2014
S-1041 Science and Engineering for a Biobased Industry and Economy
Poster Symposium Abstracts
Oral Presentation Abstracts

Oral and poster presentations at the S-1041 annual meeting on 4 and 5 August, 2014
Southern Regional Research Center, ARS, USDA, New Orleans, LA

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

Poster Symposium Coordinators

G. S. Murthy, Oregon State University
Mark Wilkins, Oklahoma State University
Mike Tumbleson, University of Illinois

The S-1041 Website

A complete description of the S-1041 multistate project, objectives and an electronic version of these abstracts can be found at:
http://nimss.umd.edu/homepages/home.cfm?trackID=9057

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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.

Participating Institutions

Administrative Advisor	William Brown
BCE, NIFA, USDA	Daniel Cassidy
National Agricultural Library	Peter Arbuckle
Auburn University	Oladiran Fasina
Clemson University	Terry Walker
Cornell University	Lindsay Anderson
Iowa State University	Buddhi Lamsal
Kansas State University	Donghai Wang
Louisiana State University	Dorin Boldor
Michigan State University	Carl Lira
Mississippi State University	Fei Yu
Montana State University	Chengci Chen
North Carolina State University	Stephen Kelley
North Dakota State University	Igathinathane Cannayen
Ohio State University	Yebo Li
Oklahoma State University	Mark Wilkins
Oregon State University	G. S. Murthy
Pennsylvania State University	Ali Demirci
Purdue University	Abby Engleberth
Rutgers University	Gal Hochman
South Dakota State University	Kasiviswanuth Muthukumarappan
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University of Minnesota	Roger Ruan
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University of Tennessee, Knoxville	Alvin Womac
University of Texas, Austin	Jonathan Chen
University of Wisconsin	Troy Runge
Washington State University	Bin Yang
West Virginia University	Kaushlendra Singh

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SOLVENT SELECTION FOR THE RECOVERY OF FERMENTATION INHIBITORS: COMPARISON OF SIMULATED AND LABORATORY RESULTS FOR LIQUID-LIQUID EXTRACTION

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Degraded products from lignocellulosic biomass pretreatment have proven to inhibit the fermentation process for biomass conversion to bioethanol (Almeida et al., 2007; Casey et al., 2010; Nichols et al., 2008). We focused on the practicality of liquid-liquid extraction to remove well characterized fermentation inhibitors after hydrolysis but prior to fermentation.

Aspen Plus™ was used to simulate the extraction system. To create the most extreme case of this hypothetical fermentation broth, the highest end of each concentration range, from a library of reported existing inhibitors, was incorporated.

Simulation outputs were not reliable without experimental evaluation because the method chosen could vary the simulation outlet stream composition. NRTL, UNIF-LL and UNIF-LBY were the methods examined for their ability to predict the liquid-liquid extraction system performance. NRTL results predict inhibitors are extracted in the same manner for each solvent as if they each react exactly the same with the solvent. UNIF-LL and UNIF-LBY outcomes were different from NRTL. In the results from UNIF-LL, the best solvents were ethyl acetate and butyl acetate that have the capacity of extracting most inhibitors, except a few including acetic and formic acids. UNIF-LBY results lead to a similar conclusion and split fraction trends as UNIF-LL; with different final numbers for split fractions. To verify the property method best suited to the simulation, liquid-liquid extraction experiments were carried out using a prototypical solution to remove acetic acid from the aqueous phase into the organic phase. Errors corresponding to different loadings and the different property methods were calculated.

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THIN STILLAGE FOULING IN MULTIPLE EFFECT EVAPORATORS

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In a corn dry grind ethanol plant, fouling occurs on evaporator surfaces during thin stillage concentration. Evaporator fouling is caused by materials that are present in thin stillage, ie, carbohydrates, protein, fiber, fat and minerals. Deposit formation on evaporator surfaces increases costs for energy consumption, maintenance, labor and cleaning chemicals (Epstein, 1981). Falling film evaporators are used in the food industry due to higher heat transfer coefficients at low evaporating temperatures and short residence times. They are economical, reliable, have continuous operation and can handle large volumes of process streams (Wiegand, 1971). Instead of a single effect, multiple effects are used to increase evaporator capacity and to reduce steam consumption. An operating parameter that affects heat transfer in a falling film evaporator is liquid concentration (Chen and Jebson, 1997). In most plants, total solids content in thin stillage increases as it passes through effects of a multi effect evaporator. Thin stillage is centrifuged to skim oil at the final stages of evaporation when thin stillage is concentrated enough to be called syrup. Earlier studies on the effects of corn oil on thin stillage fouling were conducted with refined corn oil (Singh et al., 1999). However, refined corn oil may not represent accurately the oil present in thin stillage. It is unknown whether thin stillage concentration in each effect and oil skimming have impact on fouling rates.

Fouling test conditions were maintained similar to the operating conditions in a typical dry grind ethanol plant. An annular fouling probe was used to study the fouling tendencies of thin stillage collected from various effects of a multi effect evaporator. Fouling resistances of oil skimmed and unskimmed thin stillage were determined. Effect of corn oil on thin stillage fouling was studied. Also, effects of carbohydrate mixtures were investigated.

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INCORPORATING *CAMELINA SATIVA* INTO WHEAT BASED CROPPING SYSTEMS

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Camelina sativa has been identified as an oilseed bioenergy feedstock (BioEnergy News, 2010), but a sustainable production for this energy crop has not been developed. There is a concern about bioenergy feedstock production directly competing for land use with food crops. Traditionally, Montana farmers used wheat fallow rotation system in this semiarid area for moisture conservation and stability of yield (Juergens et al., 2004). However, this practice has some negative consequences such as soil erosion, soil organic matter degradation and low precipitation use efficiency (Passianoto et al., 2003; Machado et al., 2006). Most soils of central Montana have shallow soil profiles with a limited water holding capacity. Once the soil water holding capacity is exceeded, nitrate and other soluble salts are leached out of the soil profile during summer fallow, resulting in ground water contamination and saline seepage (Deibert, 1986; Halvorson, 1974).

The objectives were to: 1) investigate the feasibility in developing a camelina production system by replacing summer fallow with camelina in the wheat based cropping systems, resulting in a complementarity, rather than substitution, to food crops and 2) assess the effect of this system on water use and nutrient leaching. The experiment was carried out at the Central Agricultural Research Center (47º03'30" N; 109º57'30" W; 1400 m elevation), Montana State University, near Moccan, MT, from 2008 to 2011. The experiment included fallow-winter wheat (FAL-WW), camelina-winter wheat (CAM-WW), canola-winter wheat (CAN-WW) and barley-winter wheat (BAR-WW) with three replications. All crop phases appeared in each year to avoid confounding effects of weather changes from year to year. Soil moisture was measured in the fall and spring. Br tracer was applied in a separate study to monitor water and solute movement.

