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THE ROLE OF BIOENERGY RESOURCES IN AMERICA'S CIRCULAR BIOECONOMY

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Abstract

This research aims to determine the extent of bioenergy resources' contribution to the circular bioeconomy in America. Focuses on specific studies in the Americas region to provide in-depth insight into the application of bioenergy in circular bioeconomy. America's outlook for circular bioeconomy was present here to learn about the barriers and challenges, drivers and opportunities also life cycle assessment issues to achieve a sustainable energy system. The overview of America's countries in the role of bioenergy for circular bioeconomy was found in this study.

Keywords: Circular bioeconomy, Bioenergy resources, America

Introduction

In the 21st century, one of humanity's greatest challenges is balancing sustainable economic growth and environmental preservation. In this context, bioenergy has emerged as a crucial solution to meet global energy needs while minimizing negative impacts on the natural environment. More than just a renewable energy source, bioenergy plays an integral role in steering America toward a circular economy which stands as one of the world's largest energy consumers, integrating bioenergy into the circular economy has the potential to transform how we meet our energy needs while mitigating negative environmental impacts.

Bioenergy is the most significant renewable energy source used in the world today. It accounts for approximately 10% of the world's energy supply and 70% of all renewables. All types of energy services can and are being provided using biomass, with the reliability, safety and efficiency required by the modern economy and society. Bioenergy options are at hand, satisfying technical, commercial, environmental and social requirements in many countries (Silveira, 2019).

The sustainable growth and continuous improvement of the already growing bioeconomy are generally regarded as stepping stones to achieving a long-term, biobased circular carbon economy, an economy that removes, efficiently uses, and sequesters more carbon than it emits. One of the main challenges in evaluating the effects of an expanding bioeconomy is that it spans economic sectors and industries (Lamers et al., 2021).

For an innovation to be considered in the context of strong sustainability, it must be holistically evaluated in terms of the environmental and social consequences for the system in which it will operate. The environmental and social limits will define the economic envelope in which the innovation can operate to contribute to a sustainable circular bioeconomy. Innovations aimed at bioeconomy must do little harm if bioeconomy is to facilitate a successful transition to a sustainable future (Holden, 2022).

To be effective in the bioeconomy it must mobilize large quantities of biomass from a range of resources, including materials that may currently be considered as wastes (e.g. agricultural and forestry residues, and the organic fraction of domestic waste). A major objective is the gradual replacement of fossil-based production with bio-based, and as such it is necessary to be sure that the economic, environmental and social benefits are real and guarantee a future based on sustainable production (Philp & Winickoff, 2018).

In the circular economy concept, the linear production model ("take, make and dispose") is replaced by a circular model in which the waste products that would be disposed of in the linear model are kept within the system - waste materials are drastically reduced, and wastes are recycled and remanufactured. While in the concept of a circular

bioeconomy uses bioresources to make high-value-added products more sustainably, cascading the use of materials, and minimizing the consumption and leakage of resources to the environment. It delivers both environmental and economic benefits, by preventing pollution; from the recovery of waste streams and promoting potential valorization; by making marketable products from waste (Grossa & Salvador, 2021).

After Europe's circular bioeconomy, the author tries to explore and investigate the pivotal role played by bioenergy resources in shaping and strengthening the foundation of America's circular bioeconomy because it has two major plans directly impacting the bioeconomy including (i) investing in biofuels R&D and (ii) developing an American biobased manufacturing system that unites research communities, manufacturing institutes and the government. Together, these plans have the potential to create a multitude of jobs and invigorate rural development (Pascoli et al., 2022).

Through a comprehensive analysis of the current status of bioenergy production and consumption, as well as its sustainability implications, we hope to provide valuable insights for stakeholders, including policymakers, academics and industry to guide forward-looking steps in advancing an inclusive and sustainable circular bioeconomy.

In the following sections of this paper, we will discuss key aspects of the role of bioenergy in America's circular bioeconomy. First, we will present a comprehensive overview of the current state of bioenergy production, distribution, and consumption in America. Furthermore, we will explore the positive impacts of bioenergy on reducing greenhouse gas emissions and its contribution to global climate change mitigation. We will also address challenges and barriers that may arise in implementing bioenergy in the circular bioeconomy and provide concrete recommendations to overcome these constraints.

