Northwest Advanced Renewables Alliance

2nd Cumulative Report

April 2013 - March 2014

Northwest Advanced Renewables Alliance

A New Vista for Green Fuels, Chemicals, and Environmentally Preferred Products

2nd Cumulative Report

April 2013 - March 2014

NARA is led by Washington State University and supported by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the USDA National Institute of Food and Agriculture.

NARA

Northwest Advanced Renewables Alliance

TABLE OF CONTENTS

NARA Strategic Analysis

2nd Cumulative Report

April 2013 - March 2014

STRATEGIC ANALYSIS

Background

In attaining the USDA NIFA aspiration goal for the Sustainable Bioenergy AFRI CAPs to *"facilitate the establishment of regional systems for the sustainable production of bioenergy and biobased products,*[1]*"* NARA is envisioning an aviation biofuels industry based upon residual materials from the existing softwood supply chain in the Northwestern US. In years 1 and 2 of our project, we focused on refining management systems and team coordination while establishing the individual technical and logistical components. Two major components that were added to aid us in evaluating progress during these early stages of the project were a Techno-Economic Analysis (TEA) on our conversion pathway and a project-wide Phase and Gate Process to guide our transition from Feasibility Assessment through to Commercialization. We have used the results of the analysis to guide the strategic direction of our project towards a continued effort to realizing a *"regional system for sustainable production of bioenergy and biobased products"*. The first two years brought us to a refined vision of how this industry might successfully develop.

One pathway is that of an integrated biorefinery with a single pretreatment process at its core. Through the first three years we have considered multiple thermochemical pretreatments that included mild bisulfite, wet oxidation, and dilute acid. Regardless of the pretreatment process, the functions and assets of such a facility could closely resemble integrated pulping facilities like those that existed in Bellingham, WA. The core of NARA's conversion research is striving to improve efficiencies, yields, and the economics of feedstock sourcing for such an approach.

Initially, economics of this model will necessitate retrofit of existing facilities in the region, ideally those with few existing product opportunities. Our supply chain analysis has demonstrated that a large-scale integrated facility located in the part of our region with lower biomass productivity (e.g. the NARA region east of the Cascade Range) would greatly benefit from rail-located biomass depots, to economically build the quantities of biomass needed for achieving economies of scale at the conversion site.

Our research has also indicated that a **second pathway for potential success may employ a distributed supply chain approach**. This distributed production model relies upon pretreatment and potentially saccharification processes moving upstream in the supply chains to depots. This pathway potentially benefits from additional opportunities to retrofit existing infrastructure including primary wood processing facilities and pulp mills (partial retrofit) for solid or liquid depots, ethanol plants for isobutanol production, and petroleum refining for alcohol-to-jet conversion.

The focus of our Year 3 efforts address the necessary technical research, integration, and scale-up to study feasibility of both pathways. In addition, the NARA Advisory Board specifically directed that the NARA leadership team *"should decide on a single pretreatment process to carry forward"* and *"use the Phase & Gate Analysis process to facilitate this action"*. We have followed these recommendations while continuing to develop impactful research to address our pathways as articulated above.

Approach

In response to this recommendation, the NARA Executive Team directed establishment of a coordinated evaluation of the mild bisulfite and wet oxidation pretreatment methods for a variety of technical metrics, co-products, and commercialization potentials. The process was led by NARA Process Development Analyst, Linda Beltz, and contributed to by all of the NARA Pretreatment, Co-Products, Conversion, and Sustainability Teams.

In addition, the techno-economic analysis (TEA) developed in Year 2 (see Task SM-TEA-1: Techno-Economics Analysis of the 2013 NARA Cumulative Report) was used to assess the specific role of multiple revenue streams from likely co-products developed in the process. To supplement the TEA effort, improvements were continually sought in reducing feedstock costs (Task FL-1: Feedstock Sourcing) and delineating supply chain assets (E-3: Regional Integrated Design Experience – IDX) within our NARA region. At this point, our team is focusing on a supply region spanning the Washington-Oregon border on the west-side of the Cascade Mountains (MC2P – Mid Cascade to Pacific Region). Stakeholder development was targeted by the Outreach Team to engage our new region and develop relationships focused in the states of Washington and Oregon. These groups were specifically developed to assist in supply chain development in the new MC2P region.

[1] USDA NIFA Agriculture and Food Research Initiative Competitive Grants Program.
Sustainable Bioenergy – 2010 Request for Application_http://www.grants.gov/search/synopsis.do;jsessionid=RvWPRSFJ2C2gNjyTL2K0G519XXJLCBcTTHyXT4pVH67H74WDGsYh!1654183736

Summary of Findings

TECHNO-ECONOMIC ANALYSIS

We found in Year 2, assuming a (1) complete greenfield construction of an integrated biorefinery and (2) a 20% internal rate of return, the current cost estimate for producing biojet (IPK) from forest residuals will be 2 to 3 times the current cost of petroleum jet fuel if the biorefinery is designed to produce only aviation biofuel products. With optimistic estimates for improved yields throughout the process, this value might be lowered to 1.45 times the cost of the petroleum equivalent.

In Year 3, we focused the TEA on discerning the impact of potential co-products on the revenue stream for a biorefinery. In this process we considered two commercially viable co-products: (1) lignosulfonates used for concrete additives, and (2) activated carbon to be used for mercury adsorption in coal fired power plants. Other revenues included the sale of alternative jet fuel at cost parity with petroleum, the RIN value of this fuel, and the sale of isooctane, which is a byproduct of producing biojet. After adjusting the expected capital and operating expenditures for the added co-product production, an internal rate of return (IRR) of 12.5% (Figure SA-1) is realized. This profit margin is still unlikely to be sufficient for investments of the magnitude required to build an integrated biorefinery through greenfield development. Our efforts in Year 4 will focus on assessing the value that retrofit of existing pulp mill facilities might bring to the computed IRR for a pulp-mill based, integrated biorefinery.

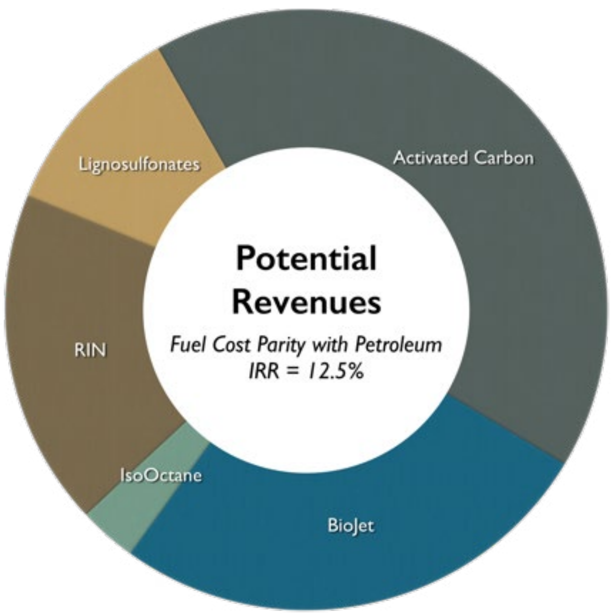

Figure SA-1. Summary of the current status of the techno-economic analysis for an integrated biorefinery producing biojet (IPK) and lignin co-products using forest residuals as a feedstock assuming a complete greenfield construction. Relative contributions of individual revenues are provided for analysis.