From an agronomic point, producing camelina in the fallow periods of the traditional wheat based cropping systems is feasible. However, since wheat and oilseed yields can not be compared directly, and different crops have different commodity prices and production costs, economic and energy analyses will be needed to evaluate the net return and energy balance for each of the cropping systems. For the shallow soil in central Montana, the soil profile could only hold a limited amount of water, camelina-wheat rotation system may reduce excessive water carrying agrochemicals to groundwater.

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EFFECT OF HARVEST MATURITY ON CARBOHYDRATES FOR ETHANOL PRODUCTION FROM SUGAR ENHANCED TEMPERATE × TROPICAL MAIZE HYBRIDS

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For bioethanol production, a northern adapted sugar maize (*Zea mays* L.) hybrid was bred by crossing temperate × tropical maize. Temperate × tropical maize (TTM) has a prolonged vegetative growth and accumulates more sugar in the stalk compared to its respective tropical and temperate parents (White et al., 2012). Sugar concentration in the stalk was increased by preventing pollination by shoot bagging (covering) ears. Starch content was eliminated and sugar content increased to 30.1% w/w in the stalks. The whole plant biomass (grain, sugars and stover) was evaluated for ethanol production. Ethanol produced from sugars and starch was comparable between pollinated and nonpollinated TTM from milk (R3) to dent (R5) reproductive growth stages, indicating that soluble sugar contents increased correspondingly with decreased starch contents.

Temperate × tropical maize samples from both pollinated and nonpollinated treatments had high extractives. Glucan and xylan percentages were increased in nonpollinated extractive free samples. Ethanol produced from cellulosic material was similar for both treatments. Total ethanol yield (from starch, sugar and stover) was comparable from milk (R3) to dent (R5) stages and ranged from 0.20 to 0.22 g/g biomass. Pollinated TTM produced higher biomass in the field and resulted in 625 gal ethanol/acre of land. Future research in TTM could be focused on increasing biomass yield of nonpollinated TTM.

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CHEMICAL MODIFICATIONS OF COTTON BASED NATURAL MATERIALS

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Processing of cotton generates a number of coproducts, two of which are cotton burr and cottonseed hull. It would be useful to find more uses and increase their value. They contain 28 to 34% cellulose, 17 to 21% lignin, 6 to 25% hemicellulose and lesser amounts of protein and oil. Under suitable conditions, both coproducts are susceptible to chemical reactions. Examples are the formation of cellulose esters and carboxymethyl derivatives. In the case of esterification, an iodine catalyzed reaction has been found to be suitable for these materials; the process required no solvent during synthesis and entailed solvents only during workup. In the case of carboxymethylation, a mixture of carboxymethylcellulose and carboxymethylxylan was produced. These products have been characterized by NMR.

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UNDERSTANDING INHIBITION OF CELLULASE BY DILUTE ACID PRETREATMENT PRODUCED COMPOUNDS FROM SWITCHGRASS

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Cellulase is an enzyme cocktail used for the saccharification of lignocellulose. It consists mainly of endoglucanase, exocellulase and β-glucosidase. It is important in the biochemical conversion of lignocellulose because it produces the monomeric sugars that will be fermented to fuels and other chemicals. Several investigators have shown the enzyme cocktail is inhibited by compounds, such as furfural, formic acid and phenolics (Arora et al., 2013). Unfortunately, these compounds, as well as many others, most likely are produced during biomass pretreatment, an upstream step necessary in the biochemical conversion of lignocellulose for fuels and chemicals. Because of inhibitory compound release during pretreatment, pretreated biomass needs to be conditioned prior to enzymatic hydrolysis. Conditioning pretreated biomass can be done by rinsing with water (Frederick et al., 2014) or using neutralizing agent (Pienkos and Zhang, 2009). To minimize resource usage in the manufacturing of lignocellulosic streams into biobased products, it is critical to identify and understand how pretreatment produced compounds affect the cellulase enzyme system.

Switchgrass was pretreated in dilute sulfuric acid using 24 combinations of time, temperature and acid concentration, ranging from 10 to 40 min, 140 to 180°C and 0.5 to 1%, respectively. The effect of these 24 liquid hydrolyzates on the cellulase enzyme cocktail was studied. Hydrolyzates reduced activity of the cellulase cocktail, and of endoglucanase, exocellulase and β-glucosidase enzymes by 26, 100, 56, and 31%, respectively. There was a multitude of compounds in need of identification. Furfural, formic acid and yet to be identified phenolics did not inhibit the cellulase cocktail, *per se*, but inhibited endoglucanase, exocellulase and β-glucosidase when added individually to each enzyme system. The role of inhibitors is complex and not straightforward, necessitating further clarification.

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DECREASING THE SEVERITY OF CHEMICAL PRETREATMENT PROCESSES IN SACCHARIFICATION OF LIGNOCELLULOSIC BIOMASS THROUGH PRETREATMENT WITH THE WHITE ROT FUNGI *PLEUROTUS OSTREATUS*

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Severe biomass pretreatments result in production of toxic byproducts, which inhibit enzymatic hydrolysis and fermentation (Kim et al., 2013). To reduce pretreatment severities, white rot fungus, *Pleurotus ostreatus,* was seeded into square bales of Alamo switchgrass (*Panicum virgatum* L.). Bales were left in the field, exposed to weather, from March to September 2013. The laccase producing fungus is believed to degrade lignin selectively and is documented as an enzyme inhibitor (Rahikainen et al., 2011).

Bales were sampled at the bottom, middle and top in March, May, July and September. Eight of the twelve bales received a fungal inoculation at the time of baling. Biomass samples from the March inoculation were pretreated in liquid hot water at 180°C for 20 min or 200°C for 10 min. Pretreatment hydrolyzates were analyzed for acetic acid, formic acid, furfural and hydroxymethylfurfural and as well as pulsed amperometric detection for xylose and xylobiose. There was a difference between 200°C pretreated *P. ostreatus* seeded biomass and the control in acetic acid, furfural and hydroxymethylfurfural concentrations. However, there was no difference in formic acid concentration. Comparing 200°C hydrolyzates produced from *P. ostreatus* seeded to control, xylose peak heights were 1434 and 2022, respectively, while xylobiose were 0 and 257, respectively. *P. ostreatus* colonies most likely were consuming hemicellulose as substrate.

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WATER WASHED COTTONSEED MEAL FOR WOOD ADHESIVES

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Although cotton is grown primarily for its fiber, enhanced utilization of cottonseed will increase the profitability of cotton production. The interest in plant seed protein isolates as wood adhesives has resurrected recently, as these plant raw materials are considered renewable and environmentally friendly. However, the isolation of plant proteins uses corrosive reagents and it makes protein isolate based adhesives relatively expensive. To look for a relatively low cost but efficient adhesive, we tested the adhesive strength and water resistance of water washed cottonseed meal (WCM), and cottonseed protein isolate (CSPI) on maple and poplar veneers.

