2016 S-1041 Science and Engineering for a Biobased Industry and Economy

Symposium Poster Abstracts
Symposium Oral Presentations

Oral and poster presentations at the
S-1041 annual meeting on
08 and 09 August, 2016
Western Regional Research Center, ARS, USDA, Albany, CA

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Encompassing poster presentations enables students, researchers and policy makers to establish cooperative endeavors for future collaborations.

Planning Committee

G. S. Murthy, Oregon State University
Kent Rausch, University of Illinois
Troy Runge, University of Wisconsin
Mike Tumbleson, University of Illinois

The S-1041 Website

A complete description of the S-1041 multistate project, objectives and other related information can be found at the following link:
http://www.nimss.org/projects/view/mrp/outline/15616

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S-1041 OBJECTIVES

Develop deployable biomass feedstock supply knowledge, processes and logistics systems that economically deliver timely and sufficient quantities of biomass with predictable specifications to meet conversion process dictated feedstock tolerances.

Investigate and develop sustainable technologies to convert biomass resources into chemicals, energy, materials and other value added products.

Build modeling and systems approaches to support development of sustainable biomass production and conversion to bioenergy and bioproducts.

Identify and develop needed educational resources, expand distance based delivery methods and grow a trained work force for the biobased economy.

Proceedings edited by
Kent Rausch and Mike Tumbleson
University of Illinois

S-1041 MEETING CHRONOLOGY

THE SCIENCE AND ENGINEERING
FOR A BIOBASED INDUSTRY AND ECONOMY

Dates	Location	Chair	Host
01 = 29-30 Nov, 2001	Atlanta, GA	David Brune	
02 = 08-09 May, 2003	Washington, DC	David Brune	
03 = 06-07 Nov, 2003	Washington, DC	William Gibbons	NIFA
04 = 30-01 Set-Oct, 2004	Golden, CO	Milford Hanna	NREL
05 = 19-20 Sep, 2005	Knoxville, TN	Terry Walker	ORNL
06 = 18-19 Sep, 2006	St. Paul, MN	Sundaram Gunasekaran	
07 = 24-25 Sep, 2007	Peoria, IL	Kent Rausch	NCAUR
08 = 15-16 Sep, 2008	Washington, DC	Julie Carrier	NIFA
09 = 21-22 Sep, 2009	Richland, WA	Dennis Wiesenborn	PNNL
10 = 02-03 Aug, 2010	Wyndmoor, PA	Sue Nokes	ERRC
11 = 01-02 Aug, 2011	Stillwater, OK	Mark Wilkins	
12 = 06-07 Aug, 2012	Washington, DC	Samir Khanal	NIFA
13 = 24-25 Jul, 2013	Kahului, HI	Dorin Bolder	
14 = 04-05 Aug, 2014	New Orleans, LA	Chengci Chen	SRRC
15 = 09-11 Aug, 2015	Wooster, OH	G. S. Murthy	
16 = 08-09 Aug, 2016	Albany, CA	Chandra Theegala	WRRC
17 =	Washington, DC	Yebo Li	NIFA
18 =		Troy Runge	

S-1041 EXECUTIVE COMMITTEE 2016

Chandra Theegala (chair)
Yebo Li (vice chair)
Troy Runge (secretary)

S-1041 SYMPOSIUM BACKGROUND

During the 2009 S-1041 meeting in Richland, WA, it was decided a short symposium (with printed proceedings) related to the objectives of the S-1041 project would enhance the annual meetings and further inform participants on topics related to the project's objectives. Eventually, these proceedings were to be posted on the S-1041 website. To this end, the first symposium was planned for the 2010 meeting at the Eastern Regional Research Center (ARS, USDA) and was to include speakers from the facility as well as the region surrounding the meeting.

Year	Symposium Title	Location
2010	Conversion Technologies for Biofuels	Eastern Regional Research Center, ARS, USDA, Wyndmoor, PA
2011	Where There's Smoke, There's Fuel: A Symposium on the Thermochemical Conversion of Biomass to Fuels	Advanced Technology and Research Center, Oklahoma State University
2012	The Science and Engineering for a Biobased Industry	National Institute of Food and Agriculture, USDA, Washington, DC
2013	none held	
2014	The Science and Engineering for a Biobased Industry	Southern Regional Research Center, ARS, USDA, New Orleans, LA
2015	Stakeholder Perspectives on the Bioeconomy	Ohio Agricultural Research and Development Center, Wooster, OH
2016	Biorefineries and Biopolymers	Western Regional Research Center, ARS, USDA, Albany, CA

S-1041
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CLOSING THE LOOP: UTILIZATION OF FOOD PROCESSING ORGANIC WASTE FOR SUSTAINABLE AGRICULTURE PEST MANAGEMENT AND BIOGAS PRODUCTION

Yigal Achmon[1,2], Jesús D. Fernández-Bayo[1,2], Joshua T. Claypool[2], Katie Hernandez[3,4], Dlinka G. McCurry[3], Duff R. Harrold[2], Joey Su[1], Ruth M. Dahlquist-Willard[3], James J. Stapleton[5], Jean S. VanderGheynst[2] and Christopher W. Simmons[1]
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Food, agriculture and energy are connected intricately. Sustainable agriculture and food processing requires recycling waste streams for beneficial processes such as soil treatment and energy production. Exploiting new energy sources that could reduce the use of fossil fuels is important for a future with sustainable energy. Renewable organic resources, such as tomato pomace (TP), can provide low cost sustainable energy. From the viewpoint of food vs energy, organic waste can be a high value energy source that does not impair food production. Additionally, food waste may be utilized for soil amendment to benefit sustainable agriculture. There is an ongoing effort to reduce the use of hazardous chemicals in soil pest management; agricultural waste amendment is one possible solution to the problem.

Through cellular respiration, soil microorganisms converted TP into different metabolites and heat. With biosolarization, there was 100% weed mortality for mustard and nightshade seeds over five days. In a high solids anaerobic digestion study, we enriched the endogenous microbial community in cattle manure to produce biogas from TP in a 30% solids digestion with a 10% organic loading rate. Biosolarization was effective by having a synergistic effect on weeds and soil pathogens by combining solar heating with microbial activity. The exploitation of agrifood waste can lead to energy recovery, soil treatment and waste management cost reduction.

INTENSIFIED DRYLAND CROPPING SYSTEMS FOR FOOD AND BIOFUEL FEEDSTOCK PRODUCTION

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Camelina has potential to substitute fallow period in the predominant wheat fallow (WW-FAL) cropping system in the Northern Great Plains. Production of biofuels on fallow land will benefit both farmers and environment without creating any “food vs fuel” crisis. In a multiple year field study (2008 to 2015), we evaluated the sustainability of replacing fallow with camelina in WW-FAL rotation with respect to agronomic, economic and energetic performance. We also examined how to improve camelina production sustainability via optimization of agronomic practices.

