

**2017 S-1041 Science and Engineering  
for a Biobased Industry and Economy  
Poster Abstracts  
Symposium Presentation Abstracts**

Oral and Poster presentations at the S-1041 annual meeting on 10 and 11 July, 2017  
National Institute of Food and Agriculture, USDA, Washington, DC

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

**Planning Committee**

G. S. Murthy, Oregon State University  
Scott Pryor, North Dakota 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 an  
electronic version of these abstracts can be found at:

<https://www.nimss.org/projects/15616>



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Proceedings edited by  
Kent Rausch and Mike Tumbleson  
University of Illinois

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# **Agenda for the 2017 Annual Meeting and Symposium**

**(Subject to Change)**

## **S-1041 Multistate Committee**

Host Institution: NIFA, USDA, Washington D.C.  
Meeting Organizing Committee: Jillian Worthen (NIFA), G.S. Murthy (OR), Kent Rausch (IL), Troy Runge (WI), and M.E. Tumbleson (IL)  
S-1041 Executive Committee: G.S. Murthy (chair), Troy Runge (vice chair), Scott Pryor (secretary)

### **Monday, July 10th (Day One): Station Reports and Symposium**

7:30 - 8:00	Sign-In, Reception. Coffee/Tea/Breakfast
7:45 - 8:00	Poster set up
8:00 - 8:05	Welcome and introduction
8:05 - 8:15	Opening remarks by Host
8:15 - 8:20	Welcome and opening remarks by S-1041 liaison and USDA, National Institute of Food and Agriculture representative
8:25 - 8:50	Introduction of attendees
8:50 - 9:45	Station reports (3 minutes for each station)
9:45 - 11:00	Poster session I and graduate student poster presentation competition
11:00 - noon	Business Meeting
	Old Business
	Approval/Additions of 2017 Meeting Agenda: Troy Runge
	Approval of 2016 meeting minutes: Troy Runge
	New Business
	Election of officers: Secretary/Vice Chair
	Symposium topic for 2018
	Discussion of rewrite in 2018 and planning for next day meeting
	Other discussion items
12:00 - 1:00	Lunch
1:00 - 5:00	S-1041 Symposium (see p. 32 for abstracts)
	1:00 - 1:45 David Turpin
	1:45 - 2:30 Todd Anderson
	2:30 - 2:45 Break
	2:45 - 3:30 Mark Elless
	3:30 - 4:15 Daniel Cassidy
5:00	Adjournment

### **Tuesday, July 11th (Day Two): Facilitated discussion on S-1041 Rewrite**

8:30	Sign-In, Reception, Coffee/Pastries
8:50	Introductory remarks by Scott Pryor/Troy Runge
9:00	Facilitated discussion on S-1041 committee 2018 rewrite
10:30	Poster session II
12:00 pm	Closing Remarks and Meeting Adjournment

## **S-1041 Objectives**

1. 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.
2. Investigate and develop sustainable technologies to convert biomass resources into chemicals, energy, materials and other value added products.
3. Build modeling and systems approaches to support development of sustainable biomass production and conversion to bioenergy and bioproducts.
4. Identify and develop needed educational resources, expand distance based delivery methods and grow a trained work force for the biobased economy.

## S-1041 Symposium Background

During the 2009 S-1041 annual 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 included speakers from the facility as well as the surrounding region.

<b>Year</b>	<b>Symposium Title</b>	<b>Location</b>
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		Western Regional Research Center, ARS, USDA, Albany, CA
2017		National Institute of Food and Agriculture, USDA, Washington, DC

# **Meeting Chronology** **S-1041: 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	NIFA
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	Honolulu, 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 = 10-11 Jul, 2017	Washington, DC	G. S. Murthy	NIFA
18 =		Troy Runge	

## **S-1041 Participating Institutions**

Administrative Advisor	Tim Rials
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	Chandra Theegala
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	Scott Pryor
Oklahoma State University	Ajay Kumar
Oregon State University	G. S. Murthy
Pennsylvania State University	Ali Demirci
Purdue University	Bernie Tao
Rutgers University	Gal Hochman
South Dakota State University	Kasiviswanuth Muthukumarappan
Texas A&M University	Sergio Capareda
University of Arizona	Joel Cuello
University of California, Davis	Ruihong Zhang
University of Hawaii	Samir Khanal
University of Illinois	Kent Rausch
University of Kentucky	Sue Nokes
University of Minnesota	Roger Ruan
University of Nebraska, Lincoln	Mark Wilkins
University of Tennessee, Knoxville	Alvin Womac
University of Texas, Austin	Jonathan Chen
University of Wisconsin	Troy Runge
Virginia Tech	Haibo Huang
Washington State University	Bin Yang
West Virginia University	Kaushlendra Singh

## Chronology of Institutions Submitting Posters

Year (20xx)	10	11	12	14	15	16	17
Clemson	x		x				
Cornell	x	x	x				
IA State					x		
KS State	x	x	x		x		
LSU		x			x		
MI State		x	x		x		
MS State		x	x	x	x		x
MT State	x		x	x	x	x	
ND State		x		x			x
OH State		x	x	x	x		
OK State	x	x	x	x	x	x	
OR State	x		x	x	x	x	x
Purdue		x	x	x	x		
Rutgers				x	x		x
SDSU		x					
TAMU			x				x
Univ AR	x	x	x	x	x	x	
UCD	x			x	x		
Univ HI	x	x	x		x		
Univ IL	x		x	x	x	x	x
Univ KY		x	x				
Univ MN	x	x	x	x	x	x	
UNL							x
UTK			x	x	x	x	x
Univ TX-A		x					
UWM			x				
VPI							x
WA State				x	x	x	x
WV					x	x	x
Total Number	25	44	29	31	50	22	19

## **Poster Abstracts**

## BULK DENSIFICATION OF BIOMASS FEEDSTOCK

Alvin R. Womac<sup>1</sup>, Mitch D. Groothuis<sup>1</sup>, Clay D. Dye<sup>2</sup>, Sam W. Jackson<sup>2</sup> and Kelly J. Tiller<sup>2</sup>

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Efficient automated handling of biomass feedstocks often is hindered with handling bales and other unit packages. University of Tennessee personnel and collaborators examined the concept of handling biomass in bulk for a continuous conveyance stream of milled biomass; also, the concept of densification within the handling system to aide efficient transportation.

