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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