Replacing fallow with camelina resulted in a 13.2% wheat yield penalty; whereas, 907 kg ha^{-1} of camelina was produced. Greater and annual biomass production thus enhanced soil organic matter, higher precipitation use efficiency and protected soil against erosion in WW-CAM indicated more agronomic sustainability of this system. WW-CAM also outperformed WW-FAL by 30% greater net energy output and similar energy efficiency. Despite agronomic, energetic and ecological benefits, economic analysis revealed that at existing market prices and production costs, WW-FAL provided greater net returns to growers due to lower variable costs. There is potential to curb production costs of camelina through improving nitrogen fertilization use efficiency and reducing herbicide application. Besides lower production cost, higher grain price (the breakeven of \$0.358 kg^{-1}) and/or greater grain yield are essential to attract producers to plant camelina.

SUSTAINABLE BIOFERTILIZER FROM ANAEROBICALLY DIGESTED ORGANIC WASTES

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We compared digestate from two anaerobic digesters of different feedstocks (food waste and dairy manure) and produced solid and liquid fertilizer products for inclusion in a farm scale tomato plant growth experiment. Laboratory experiments were conducted to evaluate vibratory screening and membrane filtration and to characterize elemental flows during processing of two digestates. Solid and liquid fertilizer products were produced in a developed pilot scale integrated vibratory screen, membrane filtration and ambient drying system.

The elemental compositions of the two digestates were different but shared some similarities. Food waste digestate had higher N and Na, similar P and K, and lower Mg contents than dairy manure digestate. The coarse solids of both digestates were nutrient poor and the K and Na were present mostly in the liquid obtained following filtration with 0.45 µm membrane. The dairy manure digestate had a higher amount of fine solids between 0.45 and 75 µm than the food waste digestate but the majority of N was contained in these fine solids for both digestates. P and Mg were present in larger particle sizes for the food waste digestate than the dairy manure digestate. For fertilizer products produced with pilot scale equipment, the TKN in the liquid product for the food waste and dairy manure digestate was 2.3 and 1.2 g/L, respectively, over 90% of which was contributed by NH4-N. The dried solid products of approximately 9% moisture content contained TKN concentrations of 6.3 and 4.7% for food waste and dairy manure digestates, respectively (db).

Pilot scale production of solid and liquid fertilizer products from food waste and dairy manure digestates was completed. Tomato and corn growth trials currently are underway testing their effectiveness against organic and synthetic fertilizers at the Russell Ranch Sustainable Agriculture Facility in Davis, CA.

WASTE TO ENERGY: DOWNDRAFT GASIFICATION OF BIOMASS AND MUNICIPAL SOLID WASTES FOR MOBILE POWER GENERATION

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There is an increasing demand for low cost, small scale (50 to100 kWe) and portable electricity generation units that can utilize carbonaceous materials, such as biomass and municipal solid wastes (MSW). These units could be deployed in remote and/or energy deficit locales domestically and internationally. Areas affected by natural disasters could use these units as stand alone or supplemental electricity sources. Unlike conventional diesel/gasoline generators, which require fuel to be transported at fully burdened costs, often over 10 times local service station costs, these units would be fueled indefinitely by locally available biomass resources.

We will report development and performance evaluation of the electricity generation unit with 50 to 100 kWe nameplate output. The technology is based on a patented design that has a unique biomass pyrolysis and tar cracking conversion zone developed at Oklahoma State University (OSU). In addition to the unique reactor design, the gasifier is capable of utilizing low bulk density carbonaceous materials which can be problematic to any gasification system. Through this project, the power generation unit has been scaled up and tested with several feedstocks including switchgrass, red cedar and municipal solid wastes.

We will show effects of operational parameters on gasification and engine efficiencies. After complete evaluation, the unit will be ready for relocation to the OSU Energy Park and made available to demonstrate to potential investors and customers. The unit will be equipped for dispatchable, distributed electricity generation that is grid tied via net metering.

ENZYME RECYCLING DURING HYDROLYSIS OF SUGAR BEET FOR BIOETHANOL PRODUCTION

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The updated renewable fuel standard (RFS2, 2007) specifies an aggregate of 36 billion gallons of renewable fuel to be used in transportation by 2022, while current production remained below 17 billion gallons this year. Sugar beet in California is a promising biofuel feedstock due to its high yield and sugar content. Sugar beet contains 16 to 20% sucrose (wb), which can be fermented by various types of microorganisms, especially yeast. Additionally, the cellulose, hemicellulose and pectin contained in the beets can be used to increase ethanol yield. To accomplish this, enzymatic hydrolysis is needed to liquefy the feedstock and convert cellulosic materials to hexose and pentose for subsequent fermentation. The high cost of enzymes is a limiting factor for economic competitiveness of sugar beet ethanol. Therefore, it is crucial to develop an enzyme recycling system to reduce total enzyme usage and improve the economic feasibility on an industrial scale.

Novozymes cellulase (Cellic CTec2) and pectinase (NS22119) were added at 3 and 2 L/wet ton raw sugar beet, respectively. Enzymatic hydrolysis was performed at 20% TS loading, 50°C for 8 hr and pH was controlled at 5.0 with citrate buffer. Residual solids and supernatant were separated via centrifugation at 8,000 rpm for 30 min. Ultrafiltration with a 50kDa MWCO polyethersulfone (PES) membrane was applied to separate enzymes in the retentate stream from monosaccharides in the permeate stream. Either the solid fraction or concentrated enzyme was applied to a new batch of sugar beet together with different amounts of fresh enzyme to determine the minimum requirement of fresh enzyme to achieve similar beet liquefaction. Enzyme recycling could reduce the requirement of fresh enzyme by up to 50% with either the solid or liquid fraction; a sugar yield of 85 g sucrose equivalent/L was achieved. Further research is being carried out to optimize the hydrolysis parameters to design a continuous sugar beet hydrolysis process with enzyme recycling.

UNSUPERVISED/SUPERVISED LEARNING METHODS TO IDENTIFY MICROBIAL MICROCOMMUNITIES

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The use of microbial ecology to gain insight into biological processes has gained momentum. These efforts have been aided by advancements in next generation sequencing (NGS). NGS often targets the 16S rRNA gene of bacteria that allows us to discern bacterial taxonomy to various degrees of evolution. However even with NGS, while we may start to see shifts in phyla or identify key niches for specific types of microbial communities, we lack relationships between community members and microbial phenotypes. Some NGS methods have started sequencing metagenomes, genomes of the entire community, or metatranscriptomes, to gain insight into the genes that the community is trying to use, but these can be data intensive to navigate and expensive.

Combining NGS of small 16S rRNA datasets and measured metabolites, a hybrid unsupervised/supervised learning can begin to connect microbial community members to phenotypes. Biosolarization is the incorporation of organic material into soil between crops to increase heating during solarization, increase weed inactivation and decrease plant pathogens. We examined several unsupervised and supervised learning methods to elucidate function of microbial community members during biosolarization. The microbial communities present secrete different volatile fatty acids (VFA) which may be vital for weed inactivation but it is unknown which organisms are responsible. By using unsupervised learning techniques, the information about applied treatments were stripped away and categories were assigned using the VFA profiles. The newly assigned categories were implemented in supervised learning techniques that assigned categories based on operational taxonomic units (OTUs) as a way of examining goodness of fit. OTUs were assigned to these different categories to create microcommunities that may be responsible for the specific VFA profile assigned to them.

