



DE-FOA-0001615: REQUEST FOR INFORMATION: CELLULOSIC SUGAR AND LIGNIN PRODUCTION CAPABILITIES

Response from Lawrence Berkeley National Lab

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Category 1: Lignocellulosic Sugars

If you are a producer of lignocellulosic sugars and are willing and able to sell or otherwise make them available to the research community, please provide information in your response to the following questions. You may respond to as many or as few questions as you wish. The questions are intended to provide the research community with useful information when looking for a supplier of lignocellulosic sugars. **BETO is requesting NON-PROPRIETARY information only:**

1.1. To which types of research entities are you willing and able to sell your lignocellulosic sugar (e.g., university researchers, national laboratories, industry/private sector)? Are there any types of research entities to whom you are not willing and able to sell your lignocellulosic sugar?

We do not sell lignocellulosic sugars, per se, but can provide them to any type of research entity on a cost recovery basis or through a collaboration on a federal or state funded project. The general approach we take with our collaborators includes: scoping the project, performing deconstruction, and providing lignocellulosic sugars coupled with process data, including mass balance and full characterization of the hydrolysate (pH, sugar concentration, level of possible inhibitors, etc). We are also able to investigate any particular research question in lignocellulosic sugar production at the lab and large scale.

1.2. What are the maximum and minimum quantities of lignocellulosic sugar you are willing and able to sell (kg)?

We possess batch reactors, the largest of which can produce up to 80 L hydrolysate with a maximum sugar concentration of 120 g/L (glucose + xylose). As such, we are able to produce a maximum of 9.6 kg glucose and xylose per batch. This upper limit of sugar production is based on solids loading during enzymatic hydrolysis. Saccharification kinetics are known to be substantially hampered beyond 20% (w/w) solids in the slurry. The reactor itself has excellent mixing capabilities that can handle solids loading beyond 30% (w/w) in slurry.

The minimum quantity can be as low as 0.1 g (20 mL hydrolysate with ca 5 g/L total sugars).

1.3. What is the sugar concentration in your product?

The typical range for glucose is 50-100 g/L and xylose is 10-40 g/L which is limited by, once again, the dependence of saccharification kinetics on solids loading.

1.4. What physical form do you sell your sugars (e.g., solid or liquid)?

We typically provide sugars in the liquid form after solids removal from the slurry. For some of our collaborators, we concentrate the sugars in the residue-free liquid hydrolysate via evaporation of water.

1.5. How do you package your lignocellulosic sugars for shipping? Do you ship in bulk?

We typically use polypropylene carboys that are either refrigerated or frozen to avoid contamination risks.



1.6. What type(s) of biomass do you use to produce lignocellulosic sugar?

We are feedstock agnostic and work with grassy and woody biomass types, algae, and municipal solid wastes. Although algae and municipal solid wastes do not qualify as lignocellulosic sugars, they can be blended with a lignocellulosic biomass prior to pretreatment.

The specific feedstocks we tested thus far are listed below:

Switchgrass, corn stover, eucalyptus, bagasse, loblolly pine, energy cane, wheat straw, municipal solid waste (MSW) blends, cyanobacteria consortia, and microalgae.

1.7. What process do you use to produce lignocellulosic sugar?

We are technology agnostic and are only limited by the configuration of our reactor: a Hastelloy 10L reactor (working volume: 3-6L) that can operate at maximum 200°C, two C20 10L reactors (working volume: 3-6L) with maximum operation temperature at 300°C, and one 210L thermochemical reactor (working volume: 30-100L) customized from Andritz with maximum operation temperature at 200°C. As such, we can utilize a range of catalysts suspended in an aqueous phase (primarily water) for pretreatment and enzymatic hydrolysis. We can perform two-stage chemical treatments, i.e. saccharification with a chemical (acid or imprinted inorganic silicates, etc.) instead of an enzyme.