A solid waste compactor and ejector transfer system provided alternative bulk compaction and hauling for low moisture switchgrass (SG) either field chopped (FC) with a forage harvester or with bales size reduced with a tub grinder as coarse (CTG) and fine (FTG) materials. In lieu of constructing a purpose built bulk compactor and self unloading semitruck trailer for biomass, the compactor and ejector trailer were selected due to commercial availability. The compactor increased and improved bulk densities, though bulk densities were slightly less than values reported for large packaged bales, either round or square. Maximum bulk densities observed were 168 kg m<sup>-3</sup> or 139 dry (d) kg m<sup>-3</sup>. Advantages were noted with bulk loading and ejection unloading, such that loading a full over the road semitrailer required a minimum of 24 min, as limited by the supply system; unloading required only 5 min. The theoretical semitruck loading time based on compactor plunger displacement and frequency, if the supply system was not limiting, was 5 min. Low energy requirements for bulk compaction and ejection indicated an economy of scale, with compaction energy as low as 1.05 kW·h dMg<sup>-1</sup> for FC and ejection unloading energy as low as 0.05 kW·h dMg<sup>-1</sup> for FC.

For commercial applications, especially for FC materials that flow well, spillage between the compactor and ejector trailer should be addressed. Bulk compaction proved viable with off the shelf designs; there is potential to improve designs with reduced friction internal surfaces and integration of compaction and ejection functions into a dedicated vehicle. Data collected will be used to provide insight into criteria for a new, mobile densification system.

## **SUSTAINABLE INTENSIVE FISH FARMING: THE PROSPECTS OF AQUAPONICS**

Justin Sarubbi<sup>1</sup>, Eric Lam<sup>1</sup>, Nadav Naveh<sup>2</sup>, Eithan Hochman<sup>2</sup> and Gal Hochman<sup>1</sup>  
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Aquaculture, the farming of aquatic animals under controlled conditions, has exhibited one of the world's highest growth rates among agricultural products in recent decades, with its share in global fish output growing annually at an average rate of 8.8% from 1980 through 2010 [1]. Given this current average growth rate, output from fish farming is expected to surpass output from commercial fishing by 2018. The aquaculture system is a reliable technology that generates a constant supply of fish at an efficient food output ratio when compared to other livestock technologies. However, aquaculture generates wastewater that contains residuals of uneaten food and high concentrations of nitrogen and phosphorus that harm the environment and can cause eutrophication [2-4]. Folke et al [5,6] suggest the “polluter pays” principle, whereby the party responsible for producing pollution pays for the damage done, resulting in contractions in fish supply and increases in fish price. However, there is an alternative sustainable option that achieves environmental and economic outcomes that are superior to those achieved under regulations based on the polluter pays principle.

We developed a biological/economic model and used it to investigate the above proposition. The model was used to show the adoption of technologies that expanded the fish supply chain and employed waste as an input to achieve economic value from fish farming that exceeded the value under the unregulated scenario. This was achieved while internalizing the negative externalities associated with intensive fish farming.

By modeling the biological and economic parameters of an aquaponics system, as well as numerically quantifying that system, we investigated the benefits of synthesizing intensive fish farming with plant growing technologies. Specifically, we assumed the use of aquaponics systems that combine aquaculture and hydroponic technologies. When developing the aquaculture system, we assumed ad libitum feeding (ie, fish eat as they please); we also assumed a one to one relationship between fish age and growth [7] and between fish biomass and the amount eaten. When modeling the hydroponic system, we focused on the steady state and assumed staggered harvesting; the plant is harvested every week at a constant rate.

Using the simple decision rule derived in the conceptual framework, we quantified three empirical applications of an aquaponics system that uses lettuce. The first grows 40 tons of tilapia per year, while the second uses garra rufa fish. Comparing simulated outcomes, when using low value fish (ie, tilapia), most of the revenues come from the lettuce. On the other hand, when using garra rufa fish (ie, high value fish), most of the revenue comes from the fish. The empirical applications illustrate the importance of the output price in creating an economically viable aquaponics system (both fish and plant) and suggest that input prices (eg, fertilizer, food prices) also play an important role when evaluating the economics of these systems. We show conceptually and then numerically how alternative aquaponics systems yield different distributions of profits among the various stakeholders located along the supply chain.

In the third application, we showed how duckweed can add value to an aquaponics system. It builds from a previous case study in which we explored the addition of hydroponic grown buttercrunch lettuce to a barramundi fish production system. We concluded the benefits of the integrated system included the reduction in barramundi effluent disposal costs and saving of water and nutrient costs of the lettuce system. We built upon that analysis by adding duckweed to the integrated system and compared variable costs and revenue of a production system of barramundi and lettuce, to that of barramundi, lettuce and duckweed. Duckweed serve as fish food and a biological filter. The addition of duckweed resulted in a decrease in food cost and effluent disposal cost, as well as reducing the area needed to build the integrated system.

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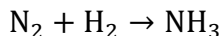
## THE ECONOMICS OF THE DIRECT NITROGEN FIXATION TO AMMONIA

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The world's crop production in 2006 was 9,500 trillion calories; it is projected to increase to a baseline of 16,000 trillion calories by 2050 [1]. To meet the demand for food, more nutrient input, such as nitrogen, will be required to support more intensive agricultural demands.