Using unsupervised learning methods to identify metabolite profiles and supervised learning to match community members to these newly assigned profiles, we were able to develop a new dimension in which NGS microbial community data can be paired with analytical data to create inferences into key microbes for creating microbial phenotypes. This technique will allow identification of the microorganisms that belong to microbial niches within the environment. This may have implications in design of synthetic microbial communities.

IMPACT OF ORGANIC WASTE MANAGEMENT PROCESSING ON WASTE STABILIZATION AND PRODUCT QUALITY FOR SOIL AMENDMENT

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Both anaerobic digestion (AD) and aerobic digestion or composting (AED) are two well established processes to stabilize organic wastes. However, more research is needed to improve the sustainability of these processes. Optimizing variables such as feedstock composition, time of digestion, and energy and water inputs could enhance process sustainability and quality of the final product for soil amendment. Our objectives were to a) examine the effect of feedstock C/N ratio and total solids content (or moisture content) of the process on rate of stabilization and b) assess quality and degree of stability of the digested product in terms of potential to improve soil properties. The selected feedstock, C/N ratio and inoculum type were the same for both types of digestion; however, inoculation level and total solids content varied to mimic current digestion practices. Feedstocks included model green waste (GW) and food waste (FW) mixed at various levels to obtain different initial C/N ratios.

Stabilization rate during AD experiments was monitored by measuring CH_4 and CO_2 evolution. Feedstock with a C/N of 34 and C/N of 17, had the lowest biomethane potential (BMP) at 14 days of incubation (< 65 mL CH4/g VS). Mixtures of GW + FW with C/N = 20 and C/N = 27 had an average 14 day BMP of 100 mL CH4/g VS. Maximum methane production potential (>150 mL CH4/g VS) was observed at a C/N ratio of 23. In AED experiments, different water content levels, between 60 and 80% of the fiber saturation point (FSP), for each C/N ratio were tested. Cumulative CO_2 evolution (cCER) was monitored as a stabilization indicator. Treatments with lower C/N ratio were more sensitive to excess water; mixtures with C/N ratios of 17, 20 and 23, had lower respiration rates when moisture content increased. The mixture with a C/N ratio of 20 had the highest cCER amongst all samples at a moisture content of 60% of the FSP. Treatments with GW only (C/N = 34) had a cCER of 400 mg CO_2/g dry weight, which was much lower than other mixtures likely because of the higher amount of recalcitrant compounds such as lignin and cellulose in GW. Mixtures with a C/N of 27 showed consistent cumulative respiration of 800 mg CO_2/g dry weight for all moisture levels applied.

Stability of products obtained after the digestion process was assessed with cross-polarization magic-angle-spinning nuclear magnetic resonance (13C-CP-MAS-NMR). The humification index (HI) was estimated as the ratio of aliphatic C to aromatic C. The undigested sample had the lowest HI value. The highest HI was found in the sample digested under aerobic conditions where the microbial activity was greatest. Carboxyl groups were reduced during AD, likely due to the lack of oxygen. These results provide evidence of the role of process management on waste stabilization and will be used to inform inputs to a life cycle assessment model.

DYNAMIC FLUX BALANCE MODELING REVEALS INSUFFICIENT NADH CONSTRAINING XYLOSE UTILIZATION IN *SACCHAROMYCES CEREVISIAE* AND POSSIBLE SOLUTION

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The use of lignocellulosic biomass as a feedstock for value added chemicals and fuels has become increasingly popular based on its widespread availability, sustainability and low cost. However, the production of commodity chemicals and fuels is cost sensitive. To compete with petroleum based production, conversion of both glucose and xylose to end product must be both rapid and of high yield.

Several possible bottlenecks have been implemented as contributing to the slow utilization of xylose by xylose fermenting strains of *Saccharomyces cerevisiae*. These include xylose transport, xylulokinase activity, multiple bottlenecks within the pentose phosphate pathway (PPP), and nonspecific bottlenecks caused by a shortage of cofactors in the correct redox state for xylose utilization (Jeppsson et al., 2002; Johansson and Hahn-Hägerdal, 2002; Karhumaa et al., 2005; Kuyper et al., 2005; Matsushika et al., 2012; Verho et al., 2003). To date, no consensus has been reached on which of these bottlenecks are most restrictive and most worth addressing.

We focused on the characterization of a series of novel strains of *S. cerevisiae* expressing a xylose inducible copy of STB5, a transcription factor known to regulate the PPP (Larochelle et al., 2006). Using molecular techniques and genome scale dynamic flux balance modeling, bottlenecks were identified during periods of aerobic and anaerobic culture. ZWF1 gene expression was found to be limiting in the NADPH regenerating oxidative portion of the PPP under oxygen replete conditions. This was found to have limited industrial relevance as industrial fermentations tend to focus on anaerobic growth to boost product yield.

Under oxygen limiting conditions, the specific rate of xylose consumption correlated with the culture cell density (Figure 1, panel a) suggesting that oxygen availability was constraining both respiration and fermentation. Under these conditions, respiration was constrained directly by the lack of oxygen for use as a terminal electron acceptor. Fermentation was constrained indirectly through NADH availability. NADH is produced during the respiratory TCA cycle and consumed during the conversion of acetaldehyde to ethanol (Figure, panel b). A consistent ethanol yield (0.25 g/g xylose) at both high and low xylose consumption rates was suggestive of a stoichiometric relationship between TCA cycle flux and fermentation.

