The Bioeconomy to the Rescue

Gordon Rausser and David Zilberman

The bioeconomy, encompassing sectors such as agriculture and forestry, presents an arena where natural resources can wield a crucial influence on climate crises management. This article unveils various burgeoning biotechnological strategies geared towards mitigating and adapting to climate change, with a view to enhancing environmental quality and human welfare.

The urgency to address the climate crisis has become a global policy priority. Despite international endeavors such as the Kyoto Protocol and the Paris Agreement, current greenhouse gas emission control measures have shown minimal success. Although these policy efforts have stimulated growth in solar and wind power sectors, as well as the electric vehicles industry, the chances of maintaining average global temperature rise below pre-industrial levels appear slim. Traditional decarbonization mechanisms primarily utilize principles of chemistry and physics within industrial contexts. However, the world has become increasingly aware of the bioeconomy's potential to significantly contribute to decarbonization, climate change mitigation, and adaptation. The bioeconomy encompasses sectors of the economy that employ renewable natural resources and living organisms to generate goods and services. Beyond climate change solutions, the bioeconomy has the potential to address other societal needs such as enhanced food security, increased biodiversity preservation, and reduced pollution.

The Bioeconomy

The bioeconomy combines technology and natural resources to produce a wide range of goods and services. The role of the traditional bioeconomy, reliant on animal power and fermentation for food preservation and production, is deeply woven into human history. With advancements in life sciences, starting with the discovery of DNA structure and the ensuing modern biotechnologies, a broad spectrum of opportunities has emerged. Modern medicine utilizes these biotechnologies to develop new drugs, and genetic engineering formed the basis for developing the vaccine for the COVID-19 pandemic. The agricultural biotechnology sector has significantly increased supplies of corn, soybean, and cotton.

Yet, the use of biotechnology remains curtailed by regulatory constraints, resulting in different governing bodies having different definitions and policies surrounding the bioeconomy. For example, the European Union has imposed stringent restrictions on the use of biotechnology—including genetically modified organisms (GMO) and clustered regularly interspaced short palindromic repeats (CRISPR)— and subscribes to a minimalistic definition of the bioeconomy. In contrast, countries such as Argentina, Brazil, the United States, and Canada perceive modern biotechnology as an essential element of their bioeconomy.

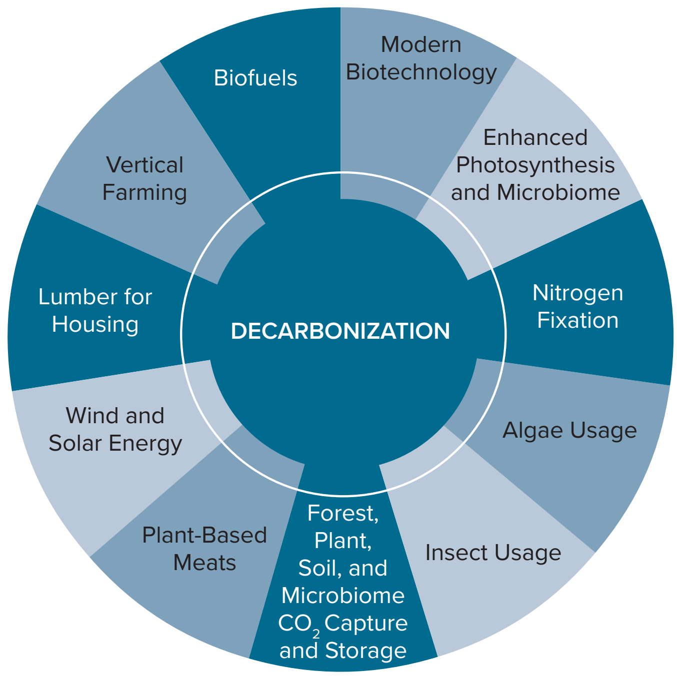
We define the bioeconomy as a sector leveraging contemporary life science knowledge and technology to use renewable natural resources for food, fuel, chemicals, pharmaceuticals, and other product manufacturing. Within this framework, agriculture provides much more than food production, and the bioeconomy is critical to transitioning from a non-renewable to a predominantly renewable resources-based economy. We emphasize the bioeconomy's circularity, highlighting the development of technologies where waste products serve as inputs for other processes—for example, technologies that convert animal wastes into food or energy products.

Bioeconomy Strategies for Decarbonization and Adaptation to Climate Change

The bioeconomy possesses the potential to catalyze decarbonization by promoting renewable, greener fuel resources, mitigating greenhouse gas (GHG) emissions from agriculture, and providing pathways for carbon sequestration. The bioeconomy's capacities can be harnessed to adapt to shifting climatic conditions, including rising sea levels, fertile land degradation, and increased susceptibility to extreme weather conditions. Several strategies can be employed to meet these challenges within the lens of the bioeconomy. The opportunities for such strategies are represented in Figure 1 (on page 6).