By highlighting the role of bioenergy in the context of America's circular bioeconomy, we hope this research will make a significant contribution towards guiding strategic steps to realize a more sustainable and functional energy system in the future.

Literature Review

America's Bioenergy Resources

Bioenergy is an entry point in a pathway that can help develop a circular bioeconomy, promoting sustainable development and prosperity. The two main agricultural raw material groups are cereals, for example: wheat, maize or barley, making up around 28% of the biomass and plants harvested green, for example: green maize, temporary green grasses or Lucerne making up another 28%. Raw materials from forestry mainly consist of saw logs and wood pulp followed by other forestry extractions and forestry residues (World Business Council for Sustainable Development, 2020).

Hardy et al., see agriculture as the core of the bio-based economy, whereby not only food and basic materials, but also multiple value-added products are produced on a larger scale and improved quality (Hardy, 2002). Agriculture biomass can be utilized as an energy source in various forms, depending on its physical and chemical properties in addition to its availability, like combustible fuel, gaseous fuel, liquid fuel, fuel pellets and generating electric power (Saleem, 2022).

In addition, other sources of biomass also exist that can serve as the basis for bio-based models, such as forests (Sweden, 2012). Giuntoli et al. found that removal of logging residues has likely been driven by bioenergy demand at least in Canada and that conversion of semi-natural forests to plantation forests might have been partially driven by bioenergy demand in the US Southeast (Giuntoli et al., 2020). Description of pathways and relevant impact categories could include removal of logging residues, afforestation and conversion to plantation forests (Giuntoli et al., 2022).

Table 1. Biofuel Production and Consumption

Thousand barrels of oil equivalent per day	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Growth rate per annum		Share 2021
												2021	2011-2021	
Production														
Canada	18	17	18	22	21	22	22	24	22	22	22	-0.9%	2.0%	1.4%
US	556	531	555	588	605	642	664	684	665	602	653	7.1%	1.5%	40.7%
Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total North America	**574**	**548**	**573**	**610**	**626**	**664**	**686**	**708**	**687**	**624**	**665**	**6.8%**	**1.5%**	**42.1%**

Argentina	42	43	38	49	38	53	58	51	46	27	38	42.8%	-0.8%	2.2%
Brazil	251	257	299	315	338	317	320	384	411	394	376	-4.3%	4.1%	21.5%
Colombia	11	12	12	13	13	13	12	14	13	12	13	7.4%	1.9%	0.7%
Other South & Cent. America	5	5	7	7	8	10	10	11	12	12	12	2.5%	9.0%	0.7%
Total South & Central America	**309**	**316**	**356**	**384**	**396**	**392**	**399**	**460**	**482**	**445**	**439**	**-1.0%**	**3.6%**	**25.2%**
Consumption														
Canada	27	35	35	36	34	32	38	39	40	36	39	6.9%	3.7%	2.1%
US	518	518	573	581	608	658	661	652	670	608	664	9.5%	2.5%	36.1%
Mexico	2	2	2	3	3	3	4	4	4	4	4	-3.9%	9.5%	0.2%
Total North America	**547**	**555**	**609**	**620**	**645**	**693**	**703**	**695**	**715**	**649**	**707**	**9.2%**	**2.6%**	**38.5%**
Argentina	14	17	19	22	24	26	30	28	29	16	17	8.6%	1.8%	0.9%
Brazil	235	222	261	288	341	310	326	378	420	390	412	5.9%	5.8%	22.4%
Colombia	12	12	12	13	13	13	14	15	14	12	16	27.2%	3.2%	0.9%
Other South & Cent. America	12	14	15	15	16	17	18	18	18	16	17	10.8%	4.2%	1.0%
Total South & Central America	**272**	**265**	**307**	**338**	**395**	**365**	**387**	**440**	**480**	**434**	**462**	**6.8%**	**5.4%**	**25.1%**

Source: (BP, 2022)

To achieve a circular bioeconomy, the use of bioenergy resources as a feedstock for valuable chemicals and biofuels contributes to more efficient use of biomass. Biofuels as the role main bioenergy in America, as shown in Table 1 and Fig 1. An example of biofuels, the USA's supply of corn ethanol represents 10% of the volume of gasoline used in cars and in Brazil 1% of its land is planted with sugarcane providing 18% of the country's energy (Souza et al., 2017).