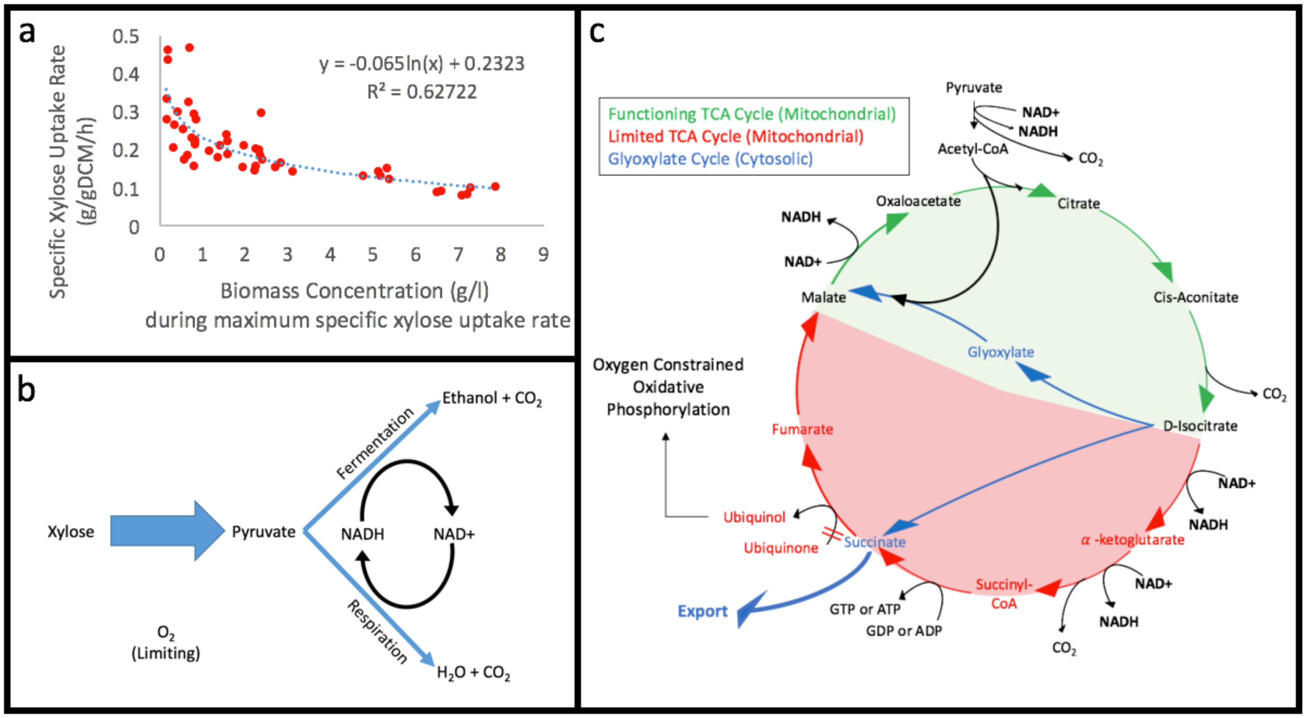

Figure 1. Panel a. Correlation between maximum specific xylose uptake rate during batch fermentation and culture cell density during measurement suggests that oxygen limits both fermentation and respiration of xylose. Panel b. NADH provides a stoichiometric link between fermentation and respiration. Panel c. Dynamic flux balance model suggests using the glyoxylate cycle to regenerate NADH and produce succinate coproduct.

The dynamic flux balance model identified the same relationship linking the TCA cycle and fermentation. Further, the model suggested that NADH could be produced via the anaplerotic glyoxylate cycle increasing ethanol production by 50% producing succinate as a coproduct at upwards of 20 g/l (Figure 1, panel c). Under normal conditions, the glyoxylate pathway experiences allosteric down regulation when intracellular succinate concentration is high. However, recently Lin et al. (2011) reported the glyoxylate pathway can be up regulated to produce high levels of excreted succinate by blocking the production of mitochondrial succinate.

In the production of high value chemicals from biomass, use of respiratory metabolism is a waste of feedstock carbon. Bottlenecks previously identified in the oxidative PPP currently are relevant only under oxygen replete conditions and cannot impact the partitioning of carbon between the respiratory and fermentative pathways. Focusing future efforts on the nonrespiratory regeneration of NADH, perhaps through the glyoxylate pathway, would improve the economics of ethanol production both directly and through coproduct formation.

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A FED BATCH APPROACH TO BIOMASS ENZYMATIC HYDROLYSIS PROCESS TO PRODUCE HIGH FINAL GLUCOSE CONCENTRATIONS

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Final glucose concentrations impact ethanol production processes, as well as industrial products that require high glucose concentration. It is critical to achieving final ethanol concentrations over 5% for the use of commercially proven technologies such as distillation for ethanol recovery. A 5% minimum ethanol concentration, in turn, requires the use of total biomass solids concentrations of greater than 20% w/w during the enzymatic hydrolysis, or simultaneous saccharification and fermentation (SSF) process (Koppram et al., 2014). However, initial solids content higher than 15% w/w pose severe mixing problems and limit enzyme action. Several challenges, such as mixing energy, solids effect, product inhibition, free water concentration and cellulase synergism and adsorption, have been identified as impediments to pursuing a high solids hydrolysis strategy (Modenbach and Nokes, 2013).

Fed batch approach has been proposed to address these challenges and meet the need of high final glucose concentration during enzymatic hydrolysis and high final ethanol concentration during fermentation. Solids loadings of 40% for wheat straw with 40% cellulose conversion in 96 hr was reported by Jorgensen et al. (2007). Bals et al. (2014) reported 36% solids loading of AFEX pretreated corn stover with 61% cellulose conversion in 72 hr. The objective was to investigate the effect of a helical impeller design combined with fed batch strategy to achieve high glucose concentrations.

Corn stover was pretreated using a dilute acid process at a pilot scale pretreatment facility of an industrial collaborator. The pretreated corn stover was washed with the 3X volume of water. Washed biomass was squeezed in a hand press to remove additional water and air dried at ambient temperatures until moisture content was 30% (w/w). Cellulose content of the pretreated and washed biomass was estimated to be 67.9% (w/w) assuming total loss of xylans, extractives and other soluble sugars. Fed batch enzymatic hydrolysis experiments were conducted in triplicate at 50°C and 5.5 pH, using CTec2 cellulase enzyme mixtures at manufacturer recommended dosing for 96 hr. A special helical type of impeller was used in the hydrolysis reactor to enable proper mixing. Enzymatic hydrolysis was initiated at 30% (w/w) solids content, and additional biomass was added to the slurry in three 5% (w/w) increments as it liquefied. The course of the hydrolysis experiment was monitored by determining the soluble sugars composition and residual suspended solids. A total of 45% biomass loading was achieved and 62.2% of cellulose in the biomass was converted to soluble sugars resulting in 205.2 g/L of soluble sugars. This, is one of the highest reported biomass concentrations used in enzymatic hydrolysis.

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FUNGAL ORGANOSOLV DELIGNIFICATION OF *Pinus taeda* SOFTWOOD FOR ENHANCED ENZYMATIC HYDROLYSIS AND LIGNIN EXTRACTION

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Softwoods, a major source of renewable lignocellulosic feedstock, have potential for conversion into fermentable carbohydrates and extraction of pure lignin. However, the recalcitrant nature of lignocellulosic biomass necessitates additional pretreatment steps. Other investigators have shown that combining biological and chemical pretreatments is an environmental friendly process to delignify and enhance the enzymatic digestibility of biomass.

We evaluated the effects of fungal and organosolv pretreatments on a) the susceptibility of pine wood chips to enzymatic hydrolysis and b) the yields of ethanol organosolv lignin (EOL). Samples of wood chips (2 to 4 mm) from *Pinus taeda* were subjected to solid substrate fermentation in the presence of white rot fungus *Trametes versicolor* for 15, 30 and 45 days. The fungal pretreated material was washed with alkali to dissolve the lignin and then hydrolyzed using a cellulolytic enzyme cocktail for conversion of glucan to glucose. In a separate experiment, fungal pretreatment was coupled with organosolv pretreatment, which was conducted at 160°C for 60 min, using 65% ethanol (v/v) and 1.1% sulfuric acid (v/v) at a liquid:wood ratio of 10:1 (v/w).

