Request for Information:
Cellulosic Sugar and Lignin Production Capabilities

RFI Number: DE-FOA-0001615

Submitted To:

Bioenergy Technologies Office (BETO)
Energy Efficiency & Renewable Energy
U.S. Department of Energy
Washington, DC

Submitted By:
ICM, Inc.
310 N. First Street
Colwich, KS 67030
DUNS: 834683369

Contact:
Douglas B. Rivers, Ph.D.
2811 S. 11th Street, Suite 100
St. Joseph, MO 64503
douglas.rivers@icminc.com
(316) 977-8502

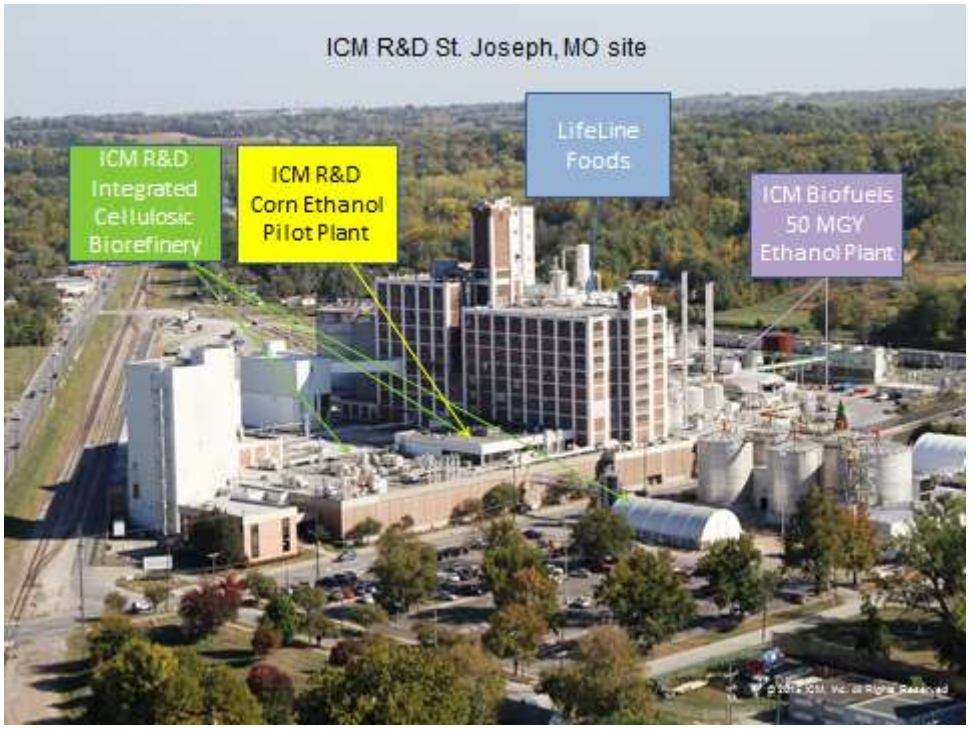
August 24, 2016

Cellulosic Sugar and Lignin Production Capabilities

Introduction

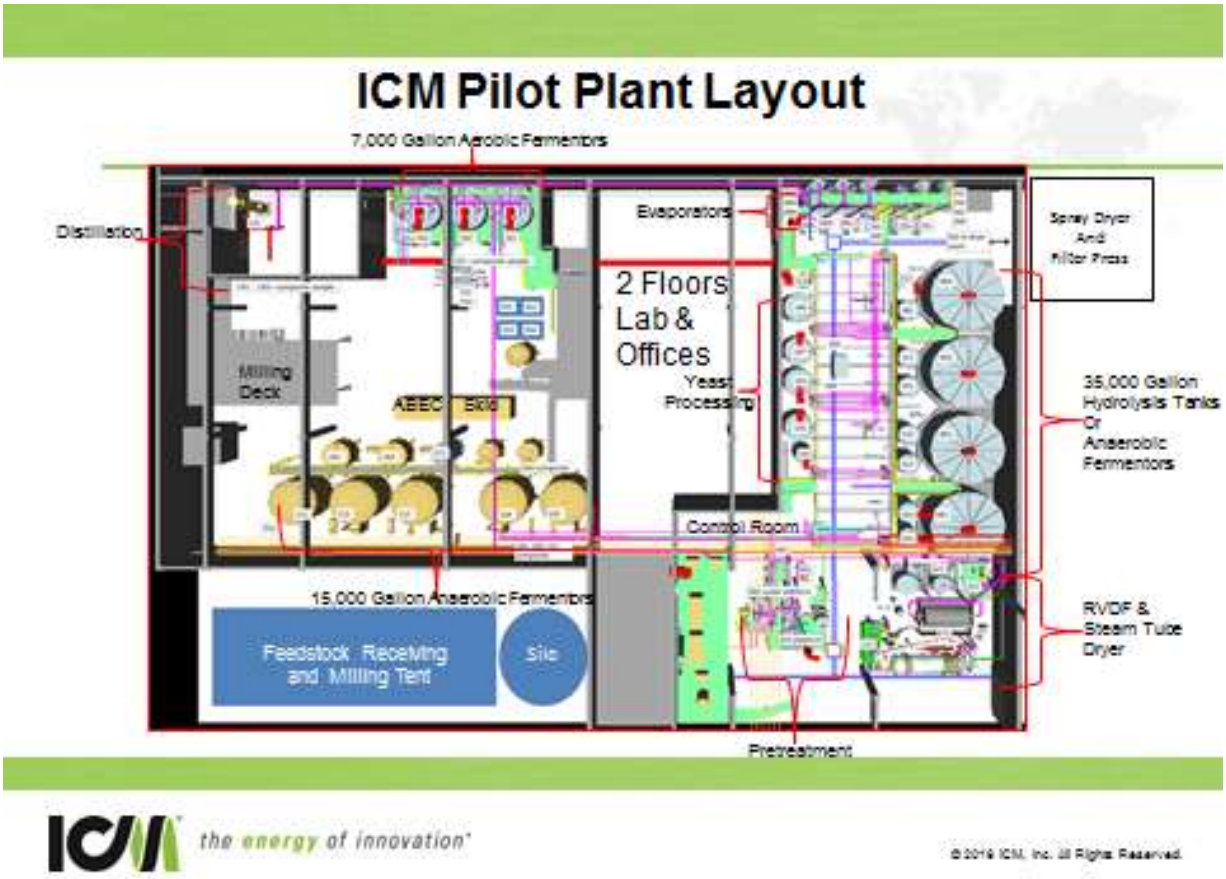
ICM possesses extensive lab and pilot plant capabilities to produce cellulosic sugars and lignin using either independent unit operations or a fully integrated piloting/demonstration of cellulose-based (Generation 1.5 and Generation 2.0) conversion processes. Since its inception in late 2007, ICM's integrated pilot biorefinery has focused on the development of fermentation ethanol, isobutanol, and various chemical intermediates from cellulosic feedstocks. The design feedstock capacity is rated at10 dry tons of cellulosic biomass per day. Much of the integrated cellulosic work was conducted to date was under Award Number DE-EE0002875.

The ICM Laboratory and Pilot Plant are located in St. Joseph, MO at 2811 S. 11th Street inside the LifeLine Foods (LLF) complex. The ICM facility occupies over 35,000 sq.ft. of pilot space and about 5,000 sq.ft. of lab and office space. This represents a $100+ million investment in the future of renewable cellulosic fuels and chemicals. An aerial view of the site is shown below.