Nitrogen, one of the essential nutrients for plant growth, is taken up by plants in the form of ammonium compounds and various forms of nitrogen oxides. In nature, atmospheric nitrogen is converted (nitrogen fixation) into the ammonium form by nitrogen fixing bacteria associated with leguminous plants. These forms of natural nitrogen cycles are susceptible to losses through leaching from soil to water or loss to atmosphere [2]. Naturally fixed nitrogen undermined by losses cannot support current levels of global food production. In fact, synthetic nitrogenous fertilizers fed nearly 45% of the world's population at 2011 count [3]. As the world's population increases, so does the requirement for nitrogenous fertilizers.

The gap between the requirement for naturally fixed nitrogen and agriculture requirement is filled by the Haber-Bosch process which uses elemental nitrogen ( $N_2$ ) and hydrogen ( $H_2$ ) to synthesis ammonia ( $NH_3$ ).



Fertilizer synthesis using the Haber-Bosch process led to multiple fold increases in crop production during the 20<sup>th</sup> century [3]. Without a synthetic source for ammonia, crop production would have required more land to compensate for reduced productivity of the soil over time.

Haber-Bosch is an energy intensive process and currently most of the production uses natural gas as a fuel and input for hydrogen production. So, any increase in ammonia production through Haber-Bosch means an increase in natural gas consumption and a loss of natural gas pollutants to the environment. This creates a need for an alternative method of hydrogen production and better management of agroecosystem to reduce nitrogen losses. Electrolysis of water is a potential method of hydrogen synthesis which can use renewable sources of electricity thus reducing the environment and energy cost of ammonia production. Another alternative is direct nitrogen reduction, which enables us to use electrolysis to convert the nitrogen directly to ammonia thus skipping the need for hydrogen production.

We compared the aforementioned three processes: (i) conventional Haber-Bosch process, (ii) electrolysis of water and (iii) direct nitrogen fixation. We compared energy usage, economic cost and pollution. We will discuss the implications to intermittency and benefits from introduction of direct nitrogen fixation, both to ammonia production and more generally to the nitrogen economy.

#### **LITERATURE CITED**

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## **DEMONSTRATION OF WATER PURIFICATION/TREATMENT/RECYCLING AND POWER GENERATION IN A COMMERCIAL DAIRY**

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A lactating cow produces 68 kg (150 lb) of manure per day which contains 450 g nitrogen and 78 g phosphorus [1]. These wastes typically are applied to nearby fields, which sometimes leads to excess application of nutrients. Manure also has properties, such as carbon and energy content that make it suitable for energy conversion. Thermochemical conversion processes have been used for animal wastes in various types of reactors such as fluidized beds that allow the highest conversion rate due to fast reaction times ( $<1.6$  s) [2]. Few studies of fluidized bed gasification of cow manure have been conducted [3-5]. Dairy farm operation practices provide difficulty in using these wastes for energy production. USDA [6] reported various types of bedding materials used in dairies in the US; the most commonly used bedding material was sand (25.8%) because it creates a clean, dry environment that prevents bacterial growth. Sand bedding also offers a comfortable and uniform bed for cows to lie on. Galvão and Eizenber [7] determined that 92% of dairy cows that bedded on sand showed no lesions, while 84% of cows lying on waterbeds had lesions.

To reduce nutrient loadings to animal waste lagoons while generating heat and power, two technologies were tested in a dairy facility (Southwest Regional Dairy Center): a water treatment and recycling process (Global Restoration, Inc and Bakercorp-Kaselco) and a manure conversion into heat and electrical power technology (Texas A&M University). Advanced oxidation treatment and electrocoagulation were used to process the waste water discharge of the dairy facility. More than 95% of phosphorus was captured and reductions in BOD and COD were observed. Solid waste preparation was designed to reduce its sand content and increase its energy content by 65% for sustainable energy conversion. Gasification of processed manure was conducted in a trailer mounted fluidized bed reactor at 650°C. The gasification system was equipped to separate the solid (biochar) and liquid byproducts from the gas. Synthesis gas with an energy content of 4 MJ Nm<sup>-3</sup> was produced and used as fuel on a modified 30 kW gas engine generator.

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# THE KINETICS OF MODEL BIOGAS REFORMING WITH CARBON DIOXIDE OVER A Ni<sub>15</sub>CeMgAl CATALYST

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Biogas is produced through the anaerobic digestion or fermentation of widely available organic matter, such as sewage, energy crops, agricultural wastes, domestic refuse and animal manure [1]. Biogas components are mainly methane (CH<sub>4</sub>, 55 to 65%) and carbon dioxide (CO<sub>2</sub>, 30 to 45%). Model biogas is a combination of methane and carbon oxide.

The reforming of model biogas with carbon dioxide is similar to the dry reforming of methane. The dry (CO<sub>2</sub>) reforming of methane (DRM) to produce syngas has received research attention in the past few decades because of its application in Fischer-Tropsch synthesis [2-4]. According to our previous study [5], a Ni-based bimodal pore catalyst (Ni<sub>15</sub>CeMgAl) has high activity, long stability, large yield and little carbon deposition for the DRM reaction in a nondiluted feed gas atmosphere. The high activity and long stability of this Ni catalyst is suggestive that it has potential to be scaled up in industry; it is necessary to obtain the kinetic information to design reactor and predict products flow rate for the scaled up operation. Due to long stability, it is feasible to obtain reliable kinetic data. A kinetic equation (Eq. 1), based on Langmuir-Hinshelwood (LH) formulism reflecting the realistic DRM reaction over Ni<sub>15</sub>CeMgAl catalyst, was obtained by considering the existence of RWGS reaction [6].