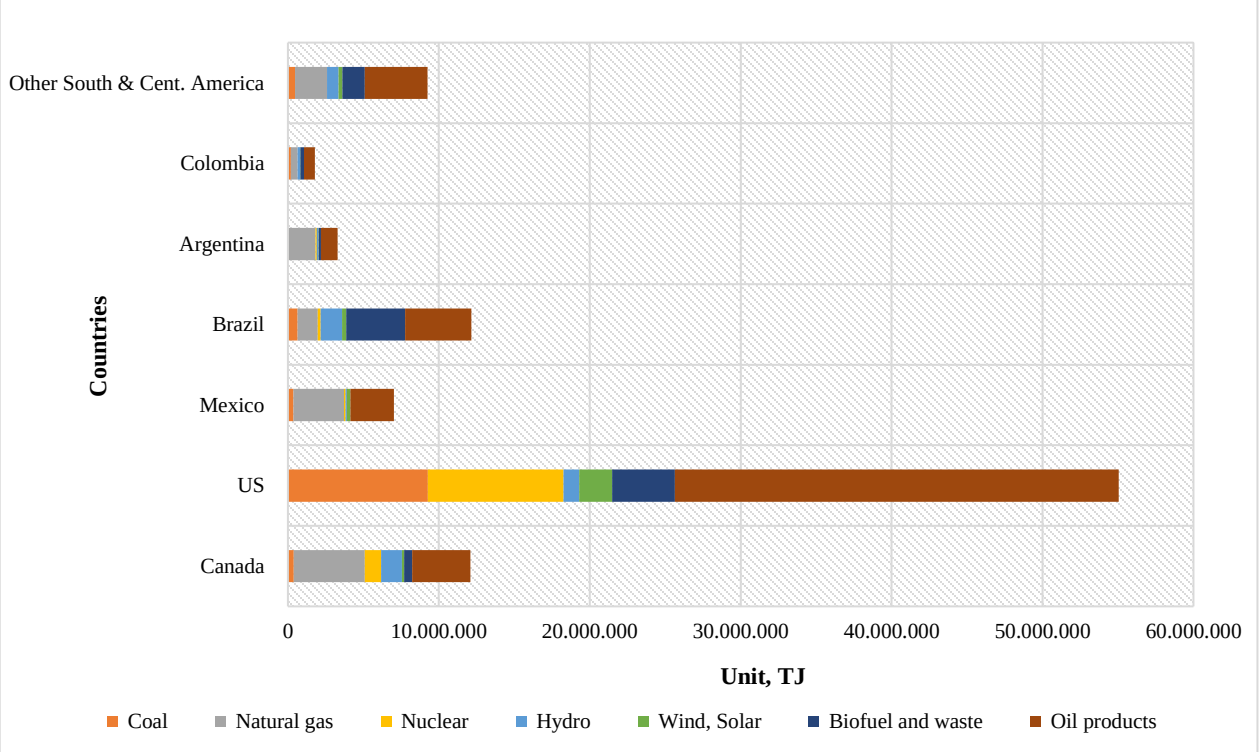

Fig 1. Energy Supply in America
Source: (Li, 2023)

Bioeconomy in America

The bioeconomy has become a popular focus of policy strategies for transformative change. It offers knowledge and technology-based opportunities to promote economic growth and social inclusion and holds the promise to help decouple economic development from increasing resource consumption and greenhouse gas emissions. Effective transformation governance is key for the bioeconomy to fulfill these goals (Dietz et al., 2023).

Indeed, the USA took the leading production position during the entire period. After 2006, it noticed a rapid growth of publications of articles by the US only. This publication rate was increased because of the Energy Policy Act that the government of their country executed in 2005. However, switching from non-renewable energy sources (fossil fuels) without introducing any economic burden is a challenging long-term issue for the US. Even though policymakers and experts usually recognize the significance of energy security, how to reach this goal and at what cost is still a contentious issue in the US (Hasan et al., 2023).

