Innovations in Bioenergy

Izabela Balicka, Maithreyi Thukaram

This review was written based on the presentations given at the Bioenergy Sustainability Conference held on October 21-22, 2019. The conference was supported by the National Science Foundation.

It is widely accepted in the scientific community that the current usage of fossil fuels is not sustainable and has negative environmental impacts such as greenhouse gas emissions. For more than 100 years, petroleum, natural gas, and coal have accounted for more than 80% of US energy consumption[i]. According to the US Energy Information Administration, that percentage will decrease only minimally to 76.6% in 2040, unless significant scientific breakthroughs are made to develop alternative sources of energy. Bioenergy represents one promising field that has the potential of drastically decreasing US and global reliance on traditional energy sources. However, new technologies are still being developed to increase the economic, environmental, and social sustainability of bioenergy. The 2019 Bioenergy Sustainability Conference was designed to explore these advances as well as the challenges that remain in the field.

Currently, bioenergy is most commonly used within industries that produce biomass residues in the manufacturing process, such as the paper industry and the food processing sector. Bioenergy is currently used for space and water heating as well as electricity generation, and accounted for 2% of the world electricity generation in 2016[ii]. Liquid biofuels can be used in the transportation industry to reduce the dependence on traditional transportation fuel sources. Common feedstocks for bioenergy sources include grains, crop residue such as corn stover, and dedicated energy crops such as switchgrass and Miscanthus. These technologies can tremendously aid in reducing greenhouse gas emissions. For instance, it is estimated that maximum potential switchgrass production on marginal land would reduce greenhouse gas emission by 29 million tons of carbon dioxide a year[iii]. Some regions are already rapidly adapting this approach, as the cropland footprint area related to European Union bioenergy is anticipated to increase to 14.3 Mha in 2020, and over 3 million tonnes of palm oil feedstock are expected to be imported from Malaysia, China, and Indonesia that same year[iv].

An increased amount of research is also needed to mitigate the negative effects of increased bioenergy usage. For instance, land conversion from native crops to biomass can lead to decreased water yield, surface runoff, increased evapotranspiration, and nitrogen loss. Additionally, using corn residue can impact soil and water conservation and soil fertility. Other significant effects of widespread biomass cultivation are compromised water quality due to nutrient pollution (e.g. nitrate) from surface runoff and infiltration to groundwater. Thus, environmental effects of various biofuel feedstocks must be further examined in order to ensure the environmental sustainability of the energy source. Life cycle assessments (LCA) can aid in assessing the effects on the surrounding environment.

The Intergovernmental Panel on Climate Change (IPCC) reports with high confidence global warming of 0.8C to 1.2C between 2030 and 2052[v]. Such predictions are further driving investments into bioenergy as well as other associated technologies, such as carbon capture. With the growing need for alternative replenishable fuels, the bioenergy market is one that is a growing and subsequent flourishing field that is estimated to reach 642 billion by the year of 2027[vi]. In 2019 alone, the global market value of Bioenergy was valued around 345 billion. The United States is one of the key drivers of this area- as many as 10 of the leading companies in Bioenergy are based in the United States. The Bioenergy Research Centers, who played a pivotal role in the conception of the conference, have also increased the regional demand of Bioenergy researchers in the United States. The Bioenergy Research Centers develop these science-based strategies to understand and create sustainable system designs that increase bioenergy production while enhancing such economic, social and environmental outcomes.

Advances in Integrated Assessments of Bioenergy Sustainability

The advances in integrated assessments within the field of bioenergy sustainability has a multitude of different factors. Life cycle assessments and techno-economic analysis, are some of the biggest tools to assess the environmental impacts and overall value of a technology.

One analysis tool that can be used to assess the feasibility of a new technology is the Policy Analysis System (POLYSYS), which is a tool that models the US agricultural sector to predict price adjustments with changing supply and demand. Matthew Langholtz *et al.* have used such tools to evaluate the feasibility of using crops such as willow or eucalyptus to meet energy demands[vii]. Alternatively, software such as BioSTEAM can be used to stimulate a biorefinery to aid in techno-economic analysis. Guest *et al.* have used the software to analyze the feasibility of lignocellulosic biomass conversion processes[viii]. Aside from analyzing scientific and economic factors, social and political dimensions are vital to analyze as well when implementing new technologies, as they will indicate the opinion and behaviors of consumers.

Integrating Systems, Designing Sustainable Bioenergy Systems

Designing sustainable biosystems requires considering various factors, such as the coproducts of the production systems, the optimization of the system, as well as effectively incorporating other technologies that can improve the sustainability of the overall system. Although the use of bioenergy is expected to tremendously reduce greenhouse gas emissions, combining this technology with other techniques such as carbon capture and storage will help to create sustainable systems that are close to carbon neutral.

In order to quantitatively determine the sustainability of a system, a trade off assessment of a new technology has to be analyzed to ensure it has a positive net effect. The Oak Ridge National Laboratory has developed a Bioenergy Sustainability Tradeoffs Assessment Resource (BioSTAR) tool to visualize the benefits of a new technology. The tool is developed based on existing literature, assesses feedstock production and logistics steps, and uses a variety of indicators to assess environmental, social and economic impacts to allow the user to better visualize a new technology's impacts[ix].

Bio-energy with carbon capture and storage (BECCS) is a popular topic of discussion in the field, as utilization of this technology can potentially result in negative emissions. Hamilton *et al.* report that the use of ethanol and CCS technologies are 204-416% better at reducing CO2 emissions than using petroleum as an energy source, and using electricity and CCS technologies is 329-558% better at reducing CO2 emissions than using petroleum as an energy source[x]. These percentages would vary according to which crop was used in the production of each energy source. Aside from carbon capture, the technologies such as anaerobic digestion can be used in wastewater treatment plants along with combined heat and power capacity in order to increase biogas production[xi].

Research frontiers for Sustainable Bioenergy

There are still various research questions that remain in the field of bioenergy. Advances in biotechnology allow researchers to modify the genomes of crops in order to make them more resilience to factors such as changing climates or pests, and increase crop resilience. Genetic engineering tools such as CRISPR enable researchers to make modifications to the biomass genome that would allow for the crops to have increased resiliency to disease, drought, climate change, and other undesirable environmental conditions. This is vital for ensuring a reliable supply of biomass that is needed for bioenergy to be utilized in long durations. Engineering the metabolic pathways of microorganisms that produce fuel precursors is another method to increase the yield of useful products. For instance, Wang *et al.* demonstrate that *C. Saccharoperbutylacetonicum* (which are butanol producers) have autolysin enzymes that results in self-destruction of the cells, and makes long term fermentation difficult thus negatively impacting production[xii]. Therefore, deleting these enzymes allows for optimized production. Such modifications are often necessary when producing energy sources on an industrial scale.

Additionally, other researchers are developing tools to allow for and support sustainable decisions. Researchers from Argonne National Lab (ANL) and Pacific Northwest National Lab (PNNL) have developed the Biomass Assessment Tool (BAT) to identify locations in the US that meet lab, biomass productivity, and carbon dioxide co-locating criteria in order to scale up the production of algae based fuels[xiii]. A tool such as BAT is useful in improving biomass yield and production efficiency to help make bioenergy production more economically feasible.

The 2019 Bioenergy Sustainability Conference aimed to create a platform for the sharing of groundbreaking research in the field. The conference was comprised of three sessions: (1) Advances in Integrated Assessments of Bioenergy Sustainability, (2) Integrated Systems, Designing Sustainable Bioenergy Systems, (3) Research Frontiers for Sustainable Bioenergy, as well as a panel on Sustainability Research Goals at Bioenergy Research Centers and a poster session. The conference was supported by the National Science Foundation, which allowed for a successful conference, which allowed us to host the conference again in 2020. The Bioenergy Sustainability Conference will take place on October 13-15, 2020 on a virtual platform. Register or submit an abstract at aiche.org/bioenergy.

References

[i] EIA, "Fossil fuels still dominate US energy consumption despite recent market share decline" (2016)

[ii] IEA, "Bioenergy and biofuels" (2017)
[iii] Wu, Y., Zhao, F., Liu, S. *et al*. "Bioenergy production and environmental impacts" Geosci. Lett. (2018) 5: 14. https://doi.org/10.1186/s40562-018-0114-y
[iv] Pulighe, G. *et al.* "Ongoing and emerging issues for sustainable bioenergy production on marginal lands in the Mediterranean regions" Renewable and Sustainable Energy Reviews. (2019) https://doi.org/10.1016/j.rser.2018.12.043
[v] IPCC
[vi] Global Newswire
[vii] Langholtz, M. et al. "Economic Comparative Advantage of Willow Biomass in the Northeast USA" (2018), AIChE
[viii] AIChE
[ix] https://bioenergykdf.net/content/biostar
[x] Ilya Gelfand, Stephen K. Hamilton, Alexandra N. Kravchenko, Randall D. Jackson, Kurt D. Thelen, and G. Philip Robertson "Empirical Evidence for the Potential Climate Benefits of Decarbonizing Light Vehicle Transport in the U.S. with Bioenergy from Purpose-Grown Biomass with and without BECCS" Environmental Science & Technology **2020** 54 (5), 2961-2974 DOI: 10.1021/acs.est.9b07019
[xi] AIChE
[xii] Zhang J, Wang P, Wang X, Feng J, Sandhu HS, Wang Y. Enhancement of sucrose metabolism in Clostridium saccharoperbutylacetonicum N1-4 through metabolic engineering for improved acetone-butanol-ethanol (ABE) fermentation. Bioresour Technol. 2018;270:430-438. doi:10.1016/j.biortech.2018.09.059, AIChE
[xiii] Xu, Hui, Lee, Uisung, Coleman, André M., Wigmosta, Mark S., and Wang, Michael. Assessment of algal biofuel resource potential in the United States with consideration of regional water stress. United States: N. p., 2018. Web. doi:10.1016/j.algal.2018.11.002.