$$r_{CH_4} = -k_5 \frac{K_a P_{CH_4}^4 P_{CO_2}^4}{P_{CO}^4 P_{H_2}^6} \left( \frac{C_t}{DEN} \right)^8 \quad (\text{Eq. 1})$$

$$\text{Where, } DEN = 1 + K_1 P_{CH_4} + \frac{K_b P_{CH_4}}{P_{H_2}^2} + \frac{P_{H_2}^{0.5}}{K_6^{0.5}} + K_3 P_{CO_2} + \frac{P_{CO}}{K_7} + \frac{K_c P_{CO_2} P_{H_2}^{0.5}}{P_{CO}}$$

$$K_a = K_1^4 K_2^4 K_3^4 K_4^4 K_6^6 K_7^4, \quad K_b = K_1 K_2 K_6^2, \quad K_c = \frac{K_3 K_4 K_7}{K_6^{0.5}}$$

A nonlinear least squares regression method was employed to optimize parameters (K<sub>1-4</sub>, k<sub>5</sub>, K<sub>6</sub>, γ) of this kinetic model, which was operated based on the minimization of the sum of residual squares of experimental and predicted DRM reaction rates. The data in effect of CH<sub>4</sub> partial pressure experiment were applied to solve these parameters. Predicted and experimental reaction rates showed a good fit at R<sup>2</sup> = 0.972 (Fig. 1L). The predicted and experimental

products (CO, H<sub>2</sub>) flow rates also showed a good fit at  $R^2 = 0.962$  and  $R^2 = 0.959$ , respectively (Fig. 1R).

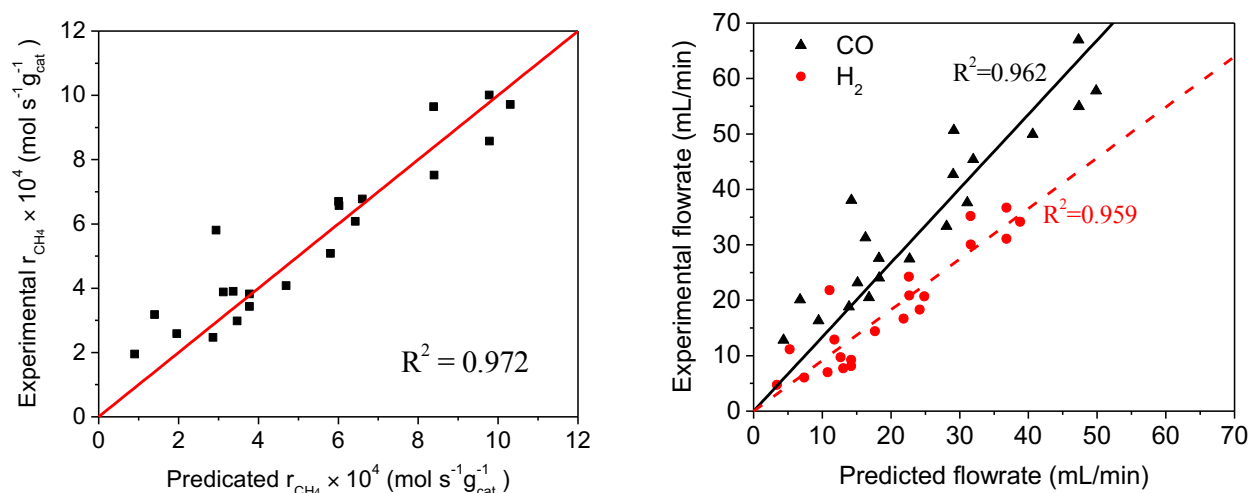


Figure 1. Parity plot of model predicted and experimental DRM reaction rates in term of CH<sub>4</sub> consumption (left, L) and product flow rates (right, R).

An LH kinetic model was derived from the proposed mechanism and suggested RDS. The derived kinetic model shows a goodness of fit between the experimental rate and predicted data. The dry reforming of methane formula ( $CH_4 + CO_2 = 2 H_2 + 2 CO$ ) was extended to an expression ( $4 CH_4 + 5 CO_2 = 7 H_2 + 9 CO + H_2O$ ) that is more representative for the realistic reaction.

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## ETHANOL YIELDS AND NUTRITIONAL VALUE OF DISTILLERS DRIED GRAINS WITH SOLUBLES FROM CORN WITH HIGHER CONCENTRATIONS OF ESSENTIAL AMINO ACIDS

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Concentrations of essential amino acids, lysine and tryptophan, are limited in corn distillers dried grains with solubles (DDGS). These amino acids currently are added as supplements to enhance the nutritional value of DDGS. Corn with higher levels of these amino acids is of particular interest to the livestock and poultry community. Mutations known to increase lysine and tryptophan concentrations were combined by breeding into two maize hybrid backgrounds that differ for grain protein concentration (FR1064 × Mo17 normal protein, FR1064 × IRHP1 high protein) [1-3]. These mutant hybrids were processed using a laboratory scale conventional dry grind process along with their nonmutant isolines and were compared on the basis of grain yield, starch concentration, ethanol yield and lysine and tryptophan concentrations in DDGS.

The mutant hybrid grain contained higher concentrations of a number of amino acids, with notable increases to at least 0.55% w/w lysine and 0.18% tryptophan. Due to lower grain yield and starch concentrations, final ethanol yields of mutant hybrids (16.7 and 16.3% v/v for FR1064 × Mo17: *o2*; *asaC28* and FR1064 × IRHP1: *o2*; *asaC28*, respectively) were reduced compared to their respective control isolines (18.5 and 17.4% v/v for FR1064 × Mo17 and FR1064 × IRHP1, respectively). DDGS yields increased for both mutant hybrids compared to controls. DDGS from the mutant hybrids contained higher concentrations of lysine (1.48 to 1.70% w/w) and tryptophan (0.32 to 0.39% w/w) compared to controls (1.09% lysine, 0.22% tryptophan). Using these mutant corn hybrids at an ethanol plant would result in a decrease in ethanol yield; however, this loss can be recovered with the higher DDGS yield and increased nutritional value of the DDGS.