Table 2. The Policies Promoting Circular Bioeconomy in America

Country	Year	Key Policy	Target Policy
United States	2012	Bioeconomy Blue Print	Agriculture, bioenergy, national security and environmental protection
	2014	2014 Farm Bill	Biomass research and development initiative
Canada	2013 - 2018	Growing Forward	R&D in the agricultural sector, bioenergy, bio-based material and renewable resources
	2007 - 2017	Sustainable Development Technology Canada	Second generation biofuels
	2013 - 2016	Natural Resources Canada	Forest and biobased material innovation
Argentina	2012	Argentina Innovation 2020	Research and Innovation
	2005	Innovation Law	Looking at resource optimization and reverse logistics
	2010	Solid Waste National Policy	
Brazil	2014	The 2023 Decennial Energy Expansion Plan	Bioenergy
Colombia	2011	Policy for Commercial Development of Biotechnology based on the Sustainable Use of Biodiversity	Technology Advancement
Mexico	2009	Undersecretary strategy of bioenergetics	Bioenergy
Paraguay	2011	National Policy and Program for Agricultural and Forestry Biotechnology of Paraguay	Technology Advancement
Uruguay	2012	Biotechnology Sector Plan 2011 - 2020	Technology Advancement

Source: (Negi et al., 2021)

Research Method

This paper focuses on specific studies in the Americas region to provide in-depth insight into the application of bioenergy in circular bioeconomy practices using secondary data from reliable sources such as government agencies, non-governmental organizations or research institutions to analyze trends and statistics regarding production, distribution and consumption bioenergy in America.

The literature research was conducted from using Scopus, Google Scholar and Dimensions database, with keywords about bioenergy resources and circular bioeconomy in America. There is no year limitation of search engine and conduct a literature review to understand the latest developments in bioenergy and carry out a full life cycle assessment to evaluate the environmental impact of bioenergy production and use within the context of a circular bioeconomy.

Results and Discussions

Implementing Circular Bioeconomy

North America has historically been known as a resource-rich economy. Canada is estimated to have the 3rd highest total value of natural resources in the world at USD 33 trillion, while the U.S. comes in at 7th highest. This reality means that scarcity of resources is less likely to be the primary driver of the circular economy. Instead, innovation and growth opportunities in areas such as the circular bioeconomy (i.e., enhanced use of forestry and agricultural feedstock, both domestically and for export) and mineral and metal recycling and secondary manufacturing should be explored (Environment and Climate Change Canada, 2021).