Fungal pretreatment for 45 days enriched the glucan content of pine chips by 11%. Glucan to glucose conversion in the order of 100% was obtained after enzymatic hydrolysis of both fungal organosolv and solely organosolv pretreated chips, using 15 FPU accelerase/g glucan, within 24 hr. With respect to EOL, fungal pretreatment increased the mass of recovered lignin. Lignin dissolution in the liquid fraction was 50 to 60% for fungal organosolv pretreated biomass, compared to 40% for solely organosolv pretreated biomass. Supplementing the organosolv process with fungal pretreatment did not display advantages from an enzymatic digestibility standpoint, but could be valuable in increasing lignin extraction yields from softwoods.

COMBINED CHEMICAL AND MECHANICAL PRETREATMENT TO IMPROVE SUGAR YIELDS FROM CORN STOVER

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In cellulosic ethanol production, the main goal of pretreatment is to disrupt the cell wall to increase the accessibility of lytic enzymes to cellulose and hemicellulose. Efficient pretreatment is essential for economic conversion of lignocellulosic feedstocks into monosaccharides for biofuel production. However, high severity pretreatments lead to high concentrations of fermentation inhibitors. Hot water or dilute acid pretreatment followed by disk milling is proposed to realize high sugar yields with low inhibitor concentrations.

Corn stover at 20% solids was pretreated with hot water at 160 to 200°C for 4 to 8 min with and without subsequent milling. Hot water pretreated samples were subjected to disk milling without a washing or neutralization step. Hot water pretreatment with disk milling acted synergistically to improve glucose yields by 89% and xylose yields by 134%, and reduce particle size by 90% compared to hot water pretreatment alone. Moreover, disk milling consumed 63% less energy after hot water pretreatment. Samples subjected to hot water pretreatment at 180°C for 4 min with disk milling had the highest yields of glucose (79%) and xylose (54%), which was comparable to 0.5% dilute acid at 160°C for 4 min with disk milling treated samples. However, samples subjected to a harsher pretreatment condition, 1% dilute acid at 150°C for 4 min, with disk milling had the highest glucose (87%) and xylose (83%) yields.

Hot water pretreatment conditions allowed pretreated samples to undergo disk milling without a washing or neutralization step, resulting in reduced water usage. Dilute acid pretreatment with disk milling achieved high sugar yields, but would require a corrosion resistant reactor for pretreatment and extra steps to wash or neutralize samples before disk milling. Thus, both processes present advantages for industrial application.

PRETREATMENT METHODS FOR SACCHARIFICATION OF TEMPERATE × TROPICAL MAIZE BIOMASS

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Temperate × tropical maize (TTM) is a novel bioenergy crop that has prolonged photosynthesis and vegetative growth stage. TTM accumulates stalk sugars and produces higher biomass when planted in temperate climates (White et al., 2012). The harvested TTM biomass is a mixture of structural, storage and soluble carbohydrates; therefore, an efficient process on polysaccharide saccharification for fuel conversion is needed. We investigated pretreatment methods used for efficiently hydrolyzing TTM cellulose, while retaining stalk sugars and starch for sequential fermentation.

Pollinated and nonpollinated TTM were studied for their initial sugar content and overall composition. Three types of chemical pretreatment (alkaline, diluted acid and autohydrolysis) were applied to TTM samples. Pretreated TTM biomass slurry was analyzed for soluble sugars by high performance liquid chromatography and hydrolyzed in pH 5.0 buffer with the addition of 30% (v/w) cellulosic enzymes. To determine the effectiveness of each pretreatment, the amount of cellulose hydrolyzed was calculated. Alkaline pretreatment, using 2 and 5% ammonia solutions heated to 160°C for 10 min, yielded 49.7 and 52.3% cellulose hydrolyzed, respectively. Dilute sulfuric acid pretreatment at 0.2 and 0.5% heated to 160°C for 10 min resulted in 49.4 and 73.5% cellulose hydrolyzed, respectively. Autohydrolysis using deionized water heated at 190°C for 15 min was found to be the most effective pretreatment method. It yielded 79.3% of cellulose in pretreated TTM, coupled with 74.1% starch and 68.2% stalk sugars recovered.

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TECHNOECONOMIC POTENTIALS OF BIOGAS FROM MUNICIPAL AND FOREST WASTE

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Municipal waste generation has exceeded more than 2.5 billion ton/yr globally and is alarming as it reduces the footprint by dumping/landfilling waste. Municipal waste contains 30 to 50% organics, which could be a source for biogas production. However, any commercialization effort necessitates a detailed feasibility study which is required from a technoeconomic perspective involving uncertainties around it. There is a knowledge gap regarding the operational problems in a biogas plant and the effects on a technoeconomic perspective. We focused on the logistical issues of transporting waste, capacity design and determining the cost of municipal waste streams that ensure a positive cash flow for processors. Similarly, forest residues are potential wastes generating 3.5 million tons/yr in Sweden, with biomethane of 154 Mm^3 CH_4/yr. However, forest residues are recalcitrant in nature and require an additional pretreatment step compared to municipal waste. Both feedstocks were analyzed from a Swedish perspective; however, results could be generalized to other regions of the world.

For technoeconomic analyses, Aspen Plus and Superpro Designer software packages were used. With respect to municipal waste, different scenarios were compared, including additional capacity and different upgrading (water scrubbing and chemical absorption) methods. The plant had a design capacity of 25 MT/day, which was obtained from the city of Boras in Sweden having a population of 100,000. The minimum biogas production cost was 0.76 USD/L, for a zero NPV. Economically viable plant operation was possible only with the average transportation distance less than 30 km. However, minimum economically viable collection distance and profitability are increased if additional revenues are generated through waste collection fees. Furthermore, when the organic load of the plant was reduced to 50% because of operational problems, such as delayed start up period, dead zone accumulation in the digester affected profit by 56%. About 20% of the energy produced in the plant is consumed for its internal use (Rajendran et al., 2014).

Forest residues were pretreated using organic solvents, including methanol, ethanol and acetic acid. About 20,000 tons/year of forest residues were considered the base case evaluation. Furthermore, a sensitivity analysis was carried out for different processing capacities of 10,000 to 200,000 tons/year. Capital investments for the base case scenario varied between 55 and 60 million USD depending on pretreatment method. Acetic acid pretreatment had the highest methane yield (0.34 m^3 CH_4/kg VS), but economic analysis revealed that methanol pretreatment could yield better profits compared to other organic solvents as the cost of methanol was cheaper. There was a trade off between methane obtained and methanol cost. For the base case, investments could be recovered in less than 8 yr. Also, increasing the plant capacity resulted in better profits; however, decreasing capacity to less than 20,000 tons/yr would not be economically feasible (Kabir et al., 2015).