The adhesive behaviors of the two adhesives on maple and poplar veneers were similar, although not always identical. With a press temperature of 110°C, the adhesive shear strength and water resistance properties of WCM on both maple and poplar veneers were comparable to those of CSPI. For further improvement of water resistance of these adhesives, we tested the effect of tung oil addition on the adhesive properties of WCM and CSPI. After 2 cycles of water soaking, the adhesive strength of the two adhesives decreased 27 and 34% for the tung oil free controls, but only 5 and 7.5% for WCM and CSPI with 0.1% tung oil, respectively, as compared to their corresponding dry shear strength. The low cost preparation of WCM with comparable adhesive properties of CSPI is a workable candidate for substituting synthetic wood adhesives.

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TECHNOECONOMIC ANALYSIS OF BIODIESEL AND ETHANOL COPRODUCTION FROM LIPID PRODUCING SUGARCANE

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Biodiesel production from vegetable oils and animal fats increased during the past decade. However, limited supply of vegetable oils and animal fats with high cost of producing biodiesel prevented its widely replacing of petroleum based diesel. Due to its higher biomass yield, genetically modified lipid producing sugarcane (lipid cane) provides potential to produce biodiesel as an alternative feedstock. Technoeconomic analysis models were developed for the biodiesel and ethanol coproduction from lipid cane with 2, 5, 10 and 20% lipid content. The models were compared to the conventional soybean biodiesel process model. Models were developed using SuperPro Designer software and incorporated the composition of raw materials and products, sizing of unit operations, utility consumption and estimation of capital and operating costs.

Lipid cane can produce up to 15 times more biodiesel than soybean for each acre of land. Although the capital investment of lipid cane biodiesel process plant was 2 to 3 times higher than the soybean biodiesel process, the unit cost of biodiesel from lipid cane was lower. With the increase of lipid content in lipid cane from 2 to 20%, biodiesel production costs decreased from $3.96 to 2.74/gal. Biodiesel production cost from soybean was $3.86/gal.

BIOCHARS FROM ANIMAL MANURE AS ADSORBENTS FOR ENVIRONMENTAL REMEDIATION

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Water quality and public health impacts of animal manure produced at large concentrated animal facilities prompted the need for viable solutions for their conversion and reuse. There are a myriad of carbonaceous precursors that can be used advantageously to produce chars, due to their low cost, availability and intrinsic properties. We, at the Southern Regional Research Center, have shown it is feasible to convert animal manure into chars and activated chars used for heavy metals remediation. Toxic metals contamination of various water sources is a problem in many parts of the United States.

Both chars and activated chars produced under different processing conditions and undergoing different pre and post treatments have been characterized for their physical properties and most importantly their ability to adsorb metal ions. These properties depend on manure source and we have determined that poultry manure based chars and activated chars exceed those sourced from coal, wood or coconut shells in their ability to remove heavy metals from solution. Depending on the end application, acid washing or water rinsing treatments to reduce ash content often have no effect in the ability of the activated char to adsorb copper ions; however, affected were surface area, pH and ash and carbon contents. Positive correlations were found between copper uptake and concentration of certain elements in the activated char such as phosphorous, sulfur and calcium. An estimated cost of production for the manure based value added chars and activated chars under different post treatment scenarios will be reported.

COMPARISON OF SOLID STATE ANAEROBIC DIGESTION AND COMPOSTING OF YARD TRIMMINGS WITH EFFLUENT FROM LIQUID ANAEROBIC DIGESTION

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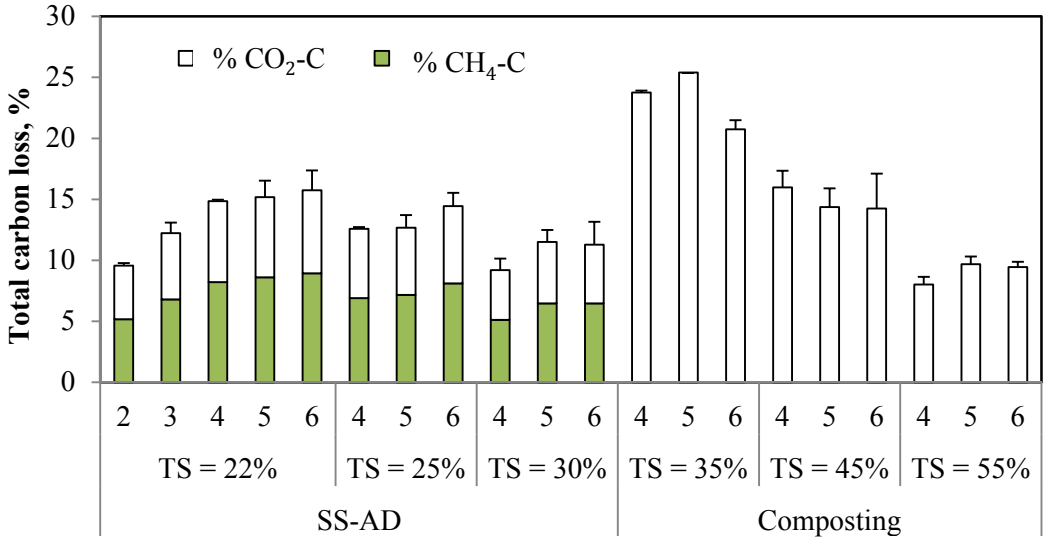
Solid state anaerobic digestion (SS-AD) and composting are two methods used for the processing of liquid anaerobic digestion (L-AD) effluent. However, no direct comparison of these two methods has been conducted. SS-AD and composting of yard trimmings with effluent from liquid AD were compared under thermophilic conditions. Total solids (TS) contents of 22, 25 and 30% were studied for SS-AD, and 35, 45 and 55% for composting. Feedstock/effluent (F/E) ratios of 2, 3, 4, 5 and 6 were tested. In composting, the greatest carbon loss was obtained at 35% TS, which was 2 to 3 times carbon loss at 55% TS and was up to 50% higher than carbon loss in SS-AD. In SS-AD, more than half the degraded carbon was converted to methane with the greatest methane yield of 121 L/kg VS feedstock. Methane production from SS-AD was low at F/E ratios of 2 and 3, likely due to inhibitory effect of high concentrations of ammonia nitrogen (up to 5.6 g/kg N). N-P-K values were similar for SS-AD digestate and compost with different dominant nitrogen forms.