Table 3. America's Outlook for Circular Bioeconomy

Country	Climate Goals	Circular Economy	Sustainability	Bioeconomy	Economic Recovery
CANADA (Baldwin, 2020)Salvador et al., 2022a)	* Exceedings 30% emissions reductions by 2030 * Achieving net-zero carbon by 2050 * Transition to Low Carbon economy	* Zero plastic waste strategy * Developing a circular economy goal	* Protect and enhance * Biodiversity * Increase Canada's protected areas * Federal Sustainable * Development Strategy	* Forest bioeconomy framework * Nature-bases solutions	* Implementing a green economic recovery policy * Inclusive growth * Green infrastructure investments * Industry transformation
USA (Frisvold et al., 2021; U.S. Department of Energy, 2023),	* A total of 62% of global greenhouse gas emissions are emitted during material extraction and processing, and the trend is increasing. * To reach the 1.5°C target of the Paris Agreement, need to ensure net zero emissions by 2050	* Bioecologi vision * Secondary biomass usage will be maximized and new raw materials can be regenerated by nature without depleting existing stocks.	* Maintaining the richness of biodiversity is essential for sustaining life on earth * Enetic resources have long been a source of technological advance and product development in agriculture and medicine	* Four Drivers of the U.S. Bioeconomy from the National Academies of Science, Engineering, and Medicine	* Turned toward technology policy, which examined critical intersections of biotechnology and other scientific disciplines, including computer science and engineering and discussed the role of biotechnology in addressing a variety of human health, food and nutrition, energy, and environmental needs * Directed federal agencies to place priority on efforts to promote job creation and sustainable economic growth
MEXICO (Ministry of Foreign Affairs, 2019; Global Green Growth Institute, 2021)	* Confirmed its unconditional target of 22% GHG emissions and 51% of black carbon emissions by 2030 * Increased its attention to the reduction of vulnerabilities through a more comprehensive adaptation plan.	* Urban Solid Waste * Food Waste * Plastic Waste * Hazardous Waste	* Ensure a sustainable circular bioeconomy that secures healthy natural systems, well-being creation practices using a sustainable land use approach, replacing deforestation with regeneration * Support relevant stakeholders to accelerate the transition to a more inclusive and less-carbon-intensive mobility	* Focused on bioenergy development * Promote the sustainable production of biofuel	* Reducing taxes on repair services increases the profitability of repair services for both customers and repair service providers * Providing financial support for repairs, profitability and competitiveness are increased in comparison to the mere replacement of a defective product
GUATEMALA (Philippidis et al., 2020; European Commission, 2021)	* Signing the Paris Agreement and adopting a National Strategy for the reduction of CO2 emissions.	* Green waste generated by this diverting it from disposal in the landfill	* Initiating a startup business, balancing what appeared to be a mix of complex economic, environmental, and social priorities	* Production and export of biofuels, biotechnological applications in agriculture, carbon neutrality in agricultural chains, and the sustainable use of biodiversity	* Plans to partially recur to external loans and public-private partnerships
NICARAGUA (Schröder et al., 2020), (Bottausci et al., 2022)	* Reduce global emissions from the production of key materials by 40 percent, or 3.7 billion tonnes, in 2050	* Implementing strategies in five major sectors – steel, cement, plastic, food and aluminium	* Organic waste to energy * Significantly supply the regional energy demand	* Increased competition for land between food crops and fuel crops	* Funds to support businesses and the unemployed, including informal sector workers.
CUBA (UNFCCC, 2022)	* Avoid the emission of an estimated 30.6 million kilotons of carbon dioxide equivalent ($ktCO_2eq$)	* Generate 24% of electricity from renewable sources by 2030	* Seeks to promote resilient development and decouple economic growth from greenhouse gas emissions	* Opportunities for local agriculture	* Strengthen the enabling framework to move towards a resilient and low-carbon economy and promote conditions conducive to mobilizing and diversifying climate finance
PUERTO RICO (Chertow et al., 2008; Brinton et al., 2023)	* Reductions in carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrous oxide (NO_x) and particulate matter smaller than 10 mm (PM_{10})	* Solid waste management	* Central government capable of enforcing regulations * Providing better support to existing employees and enforcement capabilities.	* Construct a $12.5 million Biotechnology Center for Research and Training Bioprocesses	* Federal government stakeholders' interventions and challenges * Feedback loops relating to stakeholders and financing