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BIOFUELS AND BIOPRODUCTS PRODUCTION THROUGH INNOVATIVE WASTE TO ALGAE TECHNOLOGIES

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Fast growing, high oil microalgae are potential high impact biomass feedstock for advanced biofuels and bioproducts. However, many challenges have impeded commercialization of algae based technology. They include the need for large amounts of freshwater, nutrients such as nitrogen (N), phosphorous (P) and trace elements in current cultivation processes, lack of cost effective and energy efficient processes for algal biomass harvesting and oil extraction and conversion. (Xin, et al., 2016). Coupling algae production with wastewater treatment is believed to be an economically viable and environmentally friendly way for sustainable renewable algae based biofuel and biobased chemicals production since large quantities of freshwater and nutrients required for algae growth could be saved and the associated life cycle burdens could be reduced.

Our purpose was to develop a suite of technologies for mass production of microalgae on waste streams and conversion of the harvested algal biomass into drop in fuels, animal/fish food and other high value coproducts and to investigate the environmental impacts of these technologies through life cycle analysis. We expect to shed light on the technical feasibility of utilizing wastewater resources and provide an assessment of the proposed systems approach to improving the economic and environmental viability of algae based biofuel and bioproducts technologies.

First, a strategy was developed for fast local bioprospecting of robust algal stains (up to 60 strains isolated from different sampling sites, eg, lakes, rivers, ponds and wastewater treatment facilities) which adapted well in different types of wastewater resources including municipal wastewater (CMW) and swine manure wastewater (DSM). Secondly, a low capital, low maintenance cost and highly scalable multilayer hybrid cultivation systems for year round production of algae in northern climate was developed. Thirdly, an integrated swine manure based algal platform was developed for sequential biofuel and omega-3 containing algal biomass production especially for animal/fish food. Fourthly, a novel fungi assisted bioflocculation technique for low cost, efficient microalgal cells harvesting was developed. Fifthly, an integrated biorefining concept and system process for water recycling and nutrient reuse was developed. Finally, life cycle analysis of our unique wastewater based process for environmental factors during biofuel and biobased chemical production was carried out.

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BIOFUEL PRODUCTION FROM BIOMASS THROUGH SEQUENTIAL TWO STEP FAST MICROWAVE ASSISTED PYROLYSIS AND PACKED BED CATALYTIC UPGRADING

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Most research has been focused on one step catalytic fast pyrolysis where catalysts are mixed with feedstock in a pyrolysis reactor (Xie, et al., 2015; Wang et al., 2016). However, the one step process has several disadvantages, such as fixed catalytic upgrading and cracking temperature and high coke formation on the catalyst, leading to the rapid catalyst deactivation. A two step method, combining a fast microwave assisted pyrolysis (fMAP) process for biocrude production and a packed bed catalysis for bio oil upgrading in one system, was developed. Catalyst was separated from biomass but placed within the same microwave pyrolysis reactor cavity. Catalytic upgrading and cracking operations can be controlled independent of pyrolysis, enabling optimum catalyst performances targeted at the desired products under optimized reaction temperature and residence time. This also prevents the unreacted char and mineral components from contacting the upgrading catalysts, which will extend catalyst life and reduce cost.

Experiments to convert corn stover to aromatic hydrocarbons on HZSM-5 catalyst were carried out using the two step process. The effects of fMAP temperature, catalyst bed temperature and catalyst to biomass ratio on product fractional yield and selectivity were investigated. fMAP temperature of 500℃ was the optimum condition for maximum biooil yield, while the quality of biooil was a function of temperature, with higher temperature favoring the production of aromatic hydrocarbons. The two step fMAP is superior to one step fMAP in terms of amount of catalyst needed (only about one tenth) to achieve similar biooil quality. The catalyst lasts much longer and can be recycled and reactivated. The two step fast microwave assisted pyrolysis process allows more flexibility for high quality biooil production that meets the requirements for downstream processing and application.

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CHARACTERISTICS OF ACTIVATED HYDROCHARS FROM FRUIT DEHYDRATION WASTES FOR ADSORPTION AND ELECTROCHEMICAL APLICATIONS

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Environmentally benign disposal of sugar rich waste syrups generated during commercial fruit dehydration is a costly challenge but has great potential to generate activated carbons for various applications. We investigated adsorption and electrochemical characteristics of activated hydrochars produced from two waste syrups (glycerated cherry waste sugar syrup and blueberry waste sugar syrup) from a commercial fruit processing industry. The waste syrups were treated hydrothermally to produce hydrochars at 250°C in nitrogen atmosphere for 30 min. Hydrochar yields were recorded. The hydrochars were soaked in KOH solution for 24 hr. The soaked samples were heat treated at 900°C for 1 hr to produce activated hydrochars. Heat treated samples were washed with distilled water and dried.

These activated carbons are being tested for pore characteristics (porosity, pore volume distribution and surface area). Activated carbons also are being tested for adsorption of Li ion for electrochemical applications. Additionally, activated carbons are being tested for potential use as an electrode material for Li ion batteries. All activated carbons were characterized for surface properties using scanning electron microscopy, x-ray diffraction and x-ray photospectrometry.

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INVESTIGATING SOURCES OF UNCERTAINTY WITHIN LIFE CYCLE ASSESSMENT OF BIOFUEL FEEDSTOCK PRODUCTION

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While general conclusions from life cycle assessment (LCA) studies point to lower environmental impacts of biofuels; however, environmental impacts are dependent on location, production practices and local weather variations. Production of biomass feedstock, processing and several transportation stages (McBride et al., 2011) are critical steps in the biofuels and bioproducts production process. Feedstock production is a critical step due to its major contribution to environmental impacts, water consumption and total cost (Miller and Kumar, 2013; Swanson et al., 2010). Within the feedstock production stage, fertilizer use and soil emissions during farming (Kumar and Murthy, 2012) account for most environmental impacts. Soil emissions during farming are nonlinear in time and dependent on multiple stochastic factors such as weather, soil type and farm management practices (Bessou et al., 2013).

Variations in field emissions due to soil characteristics, weather related factors and crop management practices (e.g. tillage, field operations, irrigation, fertilization schedules) can be estimated using process based agrobiogeochemistry models such as DeNitrification DeComposition (DNDC) (Dietiker et al., 2010). Variations in field emissions due to stochastic factors contribute to the uncertainty in the LCA results and could be used to identify optimal growing locations and management strategies. Therefore, study goals were to investigate the sources of uncertainty within LCA of feedstock production and then quantify the effect of the uncertainties on overall LCA of biofuel production. To study the effect of heterogeneity of weather, geographical location and management practices on field emissions, four locations with identified potential for camelina production in the Northwestern United States (Corvallis, OR, Pendleton, OR, Pullman, WA, Sheridan, WY) were selected. DNDC was used to model the field emissions, openLCA v.1.4.2 software and TRACI 2.1 method were used to conduct LCA and Monte Carlo analysis was carried out to perform uncertainty analysis.