PINUS TAEDA L. SACCHARIFICATION

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Managed pine forests, located in the southern regions of Arkansas, have been a major source of income, providing product to the timber and pulpwood industries. However, since 2006, there have been decreases in lumber and pulpwood prices, thereby adding economic stress. An alternative venue was to utilize pinewood as biomass for coproduct production (Adams et al., 2014) and cellulosic ethanol (Marzialetti et al., 2008). Unlike other biomass sources for ethanol, such as corn, switchgrass and hardwood trees, pine, along with other softwoods, are recalcitrant to traditional methods of dilute acid pretreatment and enzymatic hydrolysis. Our objective was to manipulate the traditional dilute acid pretreatment by varying time, temperature and water rinsing of solids (post pretreatment), to optimize sugar yields and decrease unwanted production of inhibitory degradation compounds.

Pine biomass was ground to 2 mm in length and pretreated in a 1 L Parr reactor with 1% dilute acid for 60 min. Tested temperatures were 140, 150 and 160°C. Saccharification of wet 160°C pretreated biomass with HTec enzymes resulted in the recovery of 70% glucose. Concurrently, ground pine biomass was pretreated in the 1 L Parr reactor with 160°C, 1% dilute acid for 30 min and rinsed with 0, 5, 10 or 30× volumes of water and saccharified with Accelerase 1500 enzymes. A minimum of a 5× volume rinse was necessary to initiate glucose recovery. No rinsing resulted in reduced saccharification. High pressure liquid chromatography analysis of enzymatic hydrolysis cocktail, detection at 210 and 280 nm 0.005 M sulfuric acid with BioRad 87-H column flowing at 1 ml/min, showed there was a reduction in formic acid, acetic acid and hydroxymethylfurfural concentrations in rinsed biomass enzymatic hydrolyzates. As in poplar hydrolyzates, presence of gallic acid, vanillic acid, 4-hydroxybenzoic acid and salicylic acid were detected in pine enzymatic hydrolyzates; however, there remained unidentified peaks (Frederick et al., 2014).

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DEVELOPEMENT OF LIFE CYCLE IMPACT ASSESSMENT METHOD BASED ON GLOBAL BIOENERGY PARTNERSHIP INDICATORS

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Intensive use of agricultural inputs in modern agriculture has led to new questions about the long term sustainability of proposed advanced biofuels. In this context, it is imperative to assess the long term sustainability of the biofuel pathways. Life cycle assessment (LCA) is one of the commonly used techniques in scientific literature to assess the sustainability of biofuel pathways. The LCA method consists of goal and scope definition, life cycle inventory, life cycle impact assessment and life cycle interpretation steps.

Within the LCA community, various impact assessment methods have been developed to quantify environmental impacts of hundreds of flows cataloged during the life cycle inventory phase of an LCA. Traditionally, LCA methods were developed to assess different industrial products and processes and this was reflected in the methodological choices used in the LCA Impact assessment phase. Therefore many of the impact assessment methods did not incorporate quantitative metrics for water, nitrogen and phosphorous use in biofuels.

Our goal was to develop an impact assessment method that incorporates quantitative metrics for water, nitrogen and phosphorous use during biofuels production into the global bioenergy partnership (GBEP) sustainability indicators. Water, nitrogen and phosphorous use metrics will be defined based on a concept similar to return on investments used in process economics to assess the impact of feedstock and biofuel production processes. Development of these methods can aid in decision making pertaining to water usage and quality standards with a particular focus on biofuel feedstock crops. Following the GBEP guidelines "sustainability indicators for bioenergy" we will be developing an OpenLCA method that accounts for environmental, social and economic impacts of biofuels and their feedstocks.

CORN ETHANOL PRODUCTION IN THE US: LAND USE, CORN GRAIN YIELD, ETHANOL PROCESSES AND COPRODUCT UTILIZATION

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The system for producing yellow corn grain is well established in the US, but its role among other biofeedstock sources should be balanced with its predominant purpose for human and animal food as well as economics, land use and environmental stewardship. We modeled land usage attributed to corn ethanol production in the US to evaluate effects of anticipated technological change in corn grain production, ethanol process methods and livestock nutrition through a multidisciplinary approach (Mumm et al., 2014). Seven scenarios were evaluated: four considered advances in corn grain production, two focused on improved efficiencies in ethanol production and one reflected inclusion rates of ethanol coproducts (eg, DDGS) in diets for dairy cattle, pigs and poultry. For each scenario, land area attributed to corn ethanol production was estimated for three time periods: 2011 (current), the period at which the 15 billion gallon Renewable Fuel Standard limit for corn ethanol was reached and 2026 (15 years from 2011).

Although 40.5% of corn grain was utilized for ethanol processing in 2011, only 25% of US corn acreage was attributable to ethanol after accounting for coproduct utilization for animal use. By 2026, land area attributed to corn ethanol production was reduced to as little as 11% depending on corn grain yield associated with the four corn production scenarios and considering oil replacement associated with the soybean meal substituted in livestock diets with DDGS. Increased efficiencies in ethanol processing, while producing more ethanol per bushel of corn processed, resulted in lower coproduct production and therefore increased corn acreage. Shifting DDGS use in animal diets to dairy cattle, pigs and poultry reduced land area attributed to corn ethanol production. However, because DDGS substitutes at a higher rate for soybean meal, oil replacement requirements intensify and land use estimates are elevated. It is important to account for anticipated technological changes in the corn ethanol system in order to understand associated land base ascribed. This approach may aid in calibrating parameters for land use models in biofuel life cycle analyses.

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SYNERGIES OF BIOMASS DENSIFICATION AND BIOCHEMICAL PROCESSING

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Pelleting biomass for cellulosic biorefineries has benefits for reducing transportation costs, required storage area, road wear, logistical hurdles and handling costs. Pelletization has been somewhat overlooked for biochemical processing because of the cost of densification. Such analyses, however, do not factor in the economic benefit of reducing pretreatment costs and enzyme loadings when using pelleted biomass. Standard thermochemical pretreatments are more severe and expensive than needed to produce high yields of fermentable sugars from pelleted biomass.

Pelleting increases baseline (no pretreatment) hydrolysis yields from switchgrass (Rijal et al., 2012) and corn stover (preliminary data) by 2 to 3 times, opening the opportunity for reducing downstream processing technologies. After soaking in aqueous ammonia (SAA) pretreatment, hydrolysis yields increased from less than 70% of theoretical to greater than 90% when using pelleted material. Further, we produced glucose yields greater than 90% from switchgrass pellets using reduced a severity SAA pretreatment, lower enzyme loadings and shorter hydrolysis times compared to results using nonpelleted material (Nahar and Pryor, 2014). We demonstrated these process synergies using switchgrass with alkaline pretreatments and have made initial estimates of the economic benefit which show a 13% overall cost reduction in producing fermentable sugars. Pelleting corn stover enabled a two fold increase in SAA solid loading without impacting subsequent hydrolysis yields.