VENEZUELA (De la Vega et al., 2019; Transform & Systems, 2022)	* Reduce CO_2 and methane emission	* Renewable energy consumption * Electric power transmission and distribution losses	* Design and apply innovative initiatives that seek more flexible legal frameworks, the knowledge that solves problems * Green technologies and a new balance with nature * Reducing levels of corruption,	* Sustainable food and agriculture	* Development of an operational directory on green jobs and occupations * Focused on boosting the circular economy and promoting green consumption and production practices to
COLUMBIA (Alviar et al., 2021; Huddart et al., 2022)	* Reduce six main of GHGs: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFC_s), Perfluorocarbons (PFC_s) and Sulfur hexafluoride (SF_6)	* Producing goods and services recycling * Reducing original raw materials including biological resources	* increase productivity of agriculture and the absence of public goods * Build infrastructure that facilitates the access to the markets.	* Bioenergy * Agriculture * Agroindustrial * Ecology * Microorganism plant	* Transformation of the industry * Increasing human capital
SURINAME (Cabinet of the President of the Republic of Suriname, 2020) (Transform & Systems, 2022)	* Reduction in CO2 emissions and negative impacts on watercourses and soil.	* Promoting the recycling of plastic waste and addressing the disposal of PET plastics	* Implementation of circular economy solutions * Progress on other environmental, social and economic	* Region's broad biodiversity * Genetic resources, diverse productive landscapes * Capacity to produce food and biomass	* Provides financial support (co-financing of up to 60 million pesos being made available for eligible projects)
GUYANA (Byone, 2012; Government of Guyana, 2013)	* Low Carbon Development	* Waste management	* Achieving a green economy	* Protect coastal and marine resources	* Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services
ECUADOR (Carrión-Mero et al., 2020; Nations, 2020)	* Zero Carbon Programme	* Plastic manufacture	* Increase the awareness of geodiversity	* Ecological transition * Promoting sustainable and deforestation-free production	* A rise in oil prices represents an opportunity for the country to invest in socio-economic development and a more diversified, less fuel-dependent economy.
PERU (Solleiro, 2021; Villarroel Diaz et al., 2021)	* Generating 70% of greenhouse gas emissions	* Intentionally 'design out' waste and pollution	* Setting and implementing policy frameworks and standards at the national level.	* Made up of naturally regenerating forests and plantations	* Establishes eight main lines of action expected to produce important structural changes in the cultural ecosystem
BRAZIL (Cruz et al., 2021; Econ-, 2020; IEA Bioenergy, 2021)	* Committed to reducing greenhouse gas emissions by 37% below 2005 levels in 2025 * Reduce greenhouse gas emissions by 43% below 2005 levels in 2030	* Design out of waste and pollution * Keep products and materials in use * Regenerate natural systems	* Implementation of the circular economy shows potential to contribute to reaching the Paris Agreement	* Biofuel and biogas production	* Industrial waste management * Regulatory framework for the management of waste products, goods or material streams
BOLIVIA (Ferronato et al., 2019, 2022)	* Lowering air emission * Reduction of GHG emission	* Decreasing deforestation * Mitigating water contamination from livestock sector	* Focuses on smart agroforestry systems	* Biofuels and bioproducts sectors	* Turning bio waste into bioresources * Bio-technologies recovery solutions
PARAGUAY (European Union, 2020; Jager, 2020; Melgarejo, 2019)	* Reducing all greenhouse gases (All GHG), methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O)	* Textile industry and its waste	* Green and resilient economy * Fight against inequalities	* Develop a plantation of Acrocomia (palm tree)	* Sustainable growth and decent jobs * Fighting inequalities by building a more inclusive economy and society
CHILE (Ellen MacArthur Foundation, 2021; Scapini	* Tackle up to 45% of global greenhouse gas emissions	* Develop a roadmap to 2040	* Focused on the efficient use of resources and energy	* Decentralized forest land	* Establishes the framework for waste management, extended producer responsibility and promotion of recycling

& Berrios, 2021; Véliz et al., 2023)		* Develop a strategy for organic waste * Establish and implement indicators and metrics on circularity to monitor progress.	* Looking at the productive process more than at their final result.		* Advancing in a regulatory framework and other instruments
URUGUAY (Brief, 2020; Mendoza, 2023) (Freeman et al., 2022; Mendoza, 2023)	* Avoid 86,000 ton(s) of CO_2 equivalent GHG emission	* Farm technologies * Waste water recycling	* Investments in circularity	* Biomass to energy * Biomass to food	* Investments in manure management technologies * Investments related to water capture and distribution (use of water on agricultural land) and wastewater cycle (use of biomass for energy, use of biomass for nutrition)
ARGENTINA (Cohen et al., 2022), (Raheem et al., 2022), (Rótolo et al., 2022)	* Reduction of emissions and environmental impacts	* Waste reduction * On recycling and reuse of goods/products	* Generate sustainable products/processes from its design * Promotes a more sustainable supply chain and logistics developments	* Agro-industrial system * Biofuel	* Education * Research and innovation in processes citizens-consumers * Incentive system and financial support

The bioeconomy represents a new and powerful opportunity for countries in Latin America and the Caribbean (LAC), where 8 of the 17 most megadiverse countries on the planet are located. In addition to being one of the primary producers of sustainable biomass, LAC possesses the necessary scientific-technological expertise, industrial infrastructure and entrepreneurial base to mobilize that potential. Regardless of the direction taken concerning any of the projected future scenarios, the region will play a strategic role in striking a global balance between food, fibers and energy, as well as in improving environmental sustainability. The bioeconomy provides new opportunities to achieve equitable growth across the region through improved agricultural, forestry and biomass production and to increase job opportunities (Chavarría et al., 2020).