1. **Activities Focusing on Production of Cellulosic Sugars and Lignin:**
   The diagram below shows the general layout of the facility. The blue areas represent the feedstock receiving tent, milling, and Harvestor™ silo for cellulosic feedstocks, which is on the west side of 11th Street. Cellulosic feedstock is conveyed into the process pneumatically. The left side of the facility includes the entire Generation 1.0 process line including milling, cook systems, slurry tanks, fermentation, separations and distillation that are common to both corn and cellulose ethanol production. Near the top left side are 3 X 7,000 gallon, steam sterilizable aerobic fermentors used in processes requiring aerobic conditions. There is also an ABEC fermentation skid with 3 X 50L and 1 X 500L steam sterilizable aerobic fermentors, a continuous medium sterilizer (not shown), and commercial scale centrifuges. The right side

of the facility is used primarily for cellulose conversion. In the lower left corner is the pretreatment skid. This is ICM's design of dilute acid pretreatment; the most widely used approach to cellulose pretreatment in developing or commercial processes. In the bottom right corner are a rotary vacuum drum filter (RVDF) and a steam tube dryer used for solid/liquid separations and solid product drying, respectively. Down the left side of the aisle is a series of temperature controlled, agitated reactors used for processing material such as cell recycle. On the right side of the aisle, the larger tanks are 35,000 gallon reactors useful for cellulose hydrolysis. These can also be used as anaerobic fermentors. There is also a series of smaller auxiliary tanks, and a GEA Westphalia disk stack centrifuge (not shown) that is located on the mezzanine deck between these sets of reactors. On the back wall (top) is a series of 6 multiple effect evaporators in three sizes to accommodate various evaporative process needs. To the right of the evaporators is a room with a spray dryer (product drying) and filter press (solid/liquid separations).



ICM built its cellulose conversion capabilities over the past 10 years through experiences gained in the laboratory, process development unit (PDU) scale unit operations, 10 dry tons per day of biomass in fully integrated process demonstrations, and full scale production plant operations. During these many successful -- and some not so successful -- developments resulting in commercial products and processes, ICM has learned not to assume anything. A key learning was that each feedstock must be considered a new case; each plant material (switchgrass, energy sorghum, corn stover, bagasse, wood, MSW, etc) has its own handling and processing characteristics. Therefore, based on ICM's experience over the past 10 years, each feedstock must

be optimized from beginning to end to mitigate risk and help assure commercial success. ICM has produced demonstration scale quantities of cellulosic sugars and lignin from cellulosic corn fiber, switchgrass, energy sorghum, and wood. Typically, ICM has achieved conversions of feedstock to sugars at 90% efficiency in fully integrated process operations running continuously over 1,000 hours of 24/7 operations. These operations included separation of residual solids containing a high concentration of lignin. We were able to collect this material in an average 46% total solids filter cake using a filter press. ICM then dried this material to 10% moisture in our steam tube dryer. ICM conducted successful co-firing of the material at a 29% w/w inclusion rate in solid fuel combustors owned by The Southern Company, a large power provider in the southeastern U.S.

Combined Answers to Questions for Category 1: Lignocellulosic Sugars and Category 2: Lignin

1. We are willing to sell lignocellulosic sugars and lignin to any academic, government, or commercial enterprise working to develop biobased products.
2. We are able to sell quantities from a few kg to syrups in totes or tanker trucks.
3. Sugars are typically produced in our hydrolysis tanks at concentrations up to 135 g/L. From that point, ICM has the ability to concentrate these sugars using commercial evaporation equipment up to about 250g/L
4. Typically we sell our sugars as a liquid and can tailor concentrations as described above, but smaller scales are often not cost effective.
5. We package liquid or solid samples in sealed containers. Smaller quantities may be in zip lock bags, liter polypropylene bottles, or 5-gallon buckets. Larger quantities are typically shipped in totes or tanker trucks. We can ship in bulk.
6. Our greatest experience in converting cellulosic biomass is with cellulosic corn kernel fiber, switchgrass, and energy sorghum. We have a proven process that has successfully completed multiple 1,000+ hours of continuous 24/7 operations with these three feedstocks. We also have more limited, but successful, experience with corn stover, bagasse, and wood chips. We are comfortable running any of these feedstocks. We are also confident in running other similar grassy or pith containing agricultural crop residues or energy crops; however, we have not optimized our dilute acid pretreatment, or feedstock handling process for these other feedstocks. Thus, either some additional cost for optimization or some reduced conversion efficiencies with these other feedstocks might be expected.
7. We use ICM's own patent pending dilute acid pretreatment process. In this process we use sulfuric acid at 2-4% w/w with feedstock in about a 10-20% solids slurry. The pretreatment typically occurs at about 150 - 200 C and atmospheric - 15 psig over saturated steam with a residence time of about 15 minutes. The slurry is then flashed to achieve an explosive decompression of the solids that gives the slurry the approximate consistency of applesauce. With this approach, ICM realizes the high efficiencies and consistent operations referenced above. Although perhaps counterintuitive, this process approach increases hydrolysis efficiencies and reduces enzyme costs compared to a high solids pretreatment process, with typical conversions to sugars $\geq$ 90% of theoretical. Following enzymatic hydrolysis, the dilute sugars are separated using a filter press. The unconverted solids are collected in a filter cake that has averaged about 46% total solids and contain an enriched level of lignin. ICM can dry this cake further to about 90% solids in our steam