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EFECT OF CHEMICALLY PRETREATED RICE STRAW HYDROLYZATES ON SUBSTRATE SACCHARIFICATION

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Globally, rice straw represents 23% of agricultural wastes and is a potential feedstock for cellulosic biofuel production, especially in countries such as India, where extensive land use changes would be unsustainable (Lal, 2005). Chemical pretreatment of rice straw is an essential process for solubilization of hemicellulose and improving yields of subsequent enzymatic hydrolysis. However, byproducts of lignocellulose degradation are inhibitory to cellulases and decrease efficiency. Inhibitor removal with water increases water consumption 3 to 6 fold (Rajan and Carrier, 2014; Frederick et al., 2014). Inhibitors lead to increase in enzyme costs and decrease in commercial feasibility. Efforts were made to characterize inhibitors found in rice straw prehydrolyzates and determine their role in commercial cellulase inhibition. Rice straw was subjected to hot water and dilute acid pretreatments; the resultant hydrolyzates were tested against the saccharification of model substrates by a commercial cellulase cocktail and individual enzymes, namely; β-glucosidase, endocellulase and exocellulase.

Hot water hydrolyzates were inhibitory to cellulolytic enzymes; an inhibitor loading of 35 mg/mL caused 82% decrease in filter paper activity of Cellic® CTec2, a commercial cellulase cocktail. At 15 mg/mL of inhibitor, CMCase activity of endocellulase was reduced 77% and exocellulase specific activity was reduced 84%. B-glucosidase was inhibited the least with the reduction in specific activity of 49% at 35 mg/mL inhibitor loading.

Hot water hydrolyzates of rice straw contained higher quantities of xylooligosaccharides and phenolic compounds, as opposed to the dilute acid hydrolyzates. LC/MS analysis of hot water hydrolyzates revealed lignin-saccharide complexes postulated to be inhibitory to cellulases. Inhibitions of cellulases were determined to be affected by the pretreatment conditions and as well as the composition of the pretreatment hydrolyzates. Identification of the most inhibitory byproduct and determination of its inhibition constant, would be an effective strategy for improving pretreatment conditions and as well as yields of enzymatic hydrolysis.

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SEPARATION OF XYLOSE OLIGOMERS FROM AUTOHYDROLYZED *MISCANTHUS* × *GIGANTEUS* USING CENTRIFUGAL PARTITION CHROMATOGRAPHY

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Xylose oligomers were produced from *Miscanthus* × *giganteus* using hot water pretreatment, at 180°C, for 20 min (Chen et al., 2014). Oligomers, ranging from xylobiose (DP2) to xylohexose (DP6), were produced. Crude oligomer hydrolyzate was separated from pretreated biomass by centrifugation. Xylose oligomers, DP2 to DP6, represented 33.9% (w/w) of dried oligomer hydrolyzate. Xylose oligomers were distributed as, 22.4, 5.5, 3.6, 0.8, 0.6 and 1.0% of DP1, DP2, DP3, DP4, DP5 and DP6, respectively.

Crude hydrolyzate was fractionated by a centrifugal partition chromatography (CPC) with a solvent system composed of 4:1:4 (v/v/v) butanol:methanol:water. Operating in an ascending mode, xylose oligomers were separated between the butanol rich mobile phase and the methanol-water rich stationary phase, at a flow rate of 8.14 mL/min. Xylose oligomers were eluted between 62 and 240 min. Eluted fractions were consolidated into DP1 to DP6 fractions based on their degree of polymerization.

Of the 339 mg of xylose oligomers, available in 1 g of dry sample, a total of 282 mg was recovered with CPC. Individual oligomer recoveries were 87.4% DP1, 71.1% DP2, 74.4% DP3, 91.3% DP4, 73.3% DP5 and 86.0% DP6. Percent purities of DP1 to DP6 fractions were 91.3, 64.3, 65.0, 47.7, 38.7 and 54.7%, respectively. The ESI–MS further elucidated the presence of sodium and potassium adducts of xylobiose and xylotriose, in the purified CPC fractionates. This is the first investigation on CPC purification of xylose oligomers directly from crude biomass hydrolyzates.

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EFFECTS OF ENZYME COMBINATIONS ON INCOMING CORN VARIABILITY IN DRY GRIND PROCESSING

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Variation in incoming grain quality impacts ethanol yields and quality of distillers dried grains with solubles (DDGS) in the dry grind industry. Parameters causing grain quality variation are test weight, percent stress cracks, unit density, moisture content and kernel weight, as well as starch, protein and oil contents. Industry wide losses in ethanol yield due to grain quality are estimated to be 0.5 billion gal/yr where freshly harvested corn and year end corn results in a lower ethanol yield compared to corn processed 2 to 3 mo after harvest (Singh, 2012). Our objectives were to monitor biweekly variation in dry grind ethanol yields for corn obtained from an ethanol plant for one year and to determine the effects of different enzyme treatments on ethanol yield variation. Laboratory based conventional dry grind procedures were followed and different liquefaction and saccharification enzyme combinations were used. Two liquefaction enzymes (optimum pH 5.8 and 5.1, respectively), a saccharification enzyme (optimum pH 5.0) and a protease enzyme resulted in four combinations (I, II, III and IV).

Ethanol yields during the first month of the study were lowest, ranging from 16.6 (I) to 17.1% v/v (IV) compared to the yields from the following 3 mo. Residual starch contents in DDGS were highest during week 1, ranging from 14.9 (II) to 9.9% v/v (IV). Highest ethanol yields were observed during week 13 (4^{th} mo) and corresponding residual starch contents were lowest. Enzyme combination IV resulted in a mean ethanol yield of 17.47% v/v during a period of one yr. This was higher by 0.28, 0.15 and 0.09% compared to combinations I, II and III, respectively. Use of proper enzyme combinations can help mitigate corn quality effects on ethanol yields and residual starch contents in DDGS.

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MAXIMIZING LACTIC ACID PRODUCTION FROM ANAEROBIC DIGESTION OF FOOD WASTE

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Anaerobic digestion (AD) can provide a renewable source of methane but the intermediate carboxylic acids produced in fermentation are higher value products and are producible with shorter retention times. Prior research into acid production of AD has been with the aim of maximizing methane production; high acid concentration can inhibit methane production (Demirel et al., 2002). As a result, maximum achievable acid concentrations have yet to be determined; a factor which is critical to evaluating their recovery. When highly soluble carbohydrates are digested, lactic acid becomes a dominant intermediate (Balch et al., 1957). Lactic acid has a growing demand in the production of polylactic acid (PLA); a polymer used predominantly in 3D printing and service ware. PLA has the benefit of being either recyclable or biodegradable. The selling price of lactic acid is fourteen times that of methane (ICIS, 2006; EIA, 2012). The amount of food wasted in the US has increased since 1980 to more than 25.9 M tonnes/yr (EPA, 2007). Food waste offers a source of highly soluble carbohydrates for AD lactic acid production.