There is a strong focus on developing a circular bioeconomy in America. Table 3, shows how America's country provides their effort to provide opportunities for job creation, economic growth and the substitution or replacement of products that currently come from fossil-based resources such as gas and oil. It is important to note that bioeconomy strategies are evolving with greater emphasis on innovation opportunities within the farm, forest and marine systems, as they can support, for example, carbon sequestration and greenhouse gas (GHG) emissions abatement, increasing biodiversity and with it the resilience of production systems. The provision of ecosystem services by natural capital is now seen as an economic and environmental opportunity (O'Connor et al., 2023).

Barriers and Challenges for America's Circular Bioeconomy

From the summary in Table 3, we can see that the development and implementation of regional circular bioeconomy in America, with a focus on bioenergy, face several significant barriers and challenges. These include:

Technological Innovation and Infrastructure Development: Advancing technologies for bioenergy production and distribution, as well as establishing a robust infrastructure, are essential. This includes developing efficient and sustainable biomass conversion technologies, biorefineries and bioenergy storage and distribution systems.

Economic Viability and Funding: Ensuring the economic viability of circular bioeconomy systems is critical. Securing funding for research, development and implementation of bioenergy projects can be challenging, particularly for smaller regional initiatives.

Policy and Regulatory Frameworks: The complex regulatory landscape surrounding bioenergy and circular bioeconomy systems can be a significant barrier. Clear and supportive policies are needed to incentivize and facilitate the integration of bioenergy into circular systems.

Resource Availability and Management: Securing a consistent and sustainable supply of biomass feedstock is crucial for bioenergy production. Competition for biomass resources from other industries, such as agriculture or forestry can pose challenges.

Socioeconomic and Community Considerations: Engaging and gaining support from local communities and stakeholders is essential. Addressing potential social impacts, ensuring equitable distribution of benefits and minimizing any negative effects on local economies are critical factors.

Technological Scale-Up and Efficiency: Scaling up bioenergy technologies to meet regional demands while maintaining high levels of efficiency is a significant challenge. Research and development efforts must focus on optimizing processes and technologies for larger-scale operations.

Environmental Sustainability and Land Use: Balancing bioenergy production with environmental sustainability is crucial. Avoiding land-use conflicts, preserving biodiversity and minimizing environmental impacts, such as deforestation or habitat destruction, are important considerations.

Waste Management and Resource Recovery: Efficiently managing waste streams and recovering valuable resources from bioenergy production processes is essential for achieving circularity. This includes addressing challenges related to waste treatment, recycling, and reuse.

Market Development and Integration: Creating and expanding markets for bioenergy products and by-products is vital for the economic viability of circular bioeconomy systems. This may involve establishing partnerships with industries and sectors that can utilize bioenergy outputs.

Education and Public Awareness: Raising awareness and educating the public about the benefits and potential of circular bioeconomy systems, particularly about bioenergy is crucial for garnering support and overcoming resistance.

Addressing these barriers and challenges requires a multi-faceted approach involving collaboration between government, industry, academia and local communities. Additionally, ongoing research, innovation and policy support are essential for the successful development and implementation of regional circular bioeconomy systems in America's bioenergy role.

Drivers and Opportunities for America's Circular Bioeconomy

The development of a regional circular bioeconomy in America, with a focus on bioenergy, is driven by several key factors and offers numerous opportunities. These include:

<u>Drivers:</u>

Climate Change Mitigation: The urgent need to reduce greenhouse gas emissions and combat climate change is a major driver. Bioenergy derived from renewable sources, can play a significant role in transitioning away from fossil fuels.
Energy Security: Bioenergy contributes to energy security by diversifying the energy mix and reducing reliance on imported fossil fuels. This enhances the resilience of regional energy systems.
Economic Growth and Job Creation: The bioenergy sector offers opportunities for economic growth and job creation, particularly in rural areas where biomass resources are abundant. This supports local economies and communities.
Waste Reduction and Resource Efficiency: The circular bioeconomy model promotes efficient resource use and waste reduction. By utilizing organic waste and by-products for bioenergy production, it helps minimize landfill waste.
Technological Innovation: Advances in bioenergy technologies and processes drive innovation and create opportunities for the development of new and improved bioenergy production methods.
Policy Support and Incentives: Supportive government policies, such as renewable energy targets and incentives, play a crucial role in driving the adoption of bioenergy in regional circular systems.
Sustainable Agriculture and Forestry Practices: Sustainable biomass production practices in agriculture and forestry contribute to the availability of biomass feedstock for bioenergy production.
Opportunities:
Diversification of Energy Sources: Implementing bioenergy in circular systems diversifies energy sources, reducing dependence on fossil fuels and enhancing energy security.
Rural Economic Development: Bioenergy projects can stimulate economic activity in rural areas by creating jobs, supporting local industries, and generating income for farmers and landowners.
Innovation and Research Opportunities: The development of bioenergy technologies and processes presents opportunities for research, development and innovation in the renewable energy sector.
Environmental Benefits: Circular bioeconomy systems reduce environmental impact by minimizing waste and emissions, promoting sustainable resource management and mitigating climate change.
Market Expansion: Bioenergy products and by-products can be integrated into existing markets, creating new revenue streams and business opportunities for industries across various sectors.
Community Engagement and Empowerment: Engaging local communities in bioenergy projects fosters a sense of ownership and empowerment, leading to increased support and successful project outcomes.
Collaborative Partnerships: Regional circular bioeconomy systems provide opportunities for collaboration between government agencies, private sector entities, research institutions and communities, fostering innovation and knowledge sharing.
Environmental and Social Co-Benefits: Beyond energy production, bioenergy projects can yield additional environmental and social benefits, including improved air and water quality, habitat restoration and enhanced community resilience.

By capitalizing on these drivers and opportunities, regional circular bioeconomy systems in America can play a pivotal role in advancing sustainable and resilient energy systems, while fostering economic growth and environmental stewardship.

Life Cycle Assessment (LCA)

LCA can be used in multiple roles to inform the transition to a sustainable and circular bioeconomy like land use, biomass production and logistics, conversion and end user.
Environmental LCA has some inherent limitations related to complex modeling, unclear or inconsistent boundary setting, the short timeframe over which outputs are considered valid, budget, availability of data, trends in politics, research, lack of an established impact model and applicability selective or partial LCA methodology.

This is especially important for the assessment of bio-based systems which are often complex combinations of technologies and practices dispersed geographically and over great distances and with broad and uncertain sets of indicators. The indicators may also be sensitive to land use patterns and their changes over time, to the logistics of biomass supply, to the combination of innovative and conventional technologies applied in the value chain, to the production and use of by-products and by-products and cultural preferences.

In a bio-based value chain, this facilitates the breakdown of budgeted costs, transfers and externalities, at each stage of the biomass supply and value chain and the identification of their respective physical and economic parameters. LCA can be used in a variety of roles to inform the transition toward a sustainable and circular bioeconomy (Sevigné-Itoiz et al., 2021).

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Conclusions

This study explores how bioenergy resources are crucial to strengthening the circular bioeconomy foundation in America. Bioenergy not only stands as a renewable energy source but also serves as a key element in directing America toward an economy that maximizes the reuse and recycling of natural resources.

A thorough analysis of bioenergy production, distribution, and consumption reveals that America has made significant strides in integrating bioenergy into the national energy system. The utilization of bioenergy has made a substantial contribution to greenhouse gas emissions reduction, providing a robust foundation for global climate change mitigation efforts.

However, challenges persist, including the need for continued technological development and innovation in bioenergy production, as well as ensuring the social and environmental sustainability of circular bioeconomy practices. The development of progressive and targeted policies will also be key in ensuring that America can fully harness the potential of bioenergy in driving sustainable economic growth.

Concrete recommendations have been identified to address existing barriers and maximize the benefits of implementing bioenergy in America's circular bioeconomy. These measures include investments in research and technology development, enhancements in regulatory policies and economic incentives to drive bioenergy adoption.

Considering all these facets, there is tremendous potential to accelerate the transition toward a more sustainable and functional economy in America. With the right commitment, bioenergy can emerge as a primary driver in realizing the vision of an inclusive and environmentally friendly circular bioeconomy.

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