FEEDSTOCK COSTS

Feedstock remains the single largest cost item within the integrated biorefinery TEA. In an effort to improve our processing efficiency, NARA undertook an extensive study of feedstock preparation. In this effort, slash piles were deconstructed, the materials were categorized, moisture levels were controlled, and all the materials were processed at a controlled site with actual harvesting equipment. Processing energy was monitored carefully to assess fuel usage. By controlling biomass size, bit type, and moisture content, this effort has demonstrated pathways that will result in ca. \$30/bone dry ton (BDT) savings to the feedstock production (Figure SA-2).

DISTRIBUTED SUGAR PRODUCTION

The core of a distributed production model is the ability to pretreat on a small scale in facilities where residues are readily available, e.g. sawmills. NARA has been investigating a pretreatment method that would be based solely on mechanical milling technologies (Figure SA-3). These efforts have been supported by work to design supply chain technologies and systems around this distributed production. For more information, see tasks C-P-5 (Clean Sugar and Lignin Pretreatment Technology, p-59) and E-8 (Distributed Sugar Depot, p-244) in this report.

The targeted energy consumption by the pulverized wood operations has been used for a techno-economics analysis (TEA) for clean sugar and lignin production from forest residual chips. Based on this TEA, if the targeted energy consumption of wood milling is met or achieved within the range of 0.56-0.84 kilowatt-hour/oven dried kg wood at a sugar conversion yield of about 58-65%, the economics by milling as a pretreatment technology looks plausible for clean sugar and lignin fuel pellet production. Examination of the milled wood sugar by Gevo is ongoing, but preliminary assessments indicate that organism growth and isobutanol production are excellent. Overall, the distributed production scenario demonstrates continued benefits for consideration.

OUTREACH AND EDUCATION TEAM SUPPORT

The assessment of existing regional assets to be applied to the emerging biofuels industry in regional supply chains is a key component of our Goal 3: Supply Chain Coalitions, and is carried out by our Outreach and Education Teams. This effort not only produces supply chain analysis resulting in site ranking and design, but critically links stakeholders to this effort to engage them in these efforts and involve them in the development of a future biofuels industry.

Efforts of the Outreach Team were successful at aligning State of Washington economic development programs with our fuels vision. A state grant was provided by the Washington Department of Commerce to assist a NARA member, Cosmo Specialty Fibers, in evaluating the potential to expand their operation to include biochemical and sugar products. NARA education teams worked with Cosmo and other regional stakeholders in western Washington and Oregon to envision supply chain nodes in the Mid-Cascade to Pacific (MC2P) region that spanned the Washington-Oregon border. These efforts resulted in site designs for facilities that included both solid and liquid depots for the distributed manufacturing model as well as integrated biorefinery designs. As a result of these combined Education and Outreach efforts, Cosmo announced at our 2013 stakeholder meeting in Seattle that they were pursuing a biorefinery business model.

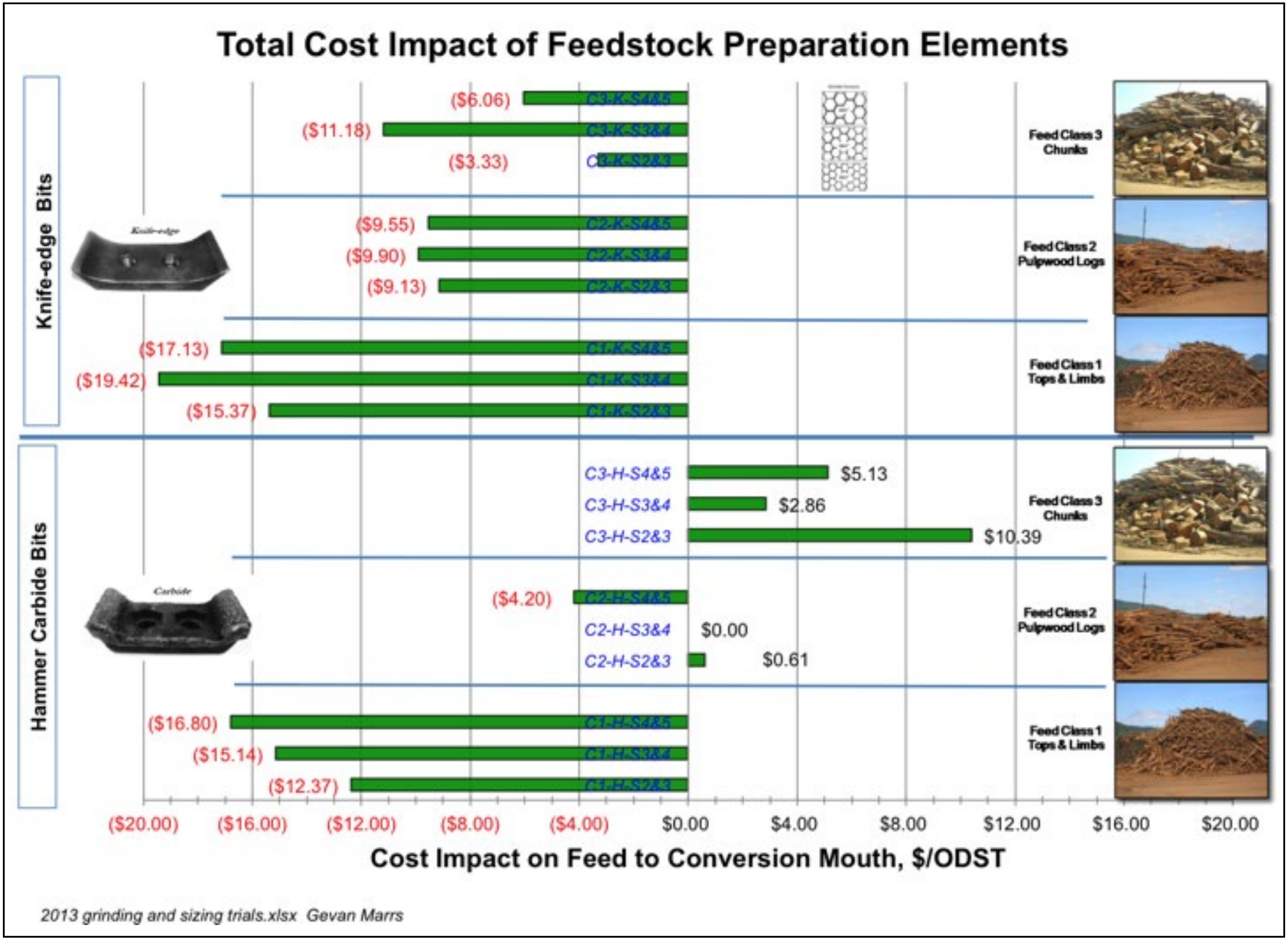

Figure SA-2. Summary of the cost impact on feedstock conversion costs for a variety of biomass and processing bit types

Figure SA-3. Milled wood powders of FS-10 chips, under various milling time, 30, 60, 80, and 100 minutes. Varying color of milled wood samples corresponds to milling temperatures. All materials were directly hydrolysable after milling with no chemical treatment.