We focused on the use of food waste and primary sludge as AD substrates for lactic acid production. With batch experiments, we explored the effect of solids loading rate, pH, temperature and retention time to maximize lactic acid concentration in the final product. A Box-Behnken surface response design was used for the experimental set up and analysis. Lactic acid concentrations of up to 48 g/L were achieved with the possibility that even higher concentrations are obtainable.

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OIL CROP WASTE BASED MEDIA FOR ENHANCED HIGH VALUE METOBOLITES ACCUMULATION VIA MICROALGAE

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The aim of this study was to evaluate the use of hydrolysates from acid hydrolysis of four different oil crop biomass residues (OCBR) as low cost nutrients for fast algae cultivation and high value PUFA production. Optimal pretreatment conditions for maximal nutrients release (TN, TP, NH4-N, TOC etc.) were found to be 3% sulfuric acid, 90°C and 20 hr for hydrolyzing through Box-Wilson Central Composite design (CCD). The two algae strains, namely UM258 and UM268, showed faster algae growth with maximal algal biomass yield and lipid content of 2.7 and 3 g/L, and 54 and 35%, respectively, in 5 days cultivation using OCBR as the sole nutrient media. Moreover, up to 18% of EPA was detected at an optimized temperature of 20°C in late stationary phase for UMN258, and protein level remained similar of 45 to 52% of algae biomass dry weight. OCBR media clearly are excellent alternative media for algae growth and have potential for large scale production of algae based high value food, feed and pharmaceutical products.

PARTITION COEFFICIENTS FOR COMPONENTS OF ESSENTIAL OIL FROM *PINUS TAEDA* L. EXTRACTS USING CENTRIFUGAL PARTITION CHROMATOGRAPHY

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Loblolly pine is an important lignocellulosic biomass species in southeast US. Research attention has been focused on the ability to produce timber as the species makes up a large fraction of the US industrial roundwood production (Smith et al., 2009). Conversion of lignocellulosic biomass to fuels and chemicals requires a pretreatment step that releases a plethora of compounds, often which are inhibitory to the enzymatic hydrolysis of cellulose into monomeric sugars and fermentation into biobased chemicals. Inclusion of bark and needles often leads to an increase in inhibitory compounds (Djioleu et al., 2013). Some compounds present in bark and needles have industrial importance, and could warrant extra cost associated with removal prior to conversion. Arkansas pine needle essential oil was reported to contain: α-pinene (0.52 to 1.02 mg g^{-1}), β-pinene (0.04 to 0.67 mg g^{-1}), limonene (0.00 to 0.06 mg g^{-1}), terpineol (0.01 to 0.18 mg g^{-1}) and (-) caryophyllene (0.02 to 0.52 mg g^{-1}) (Adams et al., 2014).

We investigated the possibility of separating terpineol, β-pinene and α-pinene by centrifugal partition chromatography (CPC) techniques. CPC uses a solvent system, which consists of two liquid phases, to separate components. The partition coefficient, K, is ratio of the peak area of the top phase compared to the peak area of the bottom phase. Partition coefficients were determined for three solvent systems: 1) hexane:acetonitrile (1:1, v/v), 2) hexane:ethanol:water (6:5:1, v/v/v) and 3) hexane:ethyl acetate:ethanol:water (1:1:1:1, v/v/v/v). K values for terpineol, β-pinene and α-pinene in the solvent system hexane:acetonitrile (1:1, v/v) were 0.60±0.01, 1.02±0.22 and 6.16±3.20, respectively. The hexane:acetonitrile (1:1, v/v) solvent system will be used to separate essential oil components using CPC.

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EFFECTS OF TORREFACTION AND DENSIFICATION ON SWITCHGRASS PYROLYSIS PRODUCTS

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Torrefaction and densification are two pretreatments that have been used to improve the properties of biomass. Torrefaction is a thermochemical process that occurs at 200 and 300°C in an inert atmosphere. During torrefaction, the biomass (primarily hemicellulose and cellulose) decomposes resulting in a hydrophobic product with reduced oxygen content and improved energy content and grindability (Chen and Kuo, 2011; Srinivasan et al., 2012). Densification converts loose biomass into pellets with more geometrical uniformity and higher bulk density (Karunanithy et al., 2012). A combination of torrefaction and densification may improve properties making the biomass more suitable for conversion into fuels and chemicals. The objective of this project was to investigate the effects of torrefaction temperature and densification on the pyrolysis product of switchgrass at temperatures ranging from 500 to 700°C. The pyrolysis behaviors of raw switchgrass and switchgrass with four pretreatments (torrefaction at 230 and 270°C, densification, and torrefaction at 270°C followed by densification) were studied using a pyroprobe attached to a gas chromatogram mass spectroscopy (Py-GC/MS).

Torrefaction pretreatment resulted in an increase of anhydrous sugars and phenolics when pyrolyzed. As torrefaction temperature increased from 230 to 270°C, anhydrous sugars and phenolics content increased. Torrefied switchgrass produced slightly higher amounts of furans than raw switchgrass at 500°C. High torrefaction temperature (270ºC) promoted the conversion of lignin oligomers, such as guaiacols and syringols, into phenolics at pyrolysis temperatures of 600 and 700°C. Higher pyrolysis temperature favored the conversion of aromatic compounds. Densified switchgrass produced less anhydrous sugars and more furanics than nondensified switchgrass when pyrolyzed at 500°C. However, no differences were observed in compositions of pyrolysis product between densified and nondensified switchgrass at 600 and 700°C.

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AN EFFICIENT NONTRADITIONAL METHOD OF DIRECTLY CONVERTING A COTTON FIBROUS MATERIAL INTO A WOVEN LIKE HYDROENTANGLED NONWOVEN FABRIC

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The traditional technology of producing cotton fabrics is comprised of about 20 mechanical and chemical processes that are costly, slow, somewhat inefficient and environmentally unfriendly. A modern system, using fewer preparatory processes, of fabricating hydroentangled cotton and cotton blend fabrics can produce a woven like nonwoven fabric at 150 meters per minute, compared to only about 5 meters per minute via the traditional yarn spinning and weaving technologies. Although the hand and drape of these nonwoven cotton fabrics are still unsatisfactory and challenging to attain, the reasonably acceptable functional attributes of these fabrics show potential and advantages over the traditional fabric forming technologies, provided an exhaustive global research and marketing support is devoted towards resolving the genuine problems of the fabric feel, drape and uniformity.

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LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCTON FROM CANOLA AND CAMELINA IN THE PACIFIC NORTHWEST

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Canola and camelina are two important proposed bioenergy crops for the Pacific Northwestern US. Production of biofuels, such as biodiesel produced from camelina and canola, can promote energy independence and revive local economies. Additionally, biofuels can have lower environmental impacts compared to fossil fuels. Life cycle assessment (LCA) can be used to quantify the environmental impacts of biofuels. While general conclusions from LCA studies point to lower environmental impacts of biofuels, it has been shown the environmental impacts are dependent on location dependent production practices.