tube dryer if desired. The resulting dilute sugars (up to about 135 g/L) can be concentrated to custom levels in our commercial evaporator system.

8. We are able to share many of the details of our process where necessary under a Confidentiality Agreement on a case-by-case basis. Any materials that ICM has presented publically in oral or written presentations can be shared.
9. The typical composition of our sugar stream, like any process converting a cellulosic feedstock, is dependent on the quality and composition of the specific feedstock. For the work completed recently by ICM for DOE under the contract referenced on page 1, the average composition of sugars on a dry weight basis were
    a. Corn Kernel Fiber: Glucose 26%, Xylose 20%, Arabinose 17%
    b. Switchgrass: Glucose 48%, Xylose 3%, Arabinose 0.8%, Galactose 0%, Mannose 2%
    c. Energy Sorghum: Glucose 41%, Xylose 5%, Arabinose 0.5%, Galactose 0.7%, Mannose 2.5%

    The purity was not determined, as such, however, we do have extensive analytical capability to do HPLC, GC, GCMS, online NIR, online MS, IC, ICP, Protein, Amino Acids, and Lipids to validate purity requirements for sugar production on site.

    We typically don't measure the composition of our lignin stream. The work we did with combustion showed an average btu content of about 7200 btu/lb. Composition depends on feedstock and we have not monitored consistency other than the % solids in the filter cake and its residual sugars.
10. The values listed above represent expected ranges based on historical experience
11. ICM's facility contains a world class analytical laboratory. ICM conducts extensive analytical testing including HPLC for sugars/organic acids/aldehydes/alcohols/etc.; Inorganic Chromatography (IC) for key anions/cations; and ICP for key elemental analyses to mention a few. Our pilot plant has real time MS and NIR analytical capabilities.
12. Our standard process does not include a purification process; however, if higher levels of purity are required, ICM has a variety of capabilities including, but not limited to, centrifugation, and micro, ultra, and nano filtration to further purify the sugar product.
13. The highest practical concentration we can provide is about 75% sugars for unpurified material.
14. The impact of transport and storage on sugars is highly dependent upon the process used to make the sugars. The more severe the conditions (acid concentration, temperature, pressure, residence time), the more stable "as produced" they will be. If sugars are concentrated, they will become more stable as water activity is reduced and inhibits microbial activity, as well.
15. ICM does not produce and inventory lignocellulosic sugars or lignin as a regular business practice. As such, we do not sell lignocellulosic sugars or lignin today as commercial products. ICM does produce lignocellulosic sugars and lignin on a contract basis for interested customers. From time to time, we may have very small quantities of residual sugars and lignin available from our own development work, but these are not available on a regular basis and may have restricted uses based on Material Transfer Agreements. If so, we can usually provide them on a cost-of-production basis.
16. We do not typically sell lignocellulosic sugars or lignin. They are only produced on a contract basis.