Future Directions

Given the need to increase production efficiency by decreasing feedstock costs and reducing capital costs, we recommend the following:

- Continue seeking regional assets that might be retrofit for an emerging biofuels industry. These facilities include primary wood processing plants for depots, pulp plants for pretreatment and hydrolysis, and ethanol plants for fermentation. We will perform an analysis of the four-state NARA region.
- Specifically evaluate the potential of a retrofitted facility by providing a modified TEA around the strategy of converting a bisulfite pulp mill into biofuels, biochemical, sugar, and lignin products.
- Further assess the role of feedstock densification prior to shipping in decreasing feedstock costs.
- Produce a full simulation and TEA of a sugar depot to further evaluate the role of distributed manufacturing.
- Seek commercial partners for our carbon co-products development.
- Develop a firm commercialization strategy that will culminate in 1,000 gallons of biojet fuel produced as an initial demonstration effort.

NARA Goal One

2nd Cumulative Report

April 2013 - March 2014

Sustainable Biojet

Develop a sustainable biojet fuel industry in the Pacific Northwest that uses residual woody biomass as feedstock.

SUMMARY

All the activities in the NARA project contribute to the goal of providing an industry road-map used to sustainability produce jet fuel (biojet) from wood residuals in the Pacific Northwest, and some activities contribute directly to the technology of this process. The NARA Feedstock and Conversion teams are focused directly on securing the wood residual feedstock and integrating the technologies employed to convert this feedstock into fuel. Specifically, the following efforts provide an integrated approach to creating a viable pathway from forest residuals to biojet:

1) Feedstock Logistics team: Integrating feedstock collection, preprocessing, and transportation to deliver cost effective materials suitable for conversion
2) Feedstock Development team: Focusing on identifying growing stock varieties amenable to sugar production and delineating traits responsible for increased volume production in Douglas-fir trees
3) Pretreatment team: Refining effective pretreatment methods to release sugars from representative forest biomass
4) Aviation Biofuels team: Refining the Gevo fermentation/separation and WSU BioChemCat processes to produce aviation biofuels from representative pretreated forest residuals.

FEEDSTOCK LOGISTICS

The NARA feedstock team is divided into two efforts: feedstock logistics and feedstock development. For this reporting period, the feedstock logistics team evaluated methods to improve the costs associated with processing and transporting forest residuals. The processing considerations evaluated were grinding, bulk density and sizing. A collaborative economic analysis indicates that accommodations to process oversized “overs” and undersized “fines” feedstock chips adds little impact to feedstock costs, whereas, methods to improve grinder and transport efficiencies had a significant impact on cost. The feedstock costs associated with grinding can vary as much as $22 per oven-dried short ton. Lowest grinding costs were achieved by: a) starting with smaller sixed pieces, b) grinding to larger final sizes, and c) using (sharp) knife bits instead of (blunt) hammer bits (Task FL-1).

Improved transport efficiencies are correlated with higher bulk density of the load. Blower tests on dry forest residues suggest significant gains in bulk density can be achieved by vertical acceleration of dry grindings. NARA’s goal is to achieve 22 bone dried tons (BDT) per chip truck with a combination of lower moisture content coupled with increased bulk density. This would reduce transport costs up to 33%. In addition, results show that the tops and limbs gave higher bulk densities for all conditions. Methods to improve bulk density could reduce feedstock transport costs by as much as $10 per oven-dried short ton (Task FL-2.4). A forest residue decision support system (Residue Evaluation and Network Optimization, RENO) was completed and is designed to improve processing and transportation costs (Task FL-2.3).

The range of net feedstock cost variation when considering grinding, bulk density and sizing options together is $30 per oven-dried short ton. This amount of change to feedstock costs in the NARA base case economic analysis changes total costs by more than $25 million per year. This variation affects the overall project internal rate of return (IRR) by about 1.4%. (Task FL-1.1).

Additional efforts undertaken to improve the cost of processing forest residuals include developing models to predict biomass availability and moisture content. Fieldwork performed to establish recovery coefficients at various costs for forest residual collection has been completed. A statistical model incorporating these recovery coefficients plus field procedures will be implemented in July 2014 and used to determine recoverable biomass from timber product output (TPO) data (Task FL-2.1). Field data for a forest residue collection model was completed February 2014 and will be incorporated into the forest residue decision support system RENO (Task FL-2.3). For the past year, temperature, humidity and radiation sensors have recorded data from slash piles, and the moisture content for live branch wood has been recorded. This data collection will conclude July 2014. Preliminary results indicate that live branches have moisture content lower than 50% in most tested sites during fall and winter seasons (Task FL-2.2).

FEEDSTOCK DEVELOPMENT

For this reporting period, the feedstock development effort has initiated screening Douglas-fir seedlings for drought response. To screen Douglas-fir seedlings, a pilot experiment was performed in which 50 Douglas-fir seedlings were screened at the WSU Phenomics facility (Task FD-2). This pilot screening helps establish the protocol used for an experiment planned in the summer of 2014 to screen over 1000 Douglas-fir seedlings.

The data from the drought screening will be combined with data derived from quantifying Douglas-fir chemical composition and recalcitrance among multiple individuals. These data will contribute to developing a Douglas-fir phenotype profile that can be linked to DNA samples assembled on a single nucleotide polymorphism (SNP) chip. The chemical composition and recalcitrance screening has advanced from last year, as 265 new tree samples have been tested. A “recalcitrance factor” parameter has been developed to quantify the degree of recalcitrance among tree samples (Task FD-5). A limited number of Douglas-fir DNA samples will be used to generate a SNP chip, therefore, initial screening steps to narrow the pool of samples has begun. A breeding simulation and testing program has been developed to assist in this process.

Significant Feedstock Team outputs for this reporting period are listed below.

- Slash pile measuring techniques were evaluated. This information is used for biomass availability models and for harvest operations planning (Task FL 2.3). http://www.ingentaconnect.com/content/saf/fs/pre-prints/content-saf_0015749x_forsci13001
- A computerized model, Residue Evaluation and Network Optimization (RENO), was completed. It is used to estimate the cost of processing and transporting forest residuals at the operational level. This model is designed to improve processing and transportation costs and is being introduced to stakeholders (Task FL 2.3). http://forestprodjournals.org/doi/abs/10.13073/FPJ-D-13-00031

PRETREATMENT

The Pretreatment team's efforts this year were focused on increasing the scale of operations and selecting a single preferred pretreatment method for continued focus in Year 4 and 5. This effort was informed by technical performance, economics, co-product opportunities, and commercialization potential and was evaluated using a phase and gate analysis. This extensive process culminated with the mild bisulfite (MBS) pretreatment protocol selected as the single pretreatment method used to produce a NARA deliverable of 1000 gallons of jet fuel. Downselection to the MBS process represents a major NARA milestone and allows for a single pretreatment protocol to be considered for the NARA techno-economic analysis (TEA) and life cycle assessment (LCA). The mild bisulfite pretreatment protocol is a modification of the SPORL process and was developed by NARA affiliates Catchlight Energy and the USDA Forest Products Laboratory.