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## EFFECTS OF NITROGENOUS SUBSTANCES ON HEAT TRANSFER FOULING USING MODEL THIN STILLAGE FLUIDS

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Fouling is unwanted deposition of materials on surfaces of processing equipment, which leads to additional investment, lower processing efficiency and potential fluid contamination [1]. In the corn ethanol industry, fouling occurs when thin stillage is concentrated into condensed distillers solubles. Several researchers have investigated operating conditions and constituents' influence on fouling characteristics [2-5]. However, understanding protein effects on fouling is limited despite its high concentration in thin stillage (17 to 33% db) [6].

Protein contributions to fouling were investigated in the dairy industry. Whey proteins, together with calcium phosphate, and casein micelle form aggregates on heated surfaces [7, 8]. 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, are hypothesized to contribute to fouling.

Due to complex composition of commercial thin stillage, it is difficult to study a single effect on fouling without interference from other factors. The objective was to investigate effects of nitrogenous substances and protease on fouling using model and commercial thin stillage fluids. Nitrogenous substances, urea and yeast, were mixed with glucose. Four thermocouples installed in an annular probe monitored inner wall temperature; fouling resistance was obtained by comparing thermal resistance of unfouled surfaces from that of fouled surfaces. Fouling was characterized by maximum fouling resistance ( $R_{\max}$ ), induction period and fouling rate.

Urea addition did not lead to fouling while glucose-yeast model fluids displayed a fouling tendency that had a positive correlation with yeast protein concentration. Protease from pineapple stem (bromelain) incubation aggravated fouling in both model and commercial fluids, which were indicative that hydrolyzed molecules such as peptides, amino acids or protease itself may contribute to deposit formation. Adjustment of pH in model fluids during incubation

reduced  $R_{\max}$  and fouling rate, and extended induction periods longer than 300 min. Total suspended solids of commercial thin stillage did not change within two weeks; they were affected more by sample batch than storage time.

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## EFFECTS OF PHYTIC ACID CONCENTRATION 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 corn steeping process and is composed of solubilized kernel compounds, microbes (principally *Lactobacilli*) and solids from recycled process streams.

Researchers on corn processing fouling have studied effects of membrane filtration, corn oil, pH, Reynolds number, solids concentration and carbohydrates [1, 2, 4, 6-8]. However, effects of phytic acid concentration or phytase addition on fouling characteristics are not known. There are reports from industry suggesting phytic acid content is correlated positively with fouling rates; adding phytase to process streams may reduce fouling. Researchers also have shown 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 [5]. From a study on a calcium phytic acid metal complex, it was concluded that concentration was correlated positively with fouling in the dairy industry [3]. They evaluated effects of phytic acid concentration and phytase addition on steepwater fouling behavior. They used commercial steepwater with phytic acid addition varying from 25 to 75 mg phytic acid/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.

Phytic acid addition lead to decreased fouling. There was no fouling when phytic acid concentrations of commercial samples were adjusted to 50 and 75 mg phytic acid/g sample. With the additional phytic acid, pH of the commercial samples decreased from 4.5 to 2.8. This result provided a better understanding of phytic acid effects on wet milling fouling and provided incentive for further investigation of the effect of pH on steepwater fouling.

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## **SUPERCAPACITOR FABRICATED FROM CARBON EXTRACTED FROM COMMERCIAL ORGANIC WASTES**

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Up to date electronic devices require a high level of energy storage with the competence to fast charge and discharge [1]. Supercapacitors are suitable for these criteria. A wide ranging selection of carbon based materials, such as activated carbons (ACs), templated carbon, carbon nanofibers and nanotubes, carbide derived carbons and graphene currently are being investigated for use as an electrode material for EDLC applications [2]. Nevertheless, ACs are the leading choice for supercapacitor applications due to abundance and price efficiency, in addition to their satisfactory capacitance performance from 40 to 100 F/g [3-4]. Hence, extensive research has been dedicated to new approaches for producing activated carbon material with high porosity levels in a cost effective way. A range of carbon materials from different sources such as sucrose, cellulose, corn grain, banana fiber, potato starch have been prepared and activated by numerous researchers for use as EDLC electrodes. Crucial aspects in using these kinds of sources are aligned with reduced cost and lower ecological effect for using the biowastes to produce value added products [5]. ACs acquired by the pyrolysis and hydrothermally carbonized of commercially spent osmotic solutions (SOS) were used and tested as EDLC. Two commercial SOS waste derived AC materials were used to form high surface areas carbons. AC-CSOS and AC-BSOS are the terms used for the berry- and cherry-derived SOS materials, respectively.

Microstructures of carbon electrode materials were characterized via scanning electron microscopy (SEM) with an attached energy dispersive x-ray spectroscopy (EDS) apparatus. Carbon chemical state was characterized using X-ray photoelectron spectroscopy (XPS). XPS was used for quantification and chemical state analysis of the elements on the surface of the carbon electrodes. Distinctive attention was paid to the quantification of functional groups on the surface. Brunauer-Emmett-Teller (BET) surface area, in addition to the gas adsorption/desorption isotherms of the carbon materials, were analyzed using nitrogen (N<sub>2</sub>) adsorption in a Micromeritics ASAP 2020. Electrochemical characterization was completed by testing the carbon material in a two electrode assembly within a CR-2032 casing architecture [6]. The AC-CSOS and AC-BSOS materials were lightly ball-milled in alcohol and casted on acid washed stainless steel foil to a thickness of ~800 µm using n-methyl-2-pyrrolidone as the binder. The electrodes were assembled using a Nafion® separator; a 6 M aqueous solution of KOH was

used as the electrolyte solution. Due to the aqueous based electrolyte solution, 1.0 V was chosen to be a maximum potential to be applied [7]. A cyclic charge-discharge method (CCD) was used to assess electrochemical performance. The tests were completed using an 8 Channel Capacitor/Battery Analyzer (MTI Corp., USA). Each sample was tested to 2000 charge-discharge cycles, or until failure from 0.1 V to 1 V using a 2 mA current. In addition, self discharge measurements were completed for each supercapacitor by charging to 1 V before removing the current and measuring the voltage for 120 min. Tests were repeated for 100 cycles or until failure.