In the LCA community, it is recognized that nitrous oxide emissions from the fields contribute a large percentage of the greenhouse gases (GHG) emitted during agricultural production. These emissions are dependent on various management practices, such as dose and timing of nitrogen fertilizer, tillage practices and irrigation schedules, in addition to soil characteristics and stochastic climatic factors such as temperature, soil moisture and rainfall. However, the comparative magnitude of the variations in nitrous oxide emissions due to these factors is not known. Hence the goal of this study was to assess the environmental impacts of biodiesel production from canola and camelina in the Pacific Northwest US using OpenLCA software to estimate the variations in GHG emissions due to variations in soil properties and annual weather patterns. Impact assessments were conducted using TRACI method using impact categories such as climate change, eutrophication, acidification, photochemical oxidation and ecotoxicity. Additionally, emissions and energy balance were estimated in three different stages including: 1) crop production, 2) oil extraction and 3) biofuel production to identify the process steps with the highest environmental impact metrics.

OPTIMAL USE OF FOOD WASTE AND MANURE IN NEW JERSEY

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Waste to energy (WTE) facilities have great potential in making maximal use of the increasing amount of waste in modern society. While current research focuses on a certain technology or specific aspects of the technology (Bernstad et al., 2011), life cycle analysis for household food waste (DEFRA, 2007), modern waste incineration in Europe (Whyte et al., 2001) for cost analysis using anaerobic digestion technology and many more), we developed a broader comparative framework and analyzed the electricity generation capacity, as well as the economic and financial benefits and costs, of alternative WTE technologies. To this end, we used food waste and manure generation data from New Jersey and developed an integrated program to analyze four theoretical scenarios: direct combustion, landfill to gas, composting and anaerobic digestion.

When calculating productivity, we estimated methane yield and corresponding green electricity generation using an integrated simulation program. Anaerobic digester with gas collection facilities generate the largest amount of methane and green electricity generation per unit of waste. In total, WTE facilities can supply hundreds to thousands of local households with green electricity. In the economic analysis, landfill to gas is the least costly method to consume a unit of waste and has the highest net revenue income stream. In comparison, direct combustion is the most costly method.

Composting and landfill to gas are the two favorable methods of treating food waste and manure on a large scale. From the aspect of land scarcity and reducing carbon footprint, anaerobic digestion has great potential to New Jersey municipalities. While discussing the limitations of the simulation analysis, we lay a foundation for further study. Regulatory recommendations also are provided to decision makers in waste management facilities.

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A NOVEL TECHNIQUE FOR ENZYME PRODUCTION IN TRICKLE BED REACTORS

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Two reactor systems are used generally for producing industrial enzymes with filamentous fungi, submerged fermentation (SmF) and solid state fermentation (SSF). SmF can be controlled easily for continuous enzyme production, but suffers from high shear forces on cells, protease formation and high viscosity. SSF mimics the natural environment for the growth of filamentous fungi, which results in high enzyme production but environmental factors in SSF reactors are difficult to control and mixing is limited. A trickle bed reactor (TBR) combines favorable aspects of both SmF and SSF but rapid production of fungal biomass can quickly clog the TBR.

To restrain excessive growth and prevent reactor clogging, a novel technique was implemented. We used an *Aspergillus nidulans* strain that produced heterologous xylanase B (XynB) as a client protein and was modified with a marker making it auxotrophic for pyridoxine. When pyridoxine was present in the medium, uncontrolled mycelium growth led to reactor clogging and the TBR was shut down after 7 days. However, when pyridoxine was removed from the medium, the TBR operated continuously for 18 days and achieved a XynB output concentration of 41 U/ml with an influent/effluent flow rate of 0.5 ml/min and a recycle flow rate of 56 ml/min.

Production yields were 1.4 times greater than a static tray culture and similar to SmF culture. Our technique allowed for continuous enzyme production with simple monitoring and control while maintaining the mycelium structure of *A. nidulans* and high enzyme yields. Also, the use of a nutrient marker to restrain growth diverted more substrate to enzyme production, thus boosting enzyme yields. This system can be scaled up and used to produce a variety of enzymes that are produced by filamentous fungi.

AUTOMATED HANDLING AND STORAGE OF SWITCHGRASS IN BULK FORMAT

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A bulk handling facility was designed and constructed to provide the capacity to receive, store and discharge bulk materials obtained from the field harvest, as part of a funded DOE high tonnage project. The unique facility allowed for data collection applicable to biomass depots. It also applies to systems at the throat of biomass conversion facilities, whether the feedstock supply originated in the field as bulk format or bale format. Use of the facility in this project addressed capabilities and capacity for herbaceous biomass regarding storage capacities, conveyance rates, reclaim rates, dust collection rates and energy per unit mass conveyed. Prior to tests conducted in this project, these basic data were not widely available.

Two large diameter (18.3 m) storage bins were used as proxies for a large storage stack envisioned for widespread commercial adoption. The bins accommodated a nominal fill height of 24 m to correspond with a tall stack to achieve overburden confining pressures and resulting bulk densities. Bins were analyzed as "very large core samples" that offered controlled test conditions for documentation of numerous variables. Bins had bottom sweeping auger reclaimers that dug into SG packed due to the overburden, and conveyed the reclaimed SG to a central discharge point underneath the bins. Bins with reclaimers were used as proxies due to project funding constraints.

The facility allowed for testing the receiving operation with a 9.1 m diameter pit, and its associated reclaimer, and the interface between mechanical and pneumatic conveyance systems. Both negative pressure and positive pressure pneumatic conveyance systems were used to demonstrate the operation of both conveyance principles. Monitored augers metered material being conveyed into the conveyance systems. A dust control system was integrated.

Extensive electronic data collection was performed through appropriate monitoring of sensors and controls integrated into the bulk handling system. Energy use per unit mass (ton) were obtained by validating mass flow rates through mass collection over measured time periods. Typically, truck or trailer loads were collected and weighed with on site commercial scales.

Handling experiments were conducted with switchgrass harvested with forage harvester (field chopped, FC) and with switchgrass prepared by tub grinding large square bales of switchgrass with two different screen combinations to produce coarse tub ground (CTG) and fine tub ground (FTG). There was higher bin reclaimer activity for CTG than FTG; FTG was higher than FC reclaimer activity. Zero or near zero values of reclaimer activity was consistent for FC whether the bin was full or had a partial load. Dry flow rates discharged by the reclaimer under partial bin load conditions were 37.8, 4.4 and 5.6 DM g/h for FC, CTG and FTG switchgrass, respectively. Physical properties of materials were measured for comparisons.