In downselecting to the MBS pretreatment, the MBS and wet oxidation (WOX) protocols were optimized using the FS-10 feedstock sample. Under optimized conditions for each pretreatment protocol, a mass balance was generated, hydrolysate was tested for fermentability, and the solid and liquid residuals were tested for co-product development (Task C-P-3, C-P-4, C-P-1). The downselection process considered these results along with economic and environmental considerations, plus feedstock and infrastructure compatibility. The NARA Advisory Board and Executive Committee reviewed the comparisons and made recommendations with the final selection made by NARA's Executive Director Ralph Cavalieri.

Improvements to the MBS pretreatment protocol include a reduction of sulfur dioxide applied to wood from 12% to 6% and a cook temperature reduction from 165°C to 145°C. It was also demonstrated that pretreatment efficiencies could occur without significant chip size reduction. These changes improve energy efficiency, reduce chemical cost and generate fewer inhibitors to the fermentation process. An integrated pretreatment/fermentation plant is economically better than a situation where sugar must be shipped to an existing ethanol plant, and producing hydrolyzing enzymes on site is more economical than purchased enzymes (Task C-P-4.1).

Another pretreatment strategy investigated this year involves wood milling. The distinction of wood milling compared to MBS and WOX pretreatment is that no chemicals, water or high temperatures are required. In areas such as the Pacific Northwest where electricity is relatively inexpensive, wood milling may prove to be an attractive pretreatment alternative. The wood milling process has four steps: (1) wood residuals chipping; (2) chip size reduction before drying; (3) chip drying to reduce chip moisture from 50% to 10%; and (4) wood milling.

During this reporting period, FS-10 feedstock samples were reduced by two grinding technologies and characterized for particle size. The reduced samples were then milled and hydrolyzed. The hydrolysate was sent to Gevo for fermentation analysis and to the NARA Co-Products team for co-product development. The carbon dioxide emissions associated with the wood milling drying process were measured and will be used for a later life cycle assessment. Energy usage was calculated for all four steps in the milling process and will be used to generate a techno-economic analysis. Based on the small-scale milling results generated thus far, the total energy requirement for wood milling could range from 1.45 to 1.73 kWh/oven-dried kg. The energy usage data for this process will be refined when large-scale milling (currently underway) is analyzed.

Significant Conversion Team outputs for this reporting period are listed below.

- MBS (mild bisulfite: based on the SPORL pretreatment protocol) pretreatment temperature at 145°C is superior to a previous 165°C temperature both economically and in reduced inhibitor formation (Task C-P-4). http://www.sciencedirect.com/science/article/pii/S1359511313007435
- The SPORL pretreatment protocol was optimized using Douglas-fir forest residuals. http://www.sciencedirect.com/science/article/pii/S0961953413003607

AVIATION BIOFUELS

The NARA Aviation Biofuels Team focused on two fermentation technologies: Gevo's fermentation, separation, and upgrading process and Washington State University's (WSU) BioChemCat process managed at the WSU-Bioproducts, Sciences & Engineering Laboratory (BSEL). During this reporting period, Gevo characterized the pretreated hydrolysate generated by the SPORL, wet-oxidation, mild bisulfite and mill wood pretreatments on FS-10 feedstock. Hydrolysate characterization included sugar and inhibitor analyses and fermentability to isobutanol. These characterizations were considered in the pretreatment downselect process (see Phase Gate model in the Organizational Structure chapter).

The isobutanol producing biocatalysts being developed are stable and continue to improve in growth rate and isobutanol production. Sodium hydroxide was substituted for ammonium hydroxide to balance pH, which reduced impurities significantly. In a 1 liter GIFT® system, biocatalyst growth rates and isobutanol production were measured in 60% hydrolysates derived from varied pretreatment processes. Growth rates were relatively similar within each hydrolysate; however, isobutanol production varied with the highest isobutanol production and hexose consumption generated from the MBS hydrolysate. A 20L GIFT® pilot scale system was designed and built for future scale-up trials.

Gevo provided NARA mass and energy balance information and capital expenditure (CapEx) costs covering Gevo's process of converting sugars into isobutanol, which is combined to form iso-paraffinic kerosene (IPK). This data will be incorporated into the NARA techno-economic and life cycle assessments. The saccharified biomass sugars are fermented and isobutanol recovered in a process essentially identical to the corn mash process currently being used at Gevo's plant in Luverne, MN. Preliminary analysis of isobutanol quality derived from Douglas-fir biomass and corn starch are very similar.

WSU BSEL fermented carbohydrates, derived from FS-01, FS-03 and FS-10 feedstock samples pretreated by wet oxidation. Calculated yields of volatile fatty acids produced ranged from 410 kg/ton biomass to 510 kg/ton. These results translate to a range of 60.1 gallons to 74.8 gallons of jet fuel per biomass ton, with FS-01 (clean wood chips) producing the highest results.
Three different separation methods: (i) pressurized carbon dioxide extraction; (ii) ion exchange resin-mediated extraction; and (iii) esterification have been investigated for efficiency in extracting organic acids from the fermentation broth.

While the extraction of volatile fatty acids (VFAs) using pressurized carbon dioxide and ion exchange show high recovery rates, the technology at its current stage can be considered expensive. Conversion of VFAs into mixed alcohols by esterification has been initiated. To integrate the fermentation/conversion process into a continuous system, a lab-scale catalytic system has been designed and is currently in the process of being set-up at the BSEL laboratory (Task C-AF-2).

NARA Goal Two

2nd Cumulative Report

April 2013 - March 2014

Value-Added Polymer and Carbon Products from Lignin

Create valuable co-products made from lignin, which is an industrial byproduct of the woody biomass to biojet process.

SUMMARY

Based on current estimates, for every bone-dry ton of forest residue converted to isobutanol, three quarters remain as residual material called co-product residuals (Tom Spinks presentation at the Idaho Small Log Conference 2013). Approximately 37% of the co-product residual is lignin (550 dry pounds) with the remainder being cooking acids, non-reacted cellulose (polysaccharides), non-fermented monomeric sugars, extractives, bark, yeast bodies, and wood ash. The most common strategy for dealing with these residual solids is to recover their fuel value to assist in heating and providing electrical power for facilities. While this strategy remains as a potentially valid one, NARA researchers are developing new products from the residual solids that provide a higher value than current use for energy. Creating high-value products from the residual solids is essential to establish a value-chain for improved bio-refinery profitability.

RESIDUAL SOLIDS AS MATERIAL FOR ACTIVATED CARBON AND SUPERCAPACITORS

To meet this challenge, NARA's co-product residual research has progressed on multiple fronts. In the first cumulative report spanning 2011-March 2013, residual solids generated from enzymatic hydrolysis on FS-03 samples were collected from the four pretreatment processes evaluated (SPORL, mild bisulfite, wet oxidation, and dilute acid), and characterized for lignin, carbohydrate and ash content. Experiments to generate activated carbon from the residual solids remaining after fermentation were initiated.