First, the introduction and assimilation of modern biotechnologies are essential, notwithstanding regulatory constraints. Empirical evidence supporting the benefits of GMOs is abundant and documents their potential to boost yields, minimize pesticide use, augment farmer profitability, reduce GHG emissions, and conserve land. Many developing countries have limited technology and infrastructure, and transgenic crops (plants that contain a gene or genes that have been artificially inserted) offer increased yields in the face of climate variations and pests. Preliminary research indicates that gene editing technologies could bring about more precision and supplementary agricultural management options, possibly expediting the development and introduction of new varieties.

Figure 1. The 11 Bioeconomy Strategies for Decarbonization



Source: Rausser and Zilberman. 2022. "Resource Economics and Modern Science to the Rescue." Available at: https://bit.ly/3QlKnUy.

However, stringent restrictions and costly, time-consuming regulations have confined the use of these biotechnologies primarily to major field crops, where large corporations dominate. Consequently, fruits, vegetables, and agricultural livestock have been subject to limited application of modern biotechnologies. The financial losses from current biotechnology regulations are estimated to be in the tens of billions of dollars, as numerous transgenic and CRISPR innovations went (or have gone) undeveloped or uncommercialized due to prohibitive regulatory costs.

The introduction of science-based technologies that balance benefits with risks, while reducing regulatory uncertainty, is likely to unlock these potent tools' full potential. Prior research suggests that the broad-scale adoption of existing transgenic crops like corn and rice could significantly reduce land use, lower food prices, mitigate food-security issues, and allocate more land for chemical and biofuel production within the bioeconomy. Coupling modern biotechnology tools with traditional agricultural practices could broaden the scope of solutions and expedite climate change adaptation. As climatic changes will require ongoing modifications to crop varieties and agricultural practices, developing the bioeconomy to leverage modern biotechnology tools will be crucial.

Second, photosynthesis productivity enhancement is a key strategy. Photosynthesis, the process that combines sunlight, carbon dioxide, water, and nutrients to generate plant material, can be optimized through biotechnology innovations. Studies show that through deeper roots and enhancing the soil microbiome, yield may be increased up to 20% or more, while also enhancing soil carbon storage.

Third, nitrogen fixation has significant potential. New research has found microbes that have the capacity to transform cereal crops like rice and corn into nitrogen-fixing crops. Nitrogen fixation could account for up to 80% of plant nitrogen uptake. Some market products propose using bacteria to replace 20% to 25% of required nitrogen, which could enhance agricultural productivity and reduce GHG emissions significantly, given nitrogen production's role as a major GHG emitter.

Fourth, algae can be harnessed as a source of food, fine chemicals, and energy. Macro- and microalgae have long been used for food and fine chemicals, like agar and beta carotene. However, new biological tools and research capabilities suggest numerous additional algae applications, such as protein, complex sugar, lubricant, plant biostimulant, and medicine sources. Algae offers considerable carbon sequestration potential, yet further research is required to understand the management of algae varieties for carbon storage, as well as the storage's magnitude and quality.

Fifth, insects represent a significant potential food source, particularly for protein. As protein prices rise with income growth, finding alternative protein sources has become a priority. Innovative methods are being developed to utilize insects, such as the black soldier fly whose larvae contain high protein levels. Notably, black soldier flies can feed on waste products, including food, plant, and animal waste, yet their larvae remain safe and edible following appropriate treatment.

Sixth, carbon sequestration can be accomplished via trees, soil, and plants. Trees and other vegetation sequester carbon through photosynthesis, store it within their roots, and transfer it into the soil. The potential exists to augment the United States' carbon sequestration capacity by 20% through the replacement and replanting of all unproductive forests. Large-scale global reforestation could notably decelerate global warming.

The adoption of low tillage agriculture has already diminished GHG emissions and fostered carbon sequestration. Numerous technologies, including biochar, pyrolysis, cover crops, and other methodologies, can enhance soil carbon storage, increase crop productivity, and yield additional benefits. In particular, the employment of cover crops and composting can boost productivity and lead to significant GHG emission reductions as well as carbon production and sequestration.

Seventh, plant-based meats have the potential to reduce reliance on the production of animal meats that inefficiently convert feedstocks and also emit substantial GHG emissions. Theoretically, leveraging improved biotechnology knowledge to directly convert plant material into meat could potentially reduce GHG emissions. Several plant-based meat substitutes are already commercially available, and more are forthcoming. However, strides must still be made regarding product quality and consumer acceptance. Should the plant-based meat industry secure a significant portion of the meat market, the resulting GHG emission reductions could be substantial.

Eighth, solar and wind power are increasingly significant energy sources; however, they require large land areas. Often, agricultural regions are best suited for solar energy storage, potentially removing agricultural land from production, or necessitating new co-management strategies for solar energy and crop production.

Ninth, replacing concrete and steel with lumber in housing would decrease GHG emissions and facilitate the storage of embodied GHGs in the lumber. The lumber industry is innovating more resilient wood products, and biotechnology may allow for the customization of wood products for specific needs. While knowledge is rapidly expanding for building high-rise buildings with lumber, there is room for further research.