GHG emissions for 1 kg of camelina produced under common practices scenario in Corvallis, Pendleton, Pullman and Sheridan were 0.76±11, 0.55±10, 0.47±18 and 1.26±6% kg CO_2-eq., respectively. Variations in management practices affected field emissions across all locations. Although, no tillage with high residue input scenario was associated with lowest field emissions compared to other scenarios, the level of reduction varied across locations. Therefore, the variation in weather and soil characteristics are important factors in determining overall field emissions. GHG emissions for 1000 MJ of camelina biodiesel using camelina produced in Corvallis, Pendleton, Pullman and Sheridan under common practices scenario were 53.6±5, 48.9±5, 44.3±7 and 78.9±4% g CO_2-eq./MJ, respectively. LCA results are sensitive to allocation methods; the energy allocation method resulted in higher environmental impact values compared to economic allocation method. Process based crop models, such as DNDC in conjunction with

Monte Carlo analysis, are helpful tools to capture the influence of regional factors on field emissions which consequently can help in quantifying uncertainties in LCA results.

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EFFECTS OF PHYTIC ACID CONCENTRATION AND PHYTASE ADDITION ON FOULING BEHAVIOR OF STEEPWATER

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Heat transfer fouling describes the phenomenon of unwanted materials forming and accumulating on heat transfer surfaces. This can lead to a decrease in process efficiency, as fouling of heat transfer equipment increases energy consumption and maintenance costs. In the corn wet milling industry, evaporator fouling takes place when steepwater is concentrated. Steepwater is the solution resulting from the steeping process and is composed of solubilized kernel compounds, microbes (principally *Lactobacilli*) and solids from recycled process streams.

Research on corn processing fouling has been focused on the effects of steepwater solids, corn oil, pH, Reynolds number, solids concentration and carbohydrates (Agbisit et al., 2003; Singh et al., 1999; Wilkins et al., 2006ab; Arora et al., 2010; Challa et al., 2014). However, effects of phytic acid concentration or phytase addition on fouling characteristics is not known. There are reports from industry suggesting phytic acid content is correlated positively with fouling rate; adding phytase to process streams may help reduce fouling. Solubility of certain phytic acid metal complexes, the product of chelation reaction between metal ions available in corn process streams (Mg, Ca, K) and phytic acid, can be influenced by adding phytase (Ekholm et al., 2003). Bansal et al., 2006 concluded that for one of these phytic acid metal complexes (Ca) the concentration was correlated positively with fouling at high temperatures in the dairy industry.

To evaluate effects of phytic acid concentration and phytase addition on steepwater fouling behavior, experiments were conducted using commercial steepwater with different phytic acid concentrations. With phytic acid addition, sampe phytic acid concentrations were adjusted to vary from 25 to 75 mg/g sample. Fouling resistances were measured using an annular probe with a 7 L batch system. Mean fouling rate, maximum fouling resistance and induction period characterized fouling behavior. Using these results, we will provide a better understanding of phytic acid effects on wet milling fouling and provide possible solutions to fouling mitigation in the wet milling process.

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EFFECT OF MUSHROOM INOCULATION DURING SWITCHGRASS STORAGE ON DOWNSTREAM PROCESSES

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The objective was to examine the effect of combining fungal treatment during storage to that of liquid hot water pretreatment (HWP) to increase switchgrass glucose release. The fungal treatment consisted of incubating switchgrass with 0, 2 and 3% of *Pleurotus ostreatus* in square bales, maintained at 50% moisture content for 25, 54 and 82 days. The digestibility of switchgrass biomass was evaluated using Accelerase 1500 enzymes.

Of the stored material that had not undergone HWP, maximum saccharification of 39% was obtained in switchgrass incubated with 3% *P. ostreatus* for 25 days, while the control with no *P. ostreatus* returned 32% saccharification. Fungal inoculation facilitated structural carbohydrate release.

HWP after storage with *P. ostreatus* at 200°C for 10 min and 180°C for 30 min was effective in improving overall enzymatic digestibility. A maximum enzymatic digestibility of 82% was obtained for samples inoculated with 3% *P. ostreatus* that were stored for 82 days and pretreated in HWP at 200°C for 10 min. Low severity pretreatment overruled the effects of fungal pretreatment, where it was determined that 25 days of storage with fungi and 54 days of storage without fungi resulted in similar digestibilities; on average 64% enzymatic digestibility was determined. Washing with water after HWP led to decreases in digestibility. Washing after HWP conducted at 200°C resulted in a maximum of 58% enzymatic digestibility as compared to that of nonwashed material pretreated at similar severity resulted in maximum of 82% enzymatic digestibility. Washing mostly removed xylose oligomers and organic acids. Washing after HWP adversely affected the return of sugars from switchgrass.

JET FUEL HYDROCARBONS AND CHEMICALS FROM BIOMASS DERIVED LIGNIN

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A catalytic process, involving the hydrodeoxygenation (HDO) of biomass derived lignin catalyzed by high efficiency and low cost multifunctional catalysts, to produce lignin substructure based hydrocarbons (C_7-C_{18}), primarily C_{12}-C_{18} cyclic structure hydrocarbons in the jet fuel range, was demonstrated. Lignin substructure based C_{12}-C_{18} cyclohexanes are generated through the plausible cleavage of C–O–C bonds without disrupting the C–C linkages in the lignin structure and/or through coupling reactions of degraded lignin monomer. The overall carbon yield was 38.3%. When using the 2013 NREL biological design case as the benchmark process, TEA analysis showed that a corn stover ethanol plant with annual capacity of 57.2 million gallons of ethanol would be able to produce an additional 20 million gallons of lignin based jet fuel if the catalytic process is applied to upgrade the waste lignin stream. Coproduction of jet fuel from waste lignin can improve the overall economic viability of an integrated process for corn stover ethanol production. The effort would grow the biofuels industry while increasing revenues from the additional fuel produced each year. The ultimate goal is to scale a flexible catalytic process that converts aromatics from biomass derived lignin for producing fuels, chemicals and polymer materials.

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PROTEIN EFFECTS ON HEAT TRANSFER FOULING USING MODEL THIN STILLAGE FLUIDS

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Fouling is the unwanted deposition of materials on surfaces of processing equipment, which leads to additional investment, lower processing efficiency and potential fluid contamination (Lalande et al.,89). In the corn ethanol industry, fouling occurs when thin stillage is concentrated into condensed distillers solubles. Researchers have investigated operating conditions and constituents' influence on fouling characteristics of thin stillage (Challa et al., 2015; Singh et al., 1999; Wilkins et al., 2006). However, research related to protein effects on thin stillage fouling is limited despite its relatively high concentration in thin stillage (33% db) (Rausch and Belyea, 2006).