For this reporting period, hydrolysis residual solids (HRS) and fermentation residual solids (FRS) were characterized (carbohydrate and lignin analysis) from Douglas-fir FS-10 samples pretreated by optimized wet oxidation (WOX) and mild bisulfite (MBS) protocols. In addition, methods have been developed to extract high purity lignin from these samples to test how lignin chemistry is affected by the WOX and MBS pretreatment protocols (Task C-CP-2.1.1).

Powdered activated carbon (PAC) was prepared from the FRS derived from the MBS and WOX pretreatment processes and is being evaluated as a material used for vapor phase mercury capture from coal power plant flue gas and for electrodes in supercapacitors (Task C-CP-2.2). The porous structure of the activated carbon samples was investigated by gas physisorption using two absoptives, nitrogen and carbon dioxide. Experiments show that the activated carbon derived from MBS and WOX pretreatment samples differs in porosity. Activated carbon derived from MBS has a larger pore size than WOX derived activated carbon. A larger pore size may allow for enhanced absorbance and ion conductivity. To test the mercury absorbance capacity, PAC samples generated from the MBS and WOX pretreated material were sent to the URS Corporation for analysis. Results from this analysis are being evaluated, and additional partners are being sought for further testing and pilot scale evaluation. The revenue potential from the activated carbon could be substantial and contribute significantly towards the biorefinery profitability.

Initial supercapacitor performance tests suggest that MBS carbons demonstrate a more capacitive behavior compared to WOX carbons.

LIGNIN USE AS THERMOPLASTIC MATERIAL

A more long-term directive is to evaluate the use of co-product residuals as a component in thermoplastics used for residential insulation and food and beverage packaging. Initial attempts to form thermoplastics using the lignin-rich solids generated from pretreated material were unsuccessful. The lignin-rich material generated from dilute-acid pretreatment contained relatively high carbohydrate content combined with low molecular weight lignin. These conditions prevented favorable cohesion. Methylated ligninsulfonates obtained from sulfite pretreatment processes, on the other hand, readily formed cohesive materials, but the casting conditions employed generated voids within the materials produced. Methylated ball-milled softwood lignin (MBML), which is a relatively purified lignin source and not produced by available pretreatment processes, does produce polymeric material exhibiting ~50% tensile strength and elongations at break around 8%. Work this year focused on improving MBML polymer characteristics by introducing blend components (Task C-CP-1.3). Perhaps the most promising methylated ball-milled lignin-based blend was one containing only 5% w/w (400 molecular weight) poly(ethylene glycol) that exhibited a 65 MPa tensile strength with an elongation at break near 10%. It is intended that once optimal blend components and casting conditions for MBML are established and characterized, that this understanding will be adapted to generate polymers from the lignin rich material generated through the pretreatment process (C-CP-1).

PARTIALLY DEPOLYMERIZED LIGNIN AS A BUILDING BLOCK FOR CHEMICAL SYNTHESIS

Our final co-products effort is aimed at partially depolymerizing the high molecular weight and recalcitrant form of lignin that results from the enzymatic hydrolysis and fermentation process. The goal of producing partially depolymerized lignin (PDL) is to create building blocks used to engineer high value polymers. In the previous cumulative report, two depolymerization protocols, mild hydrogenolysis and base-catalyzed depolymerization (BCD), were evaluated on their ability to depolymerize Kraft lignin and the lignin derived from dilute acid (DA) pretreated residual solids after enzymatic hydrolysis. For this reporting period, the mild hydrogenolysis and BCD depolymerization protocols were also applied to the lignin derived from forest residuals pretreated by the mild bisulfite

(MBS) and wet oxidation (WOX) processes. Depolymerization yields from the BCD treatments ranged from 55.2% to 88.8% depending on temperature and pretreatment sample with the highest yield and hydroxyl value resulting from the DA sample. Yield of conversion to PDL using the mild hydrogenolysis protocol ranged from 70 to 82% with a temperature optimum of 180ºC. Hydroxyl values ranged from 3.58 (DA pretreatment) to 4.68 (WOX pretreatment). The mild hydrogenolysis treatment relies on less chemicals and is performed at lower temperature that the BCD, which makes it a more attractive PDL treatment in terms of energy use and chemical cost. PDL solubility in organic solvent is an important consideration for chemical modification. The lignin subjected to hydrogenolysis dispersed well in organic solvents whereas non-depolymerized lignin was insoluble. Taken together, these results suggest that partial depolymerization methods tested produce high yields of depolymerized lignin from all pretreatment sources and that the depolymerized lignin is soluble in organic solution.

A PDL-epoxy was made from lignin derived from DA and MBS pretreated samples. These resins show promising properties with the PDL-epoxy derived from MBS material demonstrating superior mechanical properties over the PDL-epoxy derived from DA pretreated material (Task C-CP-3.2)

In addition to the PDL work, preliminary experiments to modify lignin in solid states, i.e., performing the reaction in a ball mill, have been initiated. Fatty acids were successfully introduced onto lignin to modify the lignin characteristics with the intent of producing lignin-based materials suitable as a blend in thermoplastics.

LIGNIN CONVERSION TO INDUSTRIAL CHEMICALS

During this project period, a new pathway was discovered to selectively covert biorefinery lignin to dicarboxylic acids (DCA), including muconic, maleic, and succinic acids. These DCAs are highly valuable industrial chemicals and platform intermediates used in many areas including biopolymer, pharmaceutical, and food additives industries (Task C-P-2.1). Conversion optimization and a techno-economic analysis for this pathway is in progress. In addition, an alkaline peroxide pretreatment protocol has been developed. When applied to Douglas-fir samples, the treatment converts hemicellulose simple sugars into valuable organic acids, such as lactic acid and succinic acid (Task C-P-2.3).

Significant outputs to date from the teams involved with co-product development are listed below.

- Published partial depolymerization results of lignin (Task C-CP-3.2). http://www.sciencedirect.com/science/article/pii/S0960852413019329
- A new pathway was discovered to selectively convert biorefinery lignin to dicarboxylic acids (DCA), including muconic, maleic, and succinic acids. These DCAs are highly valuable industrial chemicals and platform intermediates used in many areas including biopolymer, pharmaceutical, and food additives industries (Task C-P-2.1). http://onlinelibrary.wiley.com/doi/10.1002/cssc.201300964/abstract

NARA Goal Three

2nd Cumulative Report

April 2013 - March 2014

Rural Economic Development

Enhance and sustain rural economic development.

SUMMARY

Sustainability is the crucial attribute necessary for the emerging biofuels industry to develop our rural economy. The NARA project is assessing sustainability of this emerging industry using a triple bottom line approach of assessing economic viability (techno-economic analysis (TEA)), environmental impact (life cycle assessment (LCA)), and social impact (community impact analysis (CIA)). In addition to developing these three primary analytical tools, additional primary data is being collected. These data include social and market data through the Environmentally Preferred Products (EPP) team and environmental data through the Sustainable Production team. The following efforts within the Systems Metrics program are integrated to provide a sustainability analysis of the project:

ENVIRONMENTALLY PREFERRED PRODUCTS

The Environmentally Preferred Products Team (EPP) evaluates the social viability of the industry. This analysis of social sustainability investigates stakeholder needs and perceptions, community social assets, market opportunities for biojet and co-products, and governmental regulations and incentives for renewable products. To evaluate community social assets and predict bioenergy behaviors, the EPP Team completed and published a biogeophysical and social asset assessment for the western Montana corridor (WMC) region. This deliverable represents a NARA milestone and generates a two-tiered index that considers biogeophysical and social assets used to select facility site locations (Task SM-EPP-1.1.) The methodology will be applied to other regions within the NARA four-state operating area.