The constant current charge/discharge (CCD) profile for the supercapacitors with AC-CSOS and AC-BSOS electrodes is depicted in Fig. 1. The constant current charge/discharge measurements for both materials showed repeatable cyclic behavior, which was near the same level of performance to ACs formed using pitch based precursors [2, 8]. The CCD curves were linear and symmetrical. Specific capacitance ( $C_g$ ) for the electrode system was  $\sim 48$  and  $\sim 20$  F/g over the 1500 cycles for AC-CSOS and AC-BSOS, respectively. The AC-CSOS and AC-BSOS based carbon electrodes retain the desired electrochemical reversibility and charge/discharge capabilities.

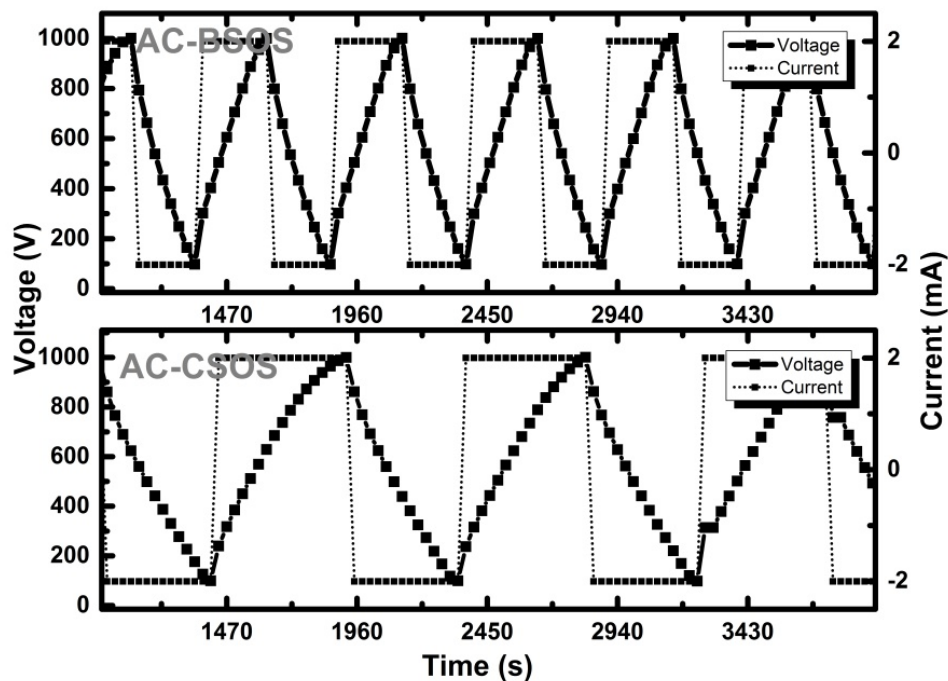


Figure 1. Constant current charge/discharge profiles for AC-CSOS and AC-BSOS supercapacitors.

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## **IMPLICATIONS OF USING PELLETTED CORN STOVER AS A CELLULOSIC BIOREFINERY FEEDSTOCK**

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Consistent supply of low-cost biomass feedstock is crucial for establishing biobased industries. The use of baled or loose biomass for establishing industrial scale cellulosic biorefineries causes significant challenges for transportation, handling and storage due to low bulk density of biomass. Densification such as pelleting increases biomass bulk density and therefore facilitates cost reductions for feedstock handling, storage, and transportation. Densified biomass has not been considered widely for biorefineries because transportation cost savings were thought to be largely offset by pelleting costs. However, processing synergies between densification and pretreatment efficacy for biochemical conversion has been overlooked in those analyses. Energy use and greenhouse gas emissions of processing technologies are also dependent on the form of feedstock. Therefore, a life cycle approach is necessary to understand the environmental impact of transporting and processing nonpelleted and pelleted biomass.

Work from our research group previously found that pelleting biomass facilitates significant benefits of downstream processing such as reduced pretreatment severity and enzyme loadings, in addition to feedstock transportation benefits [1, 2]. Our research also showed that pelleting biomass enables higher pretreatment solid loadings along with the use of milder pretreatment conditions including pretreatment time, temperature, and chemical concentrations. We were able to increase pretreatment solid loadings by a factor of two without reducing glucose yields. Decreasing reactor volume and pretreatment severity will reduce chemical costs, reactor costs, and energy use. High glucose yields from pelleted corn stover using low-severity pretreatment suggests economic and environmental benefits of biomass pelletization beyond those associated with transportation and handling.

To quantify pretreatment severity reduction, a range of high to low severity conditions using soaking in aqueous ammonia (SAA) pretreatment are being tested for pelleted and nonpelleted corn stover. A range of enzyme loadings will be tested for each pretreatment condition to determine minimum requirements to produce 90% glucose yields. Improvements from pelleting will be quantified based on increased yields under the same processing conditions, and by reductions in processing conditions while maintaining comparable yields.

This research also incorporates a study of the life cycle implications of using pelleted corn stover in a biorefinery with SAA-pretreatment. The functional unit is defined as 1 kg of glucose production from cellulosic feedstock. The system boundaries include feedstock transportation, densification, and pretreatment sufficient to reach 90% theoretical glucose yields with moderate enzyme loading. Use of alternate feedstock forms will be compared for environmental performance in terms of global warming potential and fossil energy use.

