U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Chapter 08

Looking Forward and Next Steps

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8 Looking Forward and Next Steps

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- Report landing page: https://www.energy.gov/eere/bioenergy/2023-billion-ton-report-assessment-us-renewable-carbon-resources
- Data portal: https://bioenergykdf.ornl.gov/bt23-data-portal

Summary

Bioenergy remains one of our nation’s oldest, largest, and most versatile forms of renewable energy. Fully 5% of our nation’s energy needs are provided through biomass and waste resources. Biomass is a source of renewable carbon, which can make an essential and substantial contribution in meeting our national net carbon emissions reduction goals (commonly referred to as “decarbonization”). The purpose of this document is to quantify the future availability of biomass under suitable market conditions, geospatially and with estimated costs of production. Qualitatively, this report finds that under mature-market conditions, the United States could grow its biomass resources by a factor of 3. In the longer term, assuming emerging resources can be economically brought to the market, another 1 or 2 billion tons could be available. Yet we find that no one single feedstock can supply all the biomass; different regions tend to produce different feedstocks, which collectively can be used to help address our nation’s decarbonization goals. The limiting factor becomes the cost and long-term social and environmental consequences of producing these vast quantities of biomass. One of the key benefits of a robust bioeconomy is that a large swath of the country can participate. Rural economies across the nation can produce a wide variety of feedstocks identified in this report, while urban areas can harness and utilize waste-based resources rather than simply disposing of them.

The analysis upon which this report is based includes several constraints designed to model long-term environmental sustainability. In this analysis, we relax the sustainability constraints to explore the economic incentives for producing biomass from the agricultural and forestry sectors, beyond what could be considered a sustainable level. We address the topic of direct and indirect LUC, as well as unintended deforestation, including limits to modeling in this report (e.g., the assumption that timberland does not convert to agricultural land). The primary sustainability constraints are also discussed. We find that existing management practices can serve as guides to avoid unintended consequences of biomass production, though it is unclear how widely these practices would be adopted in the future based on existing economic

incentives. Clearly more work needs to be done in these areas, but our hope is that this document continues meaningful dialogue.