Work has been completed identifying co-products and intermediate products that are produced during the wood-isobutanol-biojet life cycle and describing their application. Future work will focus on identifying common bio-product attributes related to these co-products/intermediates that indicate how the market signifies environmental preference (Task SM-EPP-1.2).

To evaluate stakeholder needs and perceptions, a stakeholder survey was developed during the last reporting period. As of November 2013, the survey was distributed to 868 stakeholders targeted in the NARA four-state region with a response rate of 37% (324 responded). Non-response bias testing has been completed and survey analysis is in progress. (Tasks SM-EPP-1.4,O-7 (see supply chain coalition report)).

To provide a techno-market assessment for jet fuels, a final literature review of global biofuels policies is in progress, with an emphasis on how these legislative tools will impact the industry moving forward. A specific focus will be on the downstream portion of the biofuels supply chain in the U.S., from biorefinery to end-user. Comparisons and contrasts with EU biofuels policies will also be examined. Parallel to these efforts, managers at the Seattle (SEA) and Portland (PDX) airports were interviewed to provide insight into aviation fuel logistics and ownership. This effort lead to the development of a jet fuel logistics, policy, and social science team, that will develop and administer a stakeholder survey of key aviation fuel supply chain stakeholders in the NARA region including airport management, fuel traders/brokers, fixed-based operators, and terminal and pipeline operators. A database of all NARA region commercial airports and terminals is in progress (Task SM-EPP-1.6). A techno-market assessment for bio-products and polymers is also underway (Task SM-EPP-1.7).

An environmental assessment to using lignin-rich residuals, generated from the SPORL and wet oxidation pretreatment procedures, to produce activated carbon shows CO_2 emissions reduced by over 80% compared to a fossil fuel–based kerosene baseline. This reduction greatly exceeds the Renewable Fuel Standards emission reduction thresholds. A similar assessment compared CO_2 emissions generated from producing plastic bottles made from polyethylene terephthalate (PET) derived from forest residual feedstock and fossil-based feedstock. Preliminary results show that manufacturing bio-based bottles derived from forest residual feedstock results in CO_2 emissions decreasing by 9% relative to the fossil-based development (Task SM-EPP-1.9).

LIFE CYCLE ASSESSMENT

The Life Cycle Assessment (LCA) Team assesses the environmental and economic impacts of producing aviation biofuels with our chosen pathway and compares it to the petroleum products for which it will substitute. For this reporting period, teams were assembled to generate LCA data for co-product development (see task SM-EPP-1.9), pretreatment (SM-AM-1) and conversion processes (Task C-AF-1). A LCA on the mild bisulfite and wet oxidation pretreatment process was generated and incorporated into the data set that directed the pretreatment downselect process (see Phase and Gate segment in Organizational Structure). A preliminary "feedstock" LCA, incorporating primary data for the western Montana corridor region feedstock, has been accepted for publication and represents a significant NARA milestone. A preliminary LCA report structure following the ISO 14044 guidelines has been developed.

COMMUNITY IMPACT ASSESSMENT

A preliminary community impact assessment (CIA) has been developed for the western Montana corridor (WMC) region. A literature review and sensitivity analysis that incorporates co-product outputs will be added to the report prior to publication. A preliminary CIA was applied to the western Washington region.

This initial assessment suggests that a biorefinery could generate as many as 1,243 jobs within forestry, transportation and the refinery operations. Indirect and direct economic impact of this refinery could total $513.4 million.

A significant output for the EPP, LCA and CIA teams is:

• A biogeophysical and social asset assessment for the western Montana corridor region has been published. This work establishes a method used to quantify a region's social capability to embrace a wood to biofuel industry (Task SM-EPP-1.1). http://www.sciencedirect.com/science/article/pii/S0961953414002086

To provide more specific information regarding the influence of removing forest residuals on sites, soil, and water, the Sustainable Production Team evaluates the influence of biomass harvesting scenarios, develops potential forest management prescriptions, assesses forest residual availability from harvest of highly managed stands, and considers the impact of industry feedstock requirements on overall supply chain dynamics. In whole, this team provides a host of primary data used to verify and reduce a variety of potential impacts from this new industry. Teams evaluating the effects of forest residual removal on soil carbon and nitrogen levels at the Fall River Long Term Soil Productivity (LTSP) site found that removing forest biomass had little impact on future tree productivity. Additional, yet less intensive research, at 73 other coastal Douglas-fir plantations from northern Vancouver Island, BC, Canada to southern Oregon is being used to give the Fall River work more impact and perspective. Publications addressing the effects of vegetative control on biomass growth, deep soil carbon, and methods to calculate standing biomass were completed in this reporting period, and work to evaluate stump decomposition rates has been initiated (Task SM-LCA-1.1). At the NARA LTSP site located near Springfield Oregon, soil samples were collected pre- and post- logging and residual removal operations so that density fractions and carbon and nitrogen content can be monitored (Task SM-SP-8). In addition, lysimeters were installed to record how forest residual removal affects nitrogen and carbon cycling in the soil (Task SM-LCA-1.1).

The NARA LTSP site is structured to provide long-term analysis on the impacts of forest residual removal and soil compaction on soil and plant productivity. The site is also used to study forest residual removal impact on water effects and wildlife. For this reporting period, timber harvest was completed on the 83-acre site and 28 1-acre plots were treated with a factorial of biomass removal and soil-compaction treatments. Weather stations plus soil moisture and temperature monitoring equipment were installed. Post harvest, 5000 conifer seedlings were planted and will be monitored for productivity against various treatments. Fencing was installed to protect the seedlings (Tasks SM-SP-1, SM-SP-8). Equipment has been purchased and a study plan submitted to evaluate how forest residual removal affects stream erosion and water retention in the soil (Task SM-SP-5-water). In addition, study plans are being developed to monitor soil microbial communities (Task SM-SP-5-water) and ground-nesting bees (Task SM-SP-6) for their response to harvesting treatments. A manuscript was submitted for publication that describes the range of management practices used to harvest biomass, and the types of forest organisms known or expected to be impacted. This initial work will direct future experiments to further understand the impact of forest residual removal on wildlife (Task SM-SP-6).

To understand the impact of prescribed fires, including slash pile burning, on local-to regional-scale air quality, air pollutant emissions data related to prescribed fires was obtained and used for simulation modeling. Results show that emissions in western states vary significantly by month with most of the burning taking place in October and November. A modeled simulation comparing the emissions on an October day with or without prescribed burning showed that prescribed burning can result in significant atmospheric loading of particulate matter 2.5 micrometers or less (PM2.5). This data shows the local importance of prescribed fires and the potential air quality benefits to be gained from harvesting these fuels for the biojet supply chain as opposed to burning them (Task SM-SP-5).