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## BIOCONVERSION OF LIGNIN TO VALUE ADDED FUELS AND CHEMICALS

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The main carbon sources in plant biomass are carbohydrates and lignin; yet most biological biofuel conversion technologies have focused on generating biofuels from sugars. Since lignin is 15 to 30% of biomass, there is a need to develop translational lignin valorization methodologies. Despite the potential, lignin conversion to biofuels and chemicals has proven to be challenging. This is especially true for the simultaneous production of monomeric sugars and reactive lignin useful for fermentation and/or catalytic upgrading. Biochemical conversion processes that utilize heat, chemicals, and enzymes to deconstruct biomass into its reactive intermediates at high yields necessary for biological processes into useful biofuels and chemicals are expensive and slow. Thus, biological upgrading processes that can achieve high biofuel yields from these reactive intermediates at low cost need to be developed. Using an advanced biological and chemical design, a research program was implemented to realize a multistream integrated biorefinery. Several natural and engineered bacteria (eg, *Rhodococcus*, *Pseudomonas*) with lignin degradation and/or lipid/PHA biosynthesis capacities were selected to establish fundamental understanding of pathways and functional modules necessary to enable a platform for biological conversion of lignin to lipids and PHA. The biological design established that biorefinery wastes can be broadly used for the production of biodiesel and bioplastics.

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## CONTINUOUS HYDROTHERMAL LIQUEFACTION OF MICROALGAE

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Hydrothermal liquefaction (HTL) has been identified as a promising conversion process for wet biomass including microalgae. The HTL process, which involves heating high moisture content feedstocks to near critical temperatures and pressures of water (523 to 647 K, 4 to 22 MPa), results in a biocrude which is a complex mixture of oxygenated compounds, which when upgraded (oxygen content is reduced) can be used in existing petroleum refineries for fuel and chemical production [1]. Most of the research on HTL has been carried out in batch reactors; there are few studies on continuous HTL [1-4]. The objective of this research was to design, develop and characterize a novel low cost continuous HTL reactor for processing wet algae slurries. A continuous reactor consisting of stainless steel reactor tube (1.27 cm OD x 6.4 m length), heating elements, slurry pump, cooling section and back pressure regulator was designed and built. Thermocouples and pressure gauges were installed to monitor temperature and pressure. Reaction temperature was controlled using an Arduino based controller. Microalga *Chlorella* sp., purchased as algae powder with 6% moisture content, was mixed with water to obtain 10% slurry and used as the substrate for the HTL reaction studies. Samples were collected and analyzed for the biocrude yields, distribution of carbon, nitrogen in biocrude and aqueous phase. Experiments were conducted at various temperatures to identify the optimal condition for highest biocrude yield with lowest nitrogen content in biocrude. Algae biocrude yields at 250, 300 and 325°C were 35, 45 and 50% (g biocrude /g algae), respectively. A continuous HTL reactor was constructed and operated at various temperatures. The HTL process is an energetically favorable process for conversion of algal biomass into biocrudes.

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## SYSTEMS ANALYSIS OF TECHNOLOGY PATHWAYS FOR LIGNOCELLULOSIC BIORERFINERIES

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Developing an industrially sustainable process addressing trifold sustainability metrics, including technological feasibility, economic viability and environmental impacts, to produce biofuels remains a challenge. Producing multiple products, such as ethyl acetate, dodecane and ethylene, in biorefineries could reduce the risk to commercialization. We assessed the feasibility of multiple biorefinery platforms using trifold metrics using high yielding tropical feedstocks such as banagrass and energycane. Analyses were conducted by developing comprehensive process models using SuperPro® and detailed life cycle assessments in OpenLCA©. Biorefinery scenarios were simulated for Hawaiian Islands where high yield tropical grass production is feasible throughout the year, enabling just in time harvest and processing.

Overall biorefinery profitability is influenced by biomass cost (\$80/dry MT) and ethanol selling price (\$2.85/gal). Compositional variations between feedstocks could result in 11% variation in ethanol production. Production costs of various products from banagrass was \$1.19/kg ethanol, \$1.00/kg ethyl acetate, \$3.01/kg dodecane (jet fuel equivalent), \$2.34/kg ethylene and \$0.32/kW·h electricity. Similarly, production costs for energycane biorefinery were \$1.31/kg ethanol, \$1.11/kg ethyl acetate, \$3.35/kg dodecane and \$2.62/kg ethylene. The most profitable scenario was based on a combination of first generation ethanol and acetic acid from lignocellulosic feedstocks to produce ethyl acetate. Ethyl acetate scenario had a payback period of 11.2 yr and an ROI of 8.93%. Thermochemical conversion was not feasible when the feedstock moisture content was high (70% wb). Among the environmental impacts, acidification potential was high when ethylene was produced from banagrass and energycane at  $2.56 \times 10^{-2}$  and  $1.71 \times 10^{-2}$  kg SO<sub>2</sub> eq., respectively, compared to other scenarios.

Global warming potentials for banagrass and energycane were -12.3 and -40.0 g CO<sub>2</sub> eq/kg ethanol, respectively. When crude oil prices increase beyond \$80/barrel, most of the scenarios would be profitable.