FAST MICROWAVE ASSISTED CATALYTIC GASIFICATION OF BIOMASS FOR SYNGAS PRODUCTION AND TAR REMOVAL

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Biomass is a carbon neutral energy source (McKendry, 2002) and efficient uses of biomass are considered promising in the future energy portfolio (Richardson et al., 2012). Among utilization technologies, syngas production from biomass gasification is considered as an attractive route to produce chemicals, biofuels, hydrogen and electricity (Damartzis and Zabaniotou, 2011).

Microwave irradiation is an effective heating method and has been applied to fast biomass gasification for syngas (H_2 + CO) production and tar removal, with Ni/Al_2O_3 as the catalyst. More than 80% of gas can be obtained; only 34 compounds were detected in the tar with the catalyst. Catalyst characterization also indicated good stability of the catalyst during the gasification process.

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LIQUID HYDROCARBONS FROM BIOGAS VIA REFORMING, SYNGAS CLEANING AND CATALYTIC CONVERSION

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Biogas components are composed mainly of CH_4 and CO_2. Landfills CH_4 content is from 45 to 55%, CO_2 from 30 to 40% and N_2 from 5 to 15% (Rasi, et al., 2007). Biogas from sewage digesters contains 55 to 65% CH_4, 35 to 45% CO_2 and 1% N_2 while biogas from organic waste digesters contains 60 to 70% CH_4, 30 to 40% CO_2 and 1% N_2 (Lau, et al., 2011). The primary considered usage of biogas is as internal combustion engine (ICE) fuel, but the high CO_2 concentration decreases its energy value and limits engine peak power (Nathan et al., 2010). Furthermore, unstable engine performance and high CH_4 concentrations in the exhaust will arise in engines with low loads (Komiyama et al., 2006). Efforts have been performed to remove CO_2 from the biogas before it is used as ICE fuel; however, this may increase the process cost and decrease its availability in power generation and in transportation (Nathan et al., 2010). Biogas has been studied to produce hydrogen as fuel cell feedstock; high purity is required which makes the process unprofitable (Vasileiadis et al., 2004). Another promising approach is reforming biogas to syngas and generate liquid hydrocarbons through FTS. High concentrated syngas could be obtained from biogas partial oxidation. After conditioning, biosyngas met the industrial requirement for Fisher-Tropsch synthesis. The developed catalyst had excellent catalytic performance, resulting in over 70% CO conversion and 40% liquid fuels selectivity. Liquid fuels possessed a similar property to commercial diesel product. We demonstrated the feasibility of biomass to wide cut diesel production and also the potential to be scaled up for commercial application by allowing for improvements in the economics of the integrated process.

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USE OF CENTRIFUGAL PARTITION CHROMATOGRAPHY FOR COPRODUCT RECOVERY

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Agricultural biomass contains a variety of chemical building blocks that can be separated and converted into a variety of everyday goods such as: plastics, solvents, adhesives, composites, fuel additives, pharmaceuticals or used as food additives. One such mechanism to purify these possible coproducts is centrifugal partition chromatography (CPC); a liquid-liquid based chromatography tool that can purify up to gram quantities of a compound of interest from a complex plant extract. CPC was used to purify a product from an agricultural source.

The first project was focused on solvent selection for the purification of xylooligasaccharides (XOS) from hemicellulose. We explored the use of a nonaqueous solvent system (heptane:butanol:acetonitrile) to purify XOS sugars in a single separation. Exclusion of water from the solvent system increased the partition coefficient (up to $K_{D,xylose} = 0.36$). The solvent system was determined as a result of empirical experimentation and use of the COSMO-RS solvent selection method (Hopmann et al., 2011; Hopmann et al., 2012). The theoretical calculation promotes the development of a more efficient, economically feasible method. The drawback of this solvent system is the solubility is comparatively low (when compared to a water based system) so the loading rate must be decreased.

The second project was focused on the recovery of lutein and zeaxanthin, plant compounds in the carotenoid family, from DDGS. They are essential for development and maintenance of the retinal macula (Krinsky et al., 2005) and to act as an antioxidant to prevent the cancer development (Khachik et al., 1995). Compounds were extracted via Soxhlet and verified with HPLC. Further purification was carried out using CPC.

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CONVERSION OF AGRICULTURAL RESIDUES DERIVED LIGNIN INTO SUSTAINABLE JET FUEL

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Lignin, one of the main constituents of lignocellulosic biomass (15 to 30% by weight, 40% by energy), is a natural amorphous polymer that acts as the essential glue that gives plants their structural integrity. However, the conversion of lignocellulosic biomass to biofuels is focused primarily on converting cellulose and hemicellulose in feedstocks into biofuels, while the lignin fraction currently is used for heat and power production, in part, because there are few efficient conversion processes available that can convert lignin into transportation biofuels or higher value chemical products. Regardless of the exact bioprocessing technology employed, almost all biological processing platforms for the conversion of plant polysaccharides to bioethanol (or biobutanol), in which the total carbon use from biomass feedstock is under 50%, result in the formation of a vast lignin process stream when commercialized. The current vision undervalues lignin's potential to address this nation's high quality liquid fuel requirements. Lignin is a promising feedstock for jet fuel production due to its availability and markedly lower oxygen content (~36%) than carbohydrates (~50%) in biomass. Coproduction of ethanol and other liquid fuels (eg, jet fuel) from all three biomass main constituents (eg, cellulose, hemicellulose, lignin) would improve the total carbon use in biomass, enhance revenues, make biomass conversion more economically competitive and support our country's mission of national energy security. The lack of technologies (eg, chemical and biological) to convert lignin into biofuel and other high value products has been a bottle neck for biomass biorefinery. A key challenge in using lignin as a biofuel resource is its complex crosslinked polymeric structure(Laskar et al., 2013a).

Leveraging funded projects from DARPA Young Faculty Award 2011-2014, National Science Foundation EAGER 2012-2014, Department of Energy-NREL 2012-2014 and Sun grant-US Department of Transportation 2013-2015, we have demonstrated the existence of characteristic structural features of biomass derived lignin dictates the feasibility for conversion to C7 to C18 jet fuel range hydrocarbons. With this catalytic approach we have achieved 38 to 45% yields of lignin conversion, with excellent selectivity (~90%) of hydrodeoxygenation (HDO) hydrocarbon products. Notably, 4 of 6 hydrocarbon classes inherent to jet fuel can be generated directly from the process. Thus, it may be possible to develop the complete suite of molecules that are required for jet fuel from only biomass feedstocks. The ability to do so would impact the necessity of blending and would add value to the product of the biomass to fuel pathway (Laskar et al., 2014; Laskar et al., 2013b; Yang and Laskar, 2013).

The impetus of this work is to use targeted fundamentals to hone the aqueous phase catalysis of depolymerized reactive lignin from biomass derived lignin into aliphatic, aromatic and cyclic hydrocarbons.

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