Tenth, vertical farming systems where plants are grown indoors, layer by layer, using LED lighting and controlled growth and nutrition systems can significantly increase yield and minimize the use of pesticides and other chemicals. Given the high infrastructure costs, vertical farming can be energy-intensive, thus requiring reliance on renewable energy sources to contribute to decarbonization. Vertical farming can enhance the production of high-value crops and promote a greener, healthier diet while reducing GHG emissions. However, its application remains limited and has yet to achieve economic scale.

Eleventh, second-generation biofuels offer the potential for broader adoption of biofuels and greater effectiveness of this technology. The biofuel sector presently provides around 5%

Table 1. The Impact of Biotechnologies on Various Objectives

Technology	Enhancing Agricultural Productivity	Enhancing Agricultural Resilience	Reducing Greenhouse Gas Emissions	Carbon Sequestration	Enhancing Biodiversity	Enhancing the Well-Being of Rural Sectors
Use of Modern Biotechnology	+++	++	++	+	0	++
Enhanced Productivity of Photosynthesis	++	+	+	+	+	++
Nitrogen Fixation	+	+	+++	+	0	++
Use of Algae	+	+	+	+++	+	0
Use of Insects for Protein and Waste Control	+	+	+	0	+	+
Sequestration of Carbon Through Soil and Forest	0	+	+	+++	+	+
Plant-Based Meats	+	+	++	0	+	0
Wind and Solar Energy	0	0	+++	0	0	+
Lumber for Housing	+	+	+	++	0	+
Vertical Farming	+	+	++	+	0	+
Biofuels	+	0	+	+	0	++

Source: Rausser and Zilberman. 2022. "Resource Economics and Modern Science to the Rescue." Available at: https://bit.ly/3QlKnUy.

of transport fuel consumption. Certain biofuels (e.g., sugarcane ethanol) contribute more to decarbonization than others (e.g., corn ethanol). However, biofuel GHG emissions tend to decline over time due to processing improvements, productivity increases, and reductions in feedstock-production GHG emissions.

The biofuel sector will likely specialize in producing aviation fuel and heavy vehicle fuel in the long term. Given the gradual diffusion of electric cars, biofuels may play a major role in passenger transportation during a transitional period. So far, second-generation biofuels have not been widely used, but they have demonstrated significant potential in recent studies. Once technological production barriers are overcome, they may play a significant role.

The Impact and Likelihood of These Strategies

We have presented 11 approaches through which the bioeconomy can contribute to decarbonization and adaptation to climate change. However, these strategies can also serve additional societal objectives, such as increasing agricultural productivity, enhancing resilience and biodiversity, and improving the well-being of the agricultural sector.

Table 1 (on page 7) illustrates how each approach contributes toward achieving a specific objective. A scale is used where 0 denotes no contribution, + signifies a minor contribution, ++ implies a moderate contribution, and +++ represents a major contribution. Based on this scale, agricultural biotechnology is hypothesized to contribute across all categories, while algae culture predominantly contributes to carbon sequestration, the utilization of solar and wind energy predominantly contributes to the reduction of GHG emissions, and biofuel production predominantly contributes to impacting the rural sector. The bioeconomy strategies discussed should not exist in isolation, but rather as complements to other strategies. These include the use of geothermal energies, battery energy storage, improved air conditioners and microgrids, and nuclear energy, all aimed at addressing climate change challenges.

The aforementioned approaches are still in their early stages. To formulate an effective selection and integration strategy, mechanisms must be established where scientists can offer some assurance regarding the scalability of each technology in terms of volume and cost reduction. Policymakers must promote policies and initiatives that stimulate investment in these alternatives. The implementation of each initiative necessitates an intelligently designed supply chain that hinges on public-private collaboration and entrepreneurship.

Possible strategies may encompass incentives such as carbon pricing and tradable permits, research and development support, and potentially credit subsidies and/or mandates. Policy design should consider economic efficiency as well as economic feasibility. Public education and outreach activities are also integral to enhancing public acceptance of certain solutions and increasing awareness of the trade-offs in addressing climate change. Agricultural and resource economists are well-placed to spearhead a multidisciplinary research agenda, identifying promising decarbonization and agricultural development strategies, proposing policies to foster their development, adoption, and acceptance, and developing tools for supply chain management.

Conclusion

The climate crisis is a global issue; changes within California and the United States alone will not sufficiently mitigate or reduce the associated damage. A worldwide effort is required that strikes a balance between curtailing GHG emissions and improving quality of life.

The concept of a bioeconomy is inherently global. Although the new bioeconomy will develop within California, it is crucial to recognize that the state is expected to develop solutions that can be globally implemented. The advantages of introducing a bioeconomy in California extend beyond the state's borders, benefiting the nation and the world. The University of California can provide the intellectual groundwork for the bioeconomy, and UC Agricultural and Natural Resources should prioritize its embedded strategies.

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For additional information, the authors recommend:

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