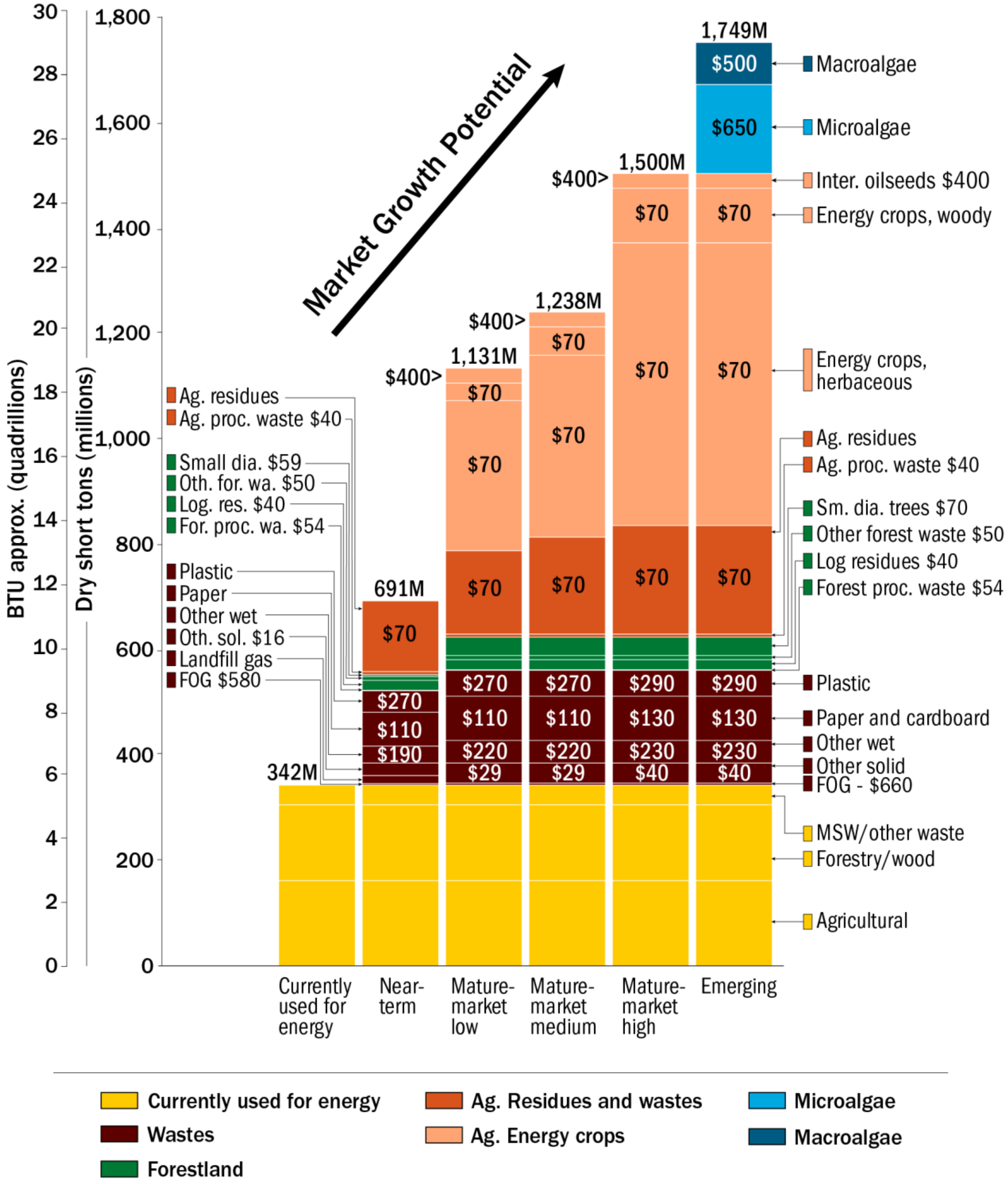

Figure 8.1. Summary of biomass resources by scenario

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As with other sources of renewable energy, a combination of supply push and market pull is needed to advance commercialization. Supply push can come in the form of technologies or practices that increase biomass supply, add value, or decrease cost. Waste resources are being used commercially today, and this trend is likely to continue. Market pull includes innovations or market changes that increase demand or willingness to pay. Supply-side innovations that provide supply push include:

- Increases in purpose-grown energy crop yield.
- Reductions in supply chain costs, uncertainty, and risk.
- Improved attributes in terms of quality and consistency.

Research needs identified in the development in this report to address supply-side limitations include:

- Alternative futures of biomass resource potential based on different demand scenarios (e.g., starch-, lipid-, terpene-, or cellulosic-specific pathways).
- Range of climate change impacts and uncertainties on agriculture, forest landscape, and biomass resource production.
- Likelihood of deviating from sustainability constraints assumed in this report and associated environmental risks, including land use pressures.
- Further analyses of potential impacts of biomass crop production on conventional markets.
- Potential for a shift to biogenic CO_2 for carbon capture and storage and/or algae fertilization if the mature-market conditions in this report are realized.

This report is not exhaustive of all biomass resources in the United States. Notable biomass resources that could increase quantities in this report include:

- Forest biomass from realization of USFS Wildfire Crisis Strategy forest fuel reductions (addressed in case studies in chapter 4, but not in national totals).
- Herbaceous intermediate crops (e.g., winter rye, alfalfa) (addressed in chapter 5, but not in national totals).
- Removal of invasive species such as melaleuca (*Melaleuca quinquenervia*), Chinese privet (*Ligustrum sinense*), and black locust (*Robinia pseudoacacia*).
- Purpose-grown energy crops produced on mined lands, reclaimed lands, brownfields, and other nonagricultural lands.
- Episodic woody biomass sources such as salvage from hurricane and storm debris, beetle kill, and wildfires.

Examples of uncertainty in this national assessment include:

- Product-specific market demands, which will incentivize a mix of energy crops different from those reported here.
- Adoption premiums, which will cause prices to vary over time and by region.
- Short-stature corn, as an agronomic innovation with unknown impacts on residue availability.
- Progress in waste reduction.
- Changes in future energy profiles, which will change point sources of CO_2 emissions, but could cause point sources of biogenic CO_2 emissions to increase.

This report is intentionally agnostic to end use, and other than describing their current uses, does not recommend the possible or optimum uses of these biomass resources. The versatility of biomass to support a variety of uses such as heat, fuel, chemicals, or durable materials is one of its strengths. Feedstock-specific quality attributes make different feedstocks more or less suited to different end use applications. Similarly, different conversion processes are more or less able to optimally process these feedstocks. Advances in conversion pathways and the willingness to develop these options will play a large part in the specific pathways brought to market. While beyond the scope of this report, it would be instructive to better explore the various uses of biomass across the transportation, industrial, and electrical sectors.

The analysis within this report assumes a robust mature market able to incentivize the conversion of near-term feedstocks such as waste, forest, and agricultural residues and the production of longer-term feedstocks such as purpose-grown energy crops and emerging resources. This report, however, does not address any of the various policy actions that might be necessary to realize that mature market. Multiple policy actions will likely be needed and helpful in stimulating this market, and the impacts of these policies both nationally and regionally need to be articulated. Similarly, policy interventions to ensure sustainability are not directly addressed, although modeling constraints have been used to assess their potential need. These costs of future policies need to be weighed against the positive impact of using biomass for different decarbonization pathways. More work needs to be done to understand the positive and negative impacts of growing a robust bioeconomy on the lives of nearby communities, especially underserved communities. But the goal of a mature market for biomass cannot be realized without growth in the bioeconomy sector. Certainly, progress has been made, but more needs to be done to begin to realize these aspirational goals. It is our hope that this report moves us in that direction.

8.1.1 Biomass Potentials in Decarbonization Studies

Many U.S. and global decarbonization scenarios feature expanded use of biomass as a renewable carbon feedstock for producing liquid fuels for hard-to-electrify sectors, or as a means of carbon removal (Butnar et al. 2020; Field et al. 2020; Langholtz et al. 2020; U.S. Department of State 2021; Hawkins et al. 2023). However, second-generation biofuels have been slow to develop.

The RFS established by the 2007 Energy Independence and Security Act (110th Congress of the United States 2007) was anticipated to drive new cellulosic biomass production on the order of 250 million tons per year to support the production of 16 billion gasoline-equivalent gallons of cellulosic ethanol annually by 2022. The Biomass Crop Assistance Program established under the 2008 Farm Bill provided supplemental payments to farmers delivering biomass to approved conversion facilities, and covered some of the costs of establishing novel dedicated energy crops (Miao and Khanna 2017). These supportive policies led to the construction of an initial cohort of commercial-scale cellulosic ethanol biorefineries about a decade ago (Peplow 2014). Those biorefineries were all shut down in the intervening years due to technical challenges and unfavorable market conditions (Lynd 2017; Dale 2018).

Because the timing of demand growth is unknown, this report presents an assessment of biomass potential—rather than a specific forecast of future production—contingent on increasing industrial demand to provide market pull and support supply chain development. The current report also deemphasizes time relative to previous ones (see Table 1.1). BT23 modeling considers some practical limitations on deployment rates and sector dynamics (e.g., stover harvest equipment adoption) but lacks other potentially important effects such as germplasm scale-up and how rates of adoption of novel energy crops might be limited by landowner risk preference and information diffusion. For example, surveys suggest that only a fraction of farmers are currently interested in producing novel energy crops, and many would only do so if the energy crops offered a substantial net revenue premium over current practices (Fewell, Bergtold, and Williams 2011; Skevas et al. 2016; Swinton et al. 2017), though these adoption dynamics are not accounted for in the current POLYSYS modeling. Future assessment efforts could attempt to incorporate some of these limitations and produce deployment projections, potentially drawing from or harmonizing with systems dynamics models such as the Biomass Scenario Model (Vimmerstedt et al. 2023).

8.1.2 Modeling Energy Crops on Marginal Land

Because dedicated energy crops make up such a large fraction of the total biomass resource, it is important to examine where within existing agricultural landscapes they might most realistically and beneficially be grown. This report models such production in competition with conventional agriculture (both row crops and grazing lands) at the county scale. The underlying PRISM-EM dataset of energy crop yields is responsive to broad environmental gradients based on climate and soil properties (Lee et al. 2018). This assessment finds that most energy crop production will likely occur outside of intensive row cropping areas such as the Corn Belt, and instead in areas of less favorable climate for conventional crops such as the southern Great Plains (Figure ES-4). In contrast, other assessment studies restrict energy crop production to areas of marginal, degraded, or abandoned land within existing agricultural landscapes, for sustainability concerns (Khanna et al. 2021; Field et al. 2023). DOE has funded large research efforts to assess and improve the performance of energy crops on such marginal lands (Gelfand et al. 2013; Peters 2018). This is complicated by multiple competing definitions for marginal land, resulting in different regional patterns (Khanna et al. 2021) and uncertain yield performance on these lands (Searle and Malins 2014).

Future billion-ton assessment efforts could consider extending POLYSYS for subcounty-scale modeling that competes energy crops with conventional crops across both prime and marginal land within existing agricultural landscapes—e.g., representing integrated landscape management (Nair et al. 2017). A variety of remote sensing studies have identified significant subfield areas that frequently lose money under conventional crops and tend to have disproportionately poor nutrient use efficiency (Brandes et al. 2018; Brandes, Plastina, and Heaton 2018). Such modeling would need to quantify sensitivity of both conventional and energy crop yields to land quality, possibly using data from the National Commodity Crop Productivity Index (Wightman et al. 2015) or remote sensing (Basso et al. 2019).

8.1.3 Biomass Production in a Changing Climate

Climate change will affect the productivity of dedicated energy crops, thus introducing a feedback where the timing of bioenergy deployment might influence its efficacy (Wagner and Schlenker 2022). BT16 Volume 2 explored how shifts in annual average temperature ranges and precipitation totals might affect energy crop yields using PRISM-EM (DOE 2017). It identified potential regionally important shifts in energy crop ranges, but only modest effects on total biomass productivity at national scale. Energy crop yields are also affected by sub-annual extreme temperature and precipitation anomalies and increased CO_2 concentrations (Jagermeyr et al. 2021), and the latter might lead to significant yield benefits for energy crops utilizing the C3 photosynthetic pathway (Gernaat et al. 2021). Perhaps even more significantly, future climate change is likely to affect conventional crop yields and ranges, which in turn influences the amount of land available for energy crops. There is already evidence that climate change is reducing the rate of yield increases (Ortiz-Bobea et al. 2021) and shifting optimal crop cultivation ranges globally (Sloat et al. 2020), creating both challenges and opportunities for bioenergy and other land-based mitigation measures (Thornton et al. 2023).

Future feedstock modeling efforts should ideally attempt to capture climate effects on agricultural land use, bioenergy crop yields, and alternative land-based mitigation measures in a self-consistent manner. The Agricultural Model Intercomparison Project has assembled an ensemble of process-based crop models driven by downscaled climate projections to robustly simulate conventional crop performance under future temperature and precipitation extremes and CO_2 levels (Jagermeyr et al. 2021). Such data could be leveraged to explore the range of possible land use futures for conventional crops, and how that affects land availability for energy cropping. Alternately, Earth system models can provide a more holistic representation of land–climate interactions, including soil carbon storage and other GHG emissions for both croplands and natural land cover, thus better capturing LUC impacts and potential trade-offs between bioenergy and natural climate solutions (Field et al. 2020; Melnikova et al. 2023). Earth system models have typically featured only limited differentiation of food and energy crops (e.g., Melnikova et al. 2021, 2023), though there are now methods available to better capture the climatic ranges of individual important crops (Xu et al. 2022). An ideal approach would seek to combine the granular approach to crop–environment modeling in the existing billion-ton workflow with these state-of-the-art agricultural and Earth system modeling tools.

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