## **GERM SOAK WATER AS A NUTRIENT SOURCE TO IMPROVE FERMENTATION OF CORN GRITS**

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Bioethanol, an important renewable transportation fuel, can be produced in significant quantities from fermentation of sugars obtained from starch or cellulose. In the US, maximum ethanol is produced from corn, mostly using the dry grind process. Using heat treatment and enzymatic action, corn starch is converted to glucose monomers, which are fermented to ethanol by yeast. During whole corn fermentation, germ is a vital source of nutrients required for yeast performance. However, germ and pericarp are removed in the dry fractionation process, which results in lower ethanol yields and slower fermentation rates. Addition of external nutrition, such as lipid supplementation, germ soaking water and B vitamins have been reported to improve fermentation of dry fractionated corn grits [1-2]. Our objective was to investigate the potential of modified germ soaking water and its combination with other additives to improve fermentation yields of corn grits. Effects of these additives were observed for both conventional dry grind process and granular starch hydrolysis process. All experiments were performed using ground flaking corn grits at 25% solid loadings; results were compared in terms of ethanol rates and ethanol yields.

Complete fermentations for both conventional and GSH processes were observed with addition of germ water from soaking conditions of 30°C for 12 hr, compared to significant residual sugars for control (no germ water). Final ethanol yields were 29 and 8% higher than that of the control for conventional and GSH processes, respectively. For the conventional dry grind process, the fermentation rate of corn grits with germ soak water (0.492 v/v-h) was higher than that of control (0.208 v/v-h) and protease addition (0.324 v/v-h) but similar to B vitamin supplementation (0.484 v/v-h). Due to leaching of micronutrients and soluble proteins, the soaking process (30°C for 12 hr) increased germ oil concentrations by 36%, which enhanced germ economic value.

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## ACETONE-BUTANOL-ETHANOL PRODUCTION FROM APPLE POMACE BY ANAEROBIC FERMENTATION

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Global climate change, decreasing supply of fossil fuels and increasing energy demand have drawn the world's attention to alternative, sustainable and cost effective energy sources [1]. Food waste as an organic and nutrient reservoir can be utilized for high value compound production [2]. Apple pomace, as a major food waste generated after apple juice processing, is a rich source of carbohydrates and other nutraceuticals [3], making it a good feedstock for the generation of biofuels which are considered as environmentally friendly energy sources. The overall goal was to convert water soluble and insoluble sugars in apple pomace to acetone, butanol and ethanol (ABE) by anaerobic fermentation. First, water soluble sugars (WSS) were extracted from apple pomace by autoclaving (121°C, 30 min). The solid residue, rich in cellulose and hemicellulose, was pretreated with sulfuric acid and sodium hydroxide at different solid to liquid ratios (1:20 and 1:40), concentrations (1 and 2%, v/v or w/v), and times (30 and 60 min), followed by cellulase and pectinase hydrolysis to obtain acid hydrolyzed sugars (ACS) and alkali hydrolyzed sugars (ALS), respectively. Finally, WSS, ACS and ALS were used as feedstocks for anaerobic fermentations to produce ABE by *Clostridium beijerinckii* P260.

A total of 28.3 g/L WSS were obtained after water extraction. In addition, 40.3 and 36.6 g/L glucose were produced after sulfuric acid (1%, v/v, 60 min) and sodium hydroxide (2%, w/v, 30 min) pretreatments followed by enzymatic hydrolysis, respectively. After fermentation, 10.1, 10.7 and 10.8 g/L of ABE were produced from WSS, WSS+ACS and WSS+ALS, respectively. The process could generate high value ABE from renewable sources and solve the waste management problem of apple pomace.

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## **Symposium Speaker Abstracts**

## **CHALLENGES IN THE PULP AND PAPER INDUSTRY**

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The Agenda 2020 Technology Alliance, a nonprofit organization, exists to identify high priority, precompetitive technology challenges for the pulp and paper industry and to promote scientific research and development projects to address them. Member companies believe that certain major common challenges too large for individual companies to tackle alone can be best addressed through cooperation among producers, suppliers, universities and government agencies. The goals of the organization are: reducing water consumption and enhancing water reuse; reducing energy use and carbon emissions; increasing manufacturing process efficiency; improving raw material yield; and developing new biobased products. We will introduce the organization and highlight industry challenges with a focus on further development of cellulosic nanomaterials.

## **DOE BASIC BIOENERGY RESEARCH: BIOLOGICAL SYSTEMS SCIENCE**

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DOE's Office of Biological and Environmental Research funds basic research addressing key challenges in bioenergy development. We will highlight several programs and associated capabilities available to researchers and some examples of the science being produced within the portfolio. We will use this presentation as an introduction to basic bioenergy research funded through DOE's Office of Science.

**DOE BIOENERGY TECHNOLOGIES OFFICE FEEDSTOCK R&D:  
ADDRESSING FEEDSTOCK COST, QUALITY AND QUANTITY  
CHALLENGES FACING THE BIOREFINERY INDUSTRY**

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Biorefineries face many challenges associated with feedstock supply system establishment, sustainability and maintenance as well as in feed handling. We will present the US Department of Energy's BioEnergy Technologies Office (BETO) mission and vision, describe the main focus areas of the Feedstock Supply and Logistics Program within BETO (eg, advanced vs conventional feedstock supply systems) and discuss the results and implications of the recently released 2016 Billion Ton Report. We will provide an overview of the feedstock handling challenges confronting biorefineries as well as development of recent technologies to overcome these challenges from a consortium consisting of partners from national laboratories, academia and industry. We will share current funding opportunities available from BETO.

## **THE BIOECONOMY ROADMAP**

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NIFA has dedicated support for building the future bioeconomy that will increase rural prosperity, generate new markets for biobased products and improve ecological services such as clean air, water and soil health; as well as social, economical and environmental sustainability. We support an integrated risk mitigation systems approach that focuses on fundamental and applied research, formal and informal education and outreach, and technology deployment. USDA-NIFA does this in partnerships with other federal agencies and also seeks to promote public-private partnerships that leverage the entire effort that all sectors are working towards to encourage the bioeconomy.

This discussion will be focused on past, current and future programmatic activities from USDA and USDA-NIFA and seeks input from the S-1041 working group.

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