Protein contributions to fouling have been verified in the dairy industry. Whey proteins, together with phosphate-calcium, interact with each other and form aggregates deposited on heated surfaces (Bansal and Chen, 2006; Visser and Jeurnink, 1997; Wilkins et al., 2006). Maillard browning is another potential factor influencing fouling since amino acids in thin stillage are able to react with reducing sugars and form brown pigments. Proteins, as well as their hydrolyzed products amino acids, with accompanying sugars in thin stillage, contribute to fouling. Due to the diverse components in commercial thin stillage, it is difficult to study a single effect on fouling without interference from other factors.

The objective was to investigate protein effects on fouling using various model thin stillage fluids with simplified compositions. Nitrogenous substances (urea, yeasts, glutamic acid, leucine and cysteine) were mixed with glucose. Fouling was characterized by fouling resistance, induction period and fouling rate. Compared with a 1% starch model, no fouling occurred during test using glucose-urea fluids. Addition of urea reduced maximum fouling resistance by 29%. Molecular weight, as well as protein structure and properties, may affect evaporator fouling.

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EFFECTS OF TEMPERATURE CONDITIONS AND HEAT TREATMENT WITHIN A MULTIPLE EFFECT EVAPORATOR ON THIN STILLAGE FOULING CHARACTERISTICS

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Heat transfer fouling is the accumulation and formation of unwanted materials on heat transfer surfaces which leads to a decrease in the overall heat transfer coefficient. Fouling of heat transfer equipment increases energy consumption and maintenance costs and thus decreases processing efficiency. In the fuel ethanol industry, evaporator fouling occurs when thin stillage is concentrated into condensed distillers solubles. Thin stillage is the liquid fraction of unfermented materials from fermentation and is composed of carbohydrate, protein, fat and ash. Fouling affects the efficiency and environmental footprint of more than 200 US biorefineries.

Research on thin stillage fouling has been focused on effects of corn oil, pH, Reynolds number, solids concentration and carbohydrates (Arora et al., 2010; Challa et al., 2015; Singh et al., 1999; Wilkins et al., 2006a; Wilkins et al., 2006b). However, temperatures and heat treatment effects on thin stillage fouling have not been evaluated. We investigated the influence of bulk fluid (T_b) temperatures and initial probe surface (T_i) temperatures on thin stillage fouling characteristics. Experiments were conducted using model thin stillage (1% starch solution) and commercial thin stillage with varied temperature conditions.

Effects of evaporator heat treatment were studied by examining fouling behavior among samples from different locations within a multiple effect evaporator. Samples before and after plant shutdown and cleaning were collected to study effects of plant cleaning.

Commercial and model thin stillage samples exhibited increasing maximum fouling resistance and decreasing induction periods with temperature increase. Deposit sloughing took place for commercial thin stillage samples at $T_i = 120°C$ and $T_b \geq 60°C$. Three weeks following plant shut down, fouling rates were reduced and induction periods were increased. $T_i = 120°C$ and $T_b = 60°C$ are the recommended temperature conditions for future fouling tests of commercial thin stillage because of the rapid fouling and repeatable induction periods. No effects of heat treatment were detected on thin stillage fouling; therefore, condensed distillers solubles could be used as a substitute for thin stillage fouling research.

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SYMPOSIUM ORAL PRESENTATIONS

DOMESTIC NATURAL RUBBER FROM GUAYULE: A MULTIPRODUCT BIOREFINERY MODEL

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Natural rubber (*cis* 1,4-polyisoprene), produced by *Hevea brasiliensis*, is a critical agricultural material which the US sources entirely through imports from tropical countries. Faced with supply security risks from at times economically and politically unstable sources, the US has supported both public and private R&D, as well as sporadic commercialization, for a century. Yet economic sustainability has remained elusive.

Thousands of plants produce natural rubber; temperate climate crops available as alternative sources of natural rubber include guayule (*Parthenium argentatum*) and Kazakh dandelion (*Taraxacum kok-saghyz*). Guayule is a perennial woody shrub native to the Chihuahuan desert of northern Mexico and southwest Texas. It produces high quality natural rubber, organic resins and an attractive feedstock for bioenergy or biofuel conversion. Currently it is cultivated, mainly for development, on semiarid farmlands in the southwest US.

Unlike the tappable latex from Hevea, guayule plants must be ground to release the natural rubber. Solvent coextraction of low molecular weight organic resins yields a resinous material which can be used as an adhesive or further purified for various applications. The ground, high density, high energy residue, guayule bagasse, can be used for power cogeneration, for ethanol production or as a feedstock for fast pyrolysis to produce bio-oil and upgraded liquid fuels. Development of enabling technologies for coproduct utilization may allow reintroduced guayule to commercialize in the 21st century, aided by the global market pull for biobased products.

PRODUCTION OF BIOPOLYMERS FROM BIOGAS

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Biogas, while often considered a waste, is a valuable resource that should be captured and utilized to produce value added products. Mango Materials is a start up company that utilizes biogas to produce biodegradable, biobased polymers that can substitute for conventionally produced plastics. This creates an incentive for anaerobic digestion and subsequent biogas capture. In Mango Materials' process, biogas is fed to a culture of methane utilizing bacteria. Specific environmental conditions are used to trigger production of the polymer polyhydroxyalkanoate (PHA), which is harvested and utilized as a versatile biopolymer.

While commercialization of PHA has been limited by its relatively high production cost compared to petrochemical based plastics, utilizing methane as a feedstock enables PHA production at a cost on par with petrochemical-based plastics, roughly $1/lb. Mango Materials personnel have shown that production of biopolymer from methane is over five times more economically favorable than production of electricity from methane, taking into account the selling price and yield per unit methane of each. We are focused on scaling the process and producing commercial samples. In addition to numerous lab scale fermentors, Mango Materials currently has a several hundred liter system on biogas at a wastewater treatment plant in Redwood City, CA.

EXPANDING MATERIALS TO IMPROVE ECONOMY: GROW PLASTICS EXPANDED PLA

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Polylactic acid (PLA) is the most commonly used biopolymer, with over 1 billion pounds having been sold by Natureworks to date[1]; it has lower life cycle costs than conventional polymers[2]. However, this is a small percentage of total thermoplastics used in packaging. The price of end products and thermal performance of PLA have limited its market adoption.

In plastic packaging and foodservice items, the cost of a package may be up to 50% in materials. Polystyrene (PS) foam is used widely in applications because products can be produced using as little as ¼ the material compared to solid products. Processes similar to PS foaming have been explored with PLA, yet products with similar quality have not been produced.

USDA and Grow Plastics have partnered to develop and demonstrate an expansion technology at pilot scale to demonstrate high performance, low cost products from PLA. This cost efficient process has been shown to reduce material use in PLA products up to 70% compared to solid products and increase the service temperatures to 85 to 100^{o}C depending on polymer blend. A pilot line is being brought up to speed at the WRRC/ASR/USDA pilot manufacturing facility in Albany, CA. The technology may serve immediately the premium US compostable food packaging market and eventually enable the replacement of billions of pounds of petroleum based polymer with a reduced amount of compostable biopolymer materials.

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