Pretreatment and hydrolysis catalysts include: Dilute and concentrated acid, dilute and concentrated alkalis, hot water (hydrothermal), ionic liquids, aqueous ammonia (Soaking Aqueous Ammonia), hydrogen peroxide, urea (NaOH/urea mixtures), solid acid catalysts, imprinted inorganic silicates, and all enzymes including cellulases, xylanases, pectinases, JTherm etc. It is important to note that we can also produce specialized enzymes via fermentation and purification to be applied on pretreated lignocellulosic biomass.

We typically perform pretreatment 10-30% (w/w) solids loading and enzymatic hydrolysis at 5-20% (w/w) solid loading.

1.8. What details of the scale of your process are you willing to share (e.g. batch and/or continuous/volumetric productivity)?

The largest pretreatment reactor at the ABPDU is a batch reactor with a volume of 210L. Due to the low bulk density of biomass (<150 kg/m³), we are able to operate a maximum of 75 kg at 30% (w/w) solids loading. We can increase the total mass of slurry to 100 kg if we reduce solid loading. Also, during high temperature and/or pressure reactions, it is necessary to provide headspace to allow for the expansion of water and catalyst.

1.9. What is the typical composition of your sugar stream (e.g., glucose, galactose, mannose, xylose, arabinose) and what is the purity?

Typically, we see 50-100 g/L glucose, up to 40 g/L xylose and up to 10 g/L for other sugars depending on the feedstock. Compositions are dependent on the process and feedstock.

1.10. Do you routinely test your cellulosic sugar for consistency within and between lots and between feedstocks (if applicable)?

No, we do not regularly test for consistency. We have, however, measured sugar concentrations and calculated sugar yields in the past to assess consistency. In our triplicate studies of acid and alkali pretreatments with corn stover, we saw less than 10% variation in sugar yields. Also, the real-time data on our process parameters aligned very well through each of the campaigns, with less than 10% variation as well.



We have not pursued many consistency studies as our technology and parameter choices depend on the goals of our collaborators, which vary substantially.

- 1.11. What impurities are present in your lignocellulosic sugar process and what testing do you perform to determine the presence of impurities?
We believe that we primarily have low molecular weight lignin in sugar rich hydrolysate. In an acid pretreated batch, we sometimes see inhibitors such as: acetic acid, hydroxymethylfurfural (HMF), furfural, phenolic compounds, etc. We use HPLC to determine the concentration of the impurities.
- 1.12. Does your process include a purification step?
No. We have capabilities to perform overliming, ultra-filtration, and/or liquid-liquid extraction, but haven't performed any thus far.
- 1.13. What is the highest concentration in grams/Liter you can provide?
120 g/L glucose+xylose
- 1.14. Have you examined the impacts of transport and storage on sugar degradation? If so, can you please provide any relevant (non-proprietary) details of these impacts?
No. We have performed rheological analysis of pretreated feedstocks to identify the pumps that will be required to perform material handling in a biorefinery. While such rheological analyses may have implications in biomass densification and transportation, we haven't performed a direct impact analysis yet.
- 1.15. What additional information are you willing and able to provide to the research community about your lignocellulosic sugar? Please provide any nonproprietary cost information you are willing to share.
We are able to produce 80L hydrolysate (pretreatment, pH adjustment, hydrolysis and monitoring, reactor prep and cleaning) in a \$10K budget, supplies excluded. If required, we are able to perform purification via ultra-filtration with a Tangential Flow Filtration unit or liquid-liquid extraction with a continuous 2L Karr® column. We are also able to perform a range of analytics including, bomb calorimeter, chromatography, rheology, etc.
- 1.16. Into what markets do you typically sell your lignocellulosic sugar? What is a typical application for your lignocellulosic sugar?
We typically support small businesses that are looking for alternative sources of sugar. They are usually testing the compatibility of their downstream process with multiple lignocellulosic sugars produced from varying feedstocks via multiple technologies.