Multiple efforts are being conducted to provide analysis and tools used to determine the amount of sustainable forest residual feedstock in the NARA four-state region. In order to better quantify the amount of standing residual biomass on a site, two seasons of biomass sampling has been completed. The data generated from this activity was used to develop allometric equations. The equations predict biomass quantities of live and dead branches, foliage, heartwood, sapwood, and bark for trees ranging from 10-77 cm in diameter at breast height (dbh) and 10-57 m in height and nutrient content. The biomass equations have been incorporated into ORGANON and CIPSANON growth models, enabling users to estimate biomass components of trees and stands. The work described represents a NARA milestone and should improve biomass estimates and allow managers to simulate the effect of varied harvesting options (Task SM-SP-4). Using data from the forest inventory and analysis program (FIA), a volume/biomass model based on the forest vegetative simulator (FVS) has been completed and applied to all plots in the NARA sub-regions to generate forest residual yield files. This model allows wide flexibility in specifying biomass pools. In addition, a transport cost model, based on commonly available GIS mapping functions, was completed and recognizes multiple road standards in computing both costs and diesel consumption in moving from each FIA plot to any desired set of log/biomass mill destinations. These tools were used to develop biomass cost curves for potential bio-refineries in Cosmopolis and Longview Washington and will provide simulations to study environmental, market and management impacts from forest residual removal (Task SM-SP-3). A survey of local and regional USFS silviculturists and NEPA planners was completed in order to understand the range of potential silvicultural options that are currently being implemented on agency lands. These prescriptions were incorporated into a model framework to test the impact that both prescription form and harvest intensity have on potential wood supply and fire hazard mitigation. This work satisfies a NARA milestone and will tie directly into the biomass availability model completed by NARA, allowing for a more accurate model simulation reflecting USFS decision options and the accounting of stand-level impacts of silvicultural treatments on future structural conditions and potential fire hazards (Task SM-SP-2).

The amount of forest residual feedstock is highly dependent on logging operations. Montana's Bureau of Business and Economic Research (BBER) Forest Industry Research Group established a database online that provides timber harvest data by county in CA, ID, MT, OR and WA. The BBER staff completed data sets for mill residue production in ID, MT and OR and are nearly complete with the WA data. This activity represents a NARA milestone and will be used for biomass availability modeling. The data indicates that virtually all mill residues currently produced in the region are used for either internal energy purposes or sold for a variety of industrial uses (primarily pulp and reconstituted board production). Bioenergy firms (such as NARA biomass pretreatment plants) will face competition for mill residues from current residue users. In this reporting period, BBER staff measured 700 trees at 25 sites to understand how felled logs are utilized. Since NARA inception, over 2000 trees from 81 sites have been measured. NARA teams use this data to understand the amount of residual biomass available from harvesting activities. Initial results indicate that logging residues as a fraction of mill delivered volume have continued to decline through time as land managers have progressively utilized more woody biomass on commercial logging units (Task SM-SP-7).

To understand the economic considerations and sustainability of a bio-jet fuel and co-products industry based on wood residuals, a techno-economic analysis (TEA) is underway. Analysis performed in the previous year illustrated that in order for a biorefinery to reach profitability, multiple products of high value must be produced in addition to bio-jet fuel. Adjusting the TEA to accommodate the production of multiple targeted products provided a scenario where the internal rate of return (IRR) for a multi-product integrated facility is 10.7%. In this scenario, co-products account for nearly twice the revenue compared to bio-jet fuel. The projected IRR was increased to 12.5% when efficiencies from the mild bisulfite (MBS) pretreatment process were incorporated in to TEA model. The MBS operational inputs were obtained from the NARA ASPEN modeling group. The ASPEN modeling efforts provide more accurate mass flow and operating cost estimates and is required for renewable identification number (RIN) placement and life cycle assessment (LCA) reporting. In addition, the ASPEN modeling was used to compare economic efficiencies between the MBS and wet oxidation pretreatment processes (Tasks SM-TEA-1, SM-AM-1). These comparisons contributed to the selection of a single pretreatment process (see phase and gate in the organizational structure segment of this report).

Significant outputs to date for the Sustainable Production and TEA teams are:

- The BBER Staff posted a database online that provides timber harvest data by county in CA, ID, MT, OR and WA (Task SM-SP-7). http://www.bber.umt.edu/FIR/H_Harvest.asp

- A biogeophysical and social asset assessment for the western Montana corridor region has been published. This work establishes a method used to quantify a region's social capability to embrace a wood to biofuel industry (Task SM-EPP-1.1). http://www.sciencedirect.com/science/article/pii/S0961953414002086

- Soil effects from vehicle trails made during thinning operations were assessed and published. http://www.ingentaconnect.com/content/saf/fs/pre-prints/content-forsci12525

NARA Goal Four

2nd Cumulative Report

April 2013 - March 2014

Supply Chain Coalitions

Envision and delineate pilot supply chains within the NARA region.

SUMMARY

The NARA project is designed to develop a roadmap for industry to produce biojet and co-products from forest residues. This roadmap can only become reality when regional stakeholders (businesses, government agencies, and private individuals) are empowered to actually build the industry. Involving stakeholders in the research process and using their input to shape the supply chain analysis is an integral step on the pathway to this new industry. The Outreach and Education teams are being used in key roles toward this end. Regional stakeholders are identified, organized, and/or engaged by the Outreach team working to develop regional assets and needs. The Education team then partners with these stakeholders and mentors student teams who analyze and design regional supply chains for potential biofuel production. This two-pronged alliance both engages stakeholders in the research process and develops the regional knowledge and interest to carry the industry forward. Finally, the diverse student teams researching the supply chains develop into the trained workforce of the future.

NARA is building regional capacity to implement a biofuel industry by focusing on three areas:

1. Identifying and engaging key stakeholders and incorporating them into the planning process

2. Cataloging regional supply chain assets, analyzing the logistical and economic relationship among these assets and providing recommendations and strategies on how best to employ them

3. Communicating researched-based strategies to stakeholders and facilitating business development where feasible

STAKEHOLDER ENGAGEMENT

To engage stakeholders and disseminate NARA findings and activities, NARA facilitated three conferences: Small Log Conference, Annual National Timber Symposium, and Harvesting Clean Energy conference. In addition, NARA members provided over 140 poster or oral presentations at over 50 different conference and meeting events. NARA invited key stakeholders to the NARA annual meeting to assess opportunities for a wood to biofuel industry.

PILOT SUPPLY CHAINS

Facilitating the development of pilot supply chains actually engages all NARA members; however, groups within the NARA Outreach and Education Teams have tasks dedicated to this goal. To identify regional stakeholders and incorporate them in the planning process, the NARA Outreach Team members delineate key stakeholders and mine existing efforts pertinent to the biomass and biofuel industry. This effort engages stakeholders ranging from landowners and economic development specialists to forest products industry and environmental NGOs.

To envision regional supply chain assets and provide recommendations and strategies on their utility, the Education team assists the outreach efforts by forming collaborations between students, NARA mentors, and stakeholders to provide regional analyses. NARA researchers and university students participate in a year long integrated design course called Integrated Design Experience (IDX), offered through the Institute for Sustainable Design at Washington State University. In this collaborative course, multidisciplinary student teams analyze biofuel supply chain scenarios in partnership with regional stakeholders. For this reporting period, this group consolidated their analyses covering the western Montana corridor (WMC) region onto a website at http://nararenewables.org/western-montanacorridor/ and worked with stakeholders to identify and design a supply chain for western Oregon and Washington in a region defined as the Mid Cascade to Pacific (MC2P) region. To effectively engage stakeholders, a profile document and fact sheet were developed and distributed that describe the project's approach and goals. In addition, a webinar series provided stakeholder updates on progress. Two analyses occurred in the MC2P region: 1) an overall supply chain analysis that examines available regional feedstock for potential conversion sites; and 2) a site selection analysis that identifies specific sites for solid depots, liquid depots and integrated biorefineries (IBRs). The preferred sites identified are:

Solid Depot:
Sierra Pacific Industries; Aberdeen, WA (Former Bradley-Woodward Lumber Co; Bradwood, OR)

Liquid Depot:
Kapstone Pulp and Packaging; Longview, WA
Weyerhaeuser Bay City Log Yard; Aberdeen, WA

Integrated Biorefinery:
Cosmo Specialty Fibers; Cosmopolis, WA

Final reports will be made available in Fall 2014 (Task E-3).

A similar collaboration of students, NARA mentors, and stakeholders was employed with the Confederated Salish and Kootenai Tribes (CSKT) for whom NARA completed a 10-year biomass supply projection study. A key finding was that ecologically-prescribed forest treatments that are intended to restore the structure and function of CSKT forests to a pre-fire exclusion regime produced timber and slash volume results comparable to typical commercial harvest practices in western Montana. (Task E-1; report is listed under bioenergy literacy chapter).

TECHNOLOGIES FOR AN EFFICIENT SUPPLY CHAIN

To utilize forest residuals from remote areas where direct woody feedstock transport to a biorefinery is cost prohibitive, a distributed production scenario is being explored where forest residuals are converted into "sugar syrup" that can be transported for further product development. Achieving this goal could potentially decrease biomass transport and labor costs while extending utilization of existing facilities. Distributed production can also provide a diversified biomass source to mitigate supply risks and reduce the supply radius. To investigate this potential, experiments were conducted to investigate transforming wood residuals inexpensively into a transportable pellets, panels or sugars. Wood residual grinding options and costs were evaluated, and it was shown that a hammer mill performed superior to a knife mill. Optimal pellet strength and energy efficiency was obtained. Size reduction via extrusion of the wood particles was evaluated for energy usage and product characterization. Experiment results demonstrated that moisture content, temperature, rotation speed, and residence time have significant effect on particle size reduction and energy consumption. Milling options were tested for how they influence a wood sample's enzymatic digestibility. Preliminary tests implied that the ring and puck mill is more efficient than the planetary ball mill in disrupting wood recalcitrance for saccharification (Task E-8).

Hot water extraction (HWE) processing is also being investigated to integrate into the supply chain of converting woody biomass into biofuels and co-products. Strategy behind HWE is to 1) pretreat the woody biomass to extract hemicellulose sugars and convert the extracted biomass into high-density panels for ease of transport, and 2) to evaluate the feasibility of deriving value-added byproducts, such as cellulose nanofibers, by mild chemo-mechanical processes (Task O-1).

Forest residues constitute a majority of the wood biomass supply considered for producing biojet. Another source of wood residue feedstock is construction and demolition debris (C&D) portion of municipal solid waste (MSW). NARA completed a GIS database that identifies MSW and municipal recycling facilities (MRFs) for each state in the NARA region. This database is used to determine potential C&D volumes available and to engage C&D owners and managers (Task E-7).

Significant outputs for this reporting period are:

- An improved knowledge base is available to the public (Task O-1). http://woodtobiofuel.org/
- The western Montana corridor supply chain analyses are available online (Task E-3). http://nararenewables.org/westernmontanacorridor/
- NARA completed a GIS database that identifies MSW and municipal recycling facilities (MRFs) for each state in the NARA region. This deliverable is a NARA milestone and allows the incorporation of C&D feedstocks into biomass quantity modeling (Task E-7). http://nararenewables.org/westernmontanacorridor/docs/Volume5-2_SolidWasteAnalysis.pdf
- A supply chain analysis was initiated for western Oregon and Washington (MC2P region) and regional assets were compiled. NARA facilitated stakeholder involvement by conducting multiple meetings, seven webinars and two informational documents including a community profile document that is a NARA milestone deliverable (Task E-3).
  Profile document: http://woodsymposium.wsu.edu/documents/MC2P-ProfileBook9-6Final.pdf
  Webinars: https://www.youtube.com/channel/UCEx98IREHWvRpdUKd0y1amQ

Significant outcomes are:

- The collaborative activities of the Outreach and Education Teams towards supply chain assessment have developed strong interest and brand recognition for NARA. These efforts have encouraged a large group of stakeholders that include the Washington State Department of Commerce as well as interest from numerous corporations around the supply chain the engage with the NARA project. A highlight of these efforts is the decision by Cosmo Specialty Fibers to pursue a biorefinery business model. Cosmo is a NARA affiliate member and a pulp company based in Grays Harbor, WA. They are initially pursuing developing both biochemical and sugar products to augment their traditional pulp offerings. This development has been assisted by direct efforts of our Conversion, Education, and Outreach Team efforts.
- A 10-year biomass projection study was completed and provided to the Confederated Salish and Kootenai Tribes (Task E-1). This deliverable is a NARA milestone and provides a basis for future tribal partnerships and undergraduate and graduate educational work experience. A key finding was that ecologically-prescribed forest treatments, that are intended to restore the structure and function of CSKT forests to a pre-fire exclusion regime, produced timber and slash volume results comparable to typical commercial harvest practices in western Montana. Due to the successful completion of this report, funding for follow-up work was secured and a new study for CSKT was established to test the fire resiliency of siliviculture treatments.

NARA Goal Five

2nd Cumulative Report

April 2013 - March 2014

Bioenergy Literacy

Improve bioenergy literacy to develop a future energy workforce, provide professional development, and enhance citizen understanding.

SUMMARY

The NARA project is designed to enable a new and technically complex industry in the Pacific Northwest. Elevating general knowledge around energy literacy serves an important role to ensure that a biofuels industry will become and remain sustainable by: 1) educating and providing training to a future energy workforce; 2) providing timely information and resources to stakeholders and professionals in industries connected to the biofuels supply chain; and 3) enhancing citizen understanding to improve public support and participation in political decision making.

To secure an effective and sustainable workforce and generate future leaders who can move the biofuels industry forward, training and educational opportunities related to Science, Technology, Engineering and Mathematics (STEM) topics, and specific to the biofuels supply chain, need to be created and promoted. For this purpose, NARA provides opportunities tailored to engage students along the education pathway from K-12 students and educators, to undergraduate and graduate students, and finally to practicing professionals.

K-12 STUDENTS AND TEACHERS

Programs targeted to K-12 students and teachers provide curriculum development and educational programs. Six new lesson plans have been developed to support energy and climate literacy curriculum. Six more are currently in process.

Completed lessons include:

- The Value of a slash tree
- Plant cell walls to alcohol
- Exploring hydropower
- Hydroelectