Use of Byproduct from Cellulosic Ethanol Production as an Additive for Concrete: A Possible Win-win Strategy?

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Technologists are facing increasing demands to achieve ecologically sustainable industrial practices. Currently the concrete industry is a significant contributor to greenhouse gas emissions. On the other hand, the scaling up of cellulosic ethanol technology has not been a very easy task. In this context, the integration of "greener" concrete with cellulosic ethanol technology may open up promising possibilities. The solid byproducts from cellulosic ethanol production process have been demonstrated to increase the strength of concrete structures when used as a partial cement replacement. Such a delicate integration can also lead to reduction in both carbon footprint and product cost. The possible commercialization of the integrated technologies would provide win-win benefits for both industries.

Keywords: Concrete; Cement; Cellulosic ethanol; Byproduct; Sustainability

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Concrete and the Greenhouse Gas Emission

Concrete is a frequently used construction material in the building industry and can be found everywhere in the world. It is used globally to build roads, buildings, bridges, runways, and sidewalks (Sullivan 2009; Rubenstein 2012). The development of civilization has been highly dependent upon the use of concrete.

Essentially, concrete is made from three major components: cement, water, and aggregate (Kansas State University 2013). Cement and water combine to form cement paste for use as the binder for the aggregate. The terms "concrete" and "cement" may be used interchangeably (Houghton Mifflin Company 2005), but it would be better and more reasonable to understand these terms separately.

The greenhouse impact associated with concrete production is very significant (Amato 2013). In this regard, cement is the predominate contributor. Despite the fact that making concrete is less energy-intensive than making steel or other building materials, concrete production can account for between 3 to 8 percent of global carbon dioxide emissions (Rubenstein 2012; Kansas State University 2013). Note that carbon dioxide is the primary greenhouse gas released as a result of human activities. The carbon dioxide emission from concrete production can be derived from the calcination process that releases carbon dioxide. Carbon dioxide also is released due to the energy input to the production processes and for transportation of materials (Rubenstein 2012). As a construction material, concrete is not likely to be truly sustainable, but it is possible to reduce its impact on the environment using various technologies (Leung 2009).

Cellulosic Ethanol and the Possibilities Associated with the Use of Its Byproduct in Concrete

The replacement of fossil-derived nonrenewable fuels with biofuels is essential to a sustainable future. As a combustible liquid suitable for use as a transportation fuel, a versatile solvent, and a chemical raw material, ethanol can be produced from inedible lignocellulosic feedstocks including wood chips, forest wastes, agricultural crop residues, industrial wastes, and energy crops (Wang *et al.* 2011). While first-generation bioethanol is derived from sugar or starch produced by food crops (*e.g.*, wheat, corn, sugar beet, sugar cane), cellulosic ethanol may be considered as second-generation bioethanol. The feedstocks for cellulosic ethanol production are more abundant and generally considered to be more sustainable (EBTP 2015). A process for the production of cellulosic ethanol is illustrated in Fig. 1. It is noted that although hemicellulosic components of lignocellulosic feedstocks may also be utilized to produce ethanol, the process still is named “cellulosic ethanol”.

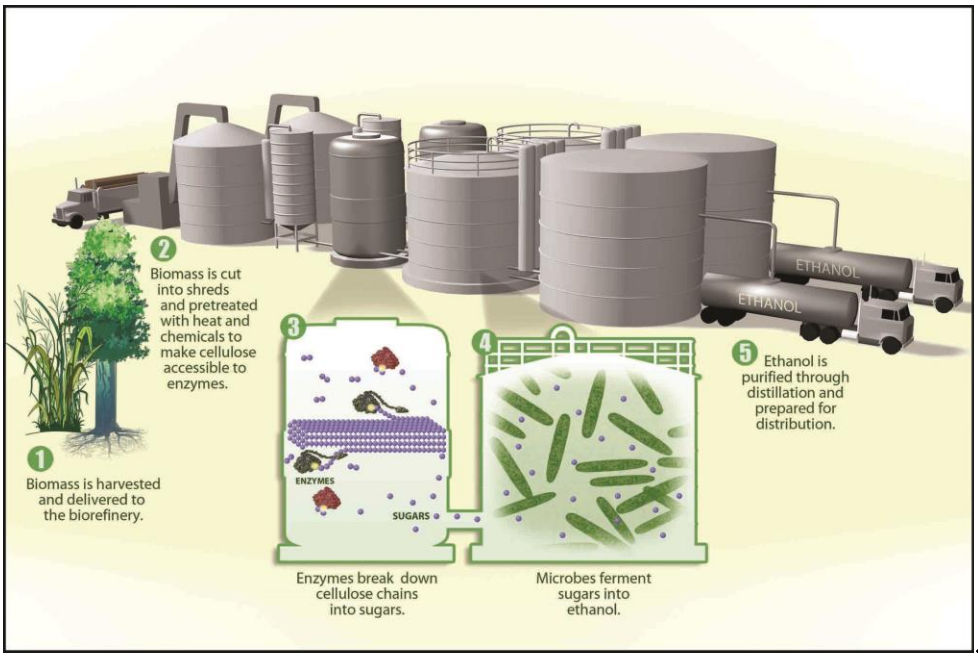

Fig. 1. Schematic of an example of cellulosic ethanol production process
(Office of Biological and Environmental Research of the U.S. Department of Energy Office of Science)

Currently, there are some commercial-scale plants around the globe for production of cellulosic ethanol. It may be predicted that ongoing efforts to commercialize this clean energy would lead the world to a more independent energy future (Christian 2015). However, partly due to the complex and not-easily-accessible structure of lignocellulosic feedstocks, scaling up the cellulosic ethanol technology has proven difficult and costly (Fitzpatrick 2015). Overcoming the barriers to cellulosic ethanol may involve a combination of different strategies (Fig. 2). In this sense, making better use of the waste streams for the production of value-added products can facilitate the survival and sustainable growth of the cellulosic ethanol biorefinery industry. On the other hand, the government policies and economic factors would play a significant role.

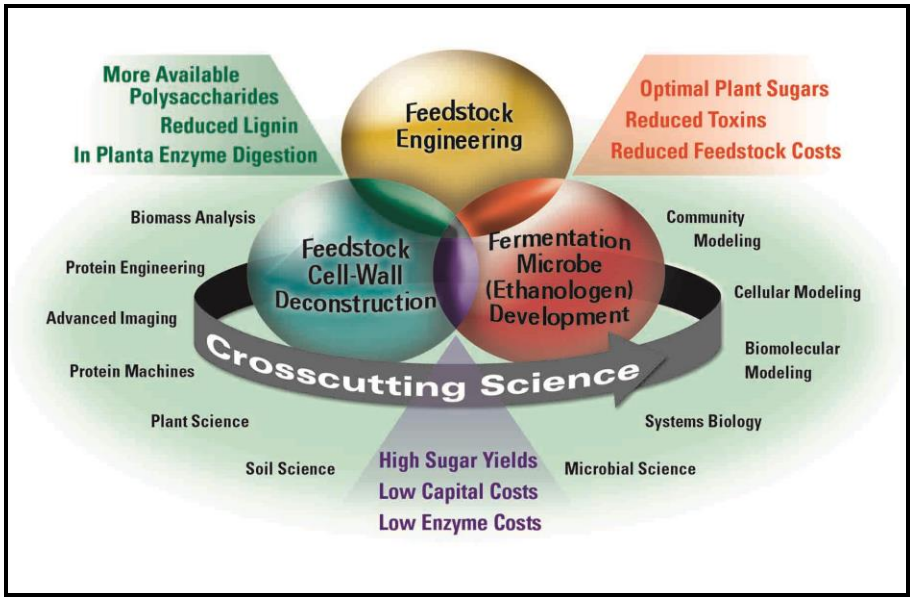

Fig. 2. Possible strategies for overcoming barriers to cellulosic ethanol.
(Biological and Environmental Research Information System, Oak Ridge National Laboratory. Sponsored by the U.S. Department of Energy Biological and Environmental Research Program)

Quite encouragingly, the concept of using the solid byproduct from cellulosic ethanol production process as a partial replacement of cement in concrete has recently been demonstrated (Kansas State University 2013). A pronounced feature of the concept is that the use of the byproduct would reduce the carbon footprint of concrete materials as a result of the partial replacement of cement. Also, the addition of the byproduct to cement can increase the strength of concrete through chemical interactions. For example, a 20% replacement can lead to a 32% increase in strength. Further, the production cost of cellulosic ethanol would be reduced by adding value to the byproduct.

Basically, after processing or treatment, this byproduct can be used as a supplementary cementitious material for concrete (Ataie and Riding 2014a,b). In contrast to alkali-based pretreatment, dilute sulfuric acid pretreatment of silica-rich agricultural crop residues is preferred due to the higher amount of reactive silica, which is favorable for the strengthening of concrete structures. The combination of dilute sulfuric acid pretreatment with subsequent enzymatic hydrolysis can lead to the formation of a byproduct that is effective as supplementary cementitious material (Ataie and Riding 2011). Due to the need for "reactivity" associated with silica, crop residues such as wheat straw, rice straw, and corn stover would be a better choice in comparison to woody materials (*i.e.* woody materials has a lower silica content). The commercially available cement and the byproduct may have good compatibility with each other due to their structures and chemistries.

Therefore, the integration of cellulosic ethanol industry with the concrete industry may possibly create a win-win situation for a sustainable future, particularly with regards to cost-effectiveness, sustainability, and low-carbon economy. In this concept, the leftovers from the cellulosic ethanol industry would be converted to value-added products for possible widespread utilizations. Such usage can be regarded as a valuable alternative to burning for energy recovery or landfilling. For now, the answer pertaining to the title of this editorial would be obvious, and it is "yes". Continuing efforts are still needed, so that the technologies can be easily scaled up for large-scale commercial applications.

Academy-industry-government collaborations are likely to play a key role. Nonetheless, in addition to the use of bioethanol byproduct in concrete, other value-added possibilities may still be conceived and demonstrated, so that diversified opportunities/options will be available for decision-makers. All of these would help to lead the way to a green and sustainable future.

Acknowledgement

The authors wish to acknowledge the permission from U.S. Department of Energy to use the images, which can be found at https://public.ornl.gov/site/gallery/detail.cfm?id=252&topic=&citation=&general=&restsection and https://public.ornl.gov/site/gallery/detail.cfm?id=232&topic=&citation=&general=ethanol&restsection=all.

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DOI: 10.15376/biores.10.4.6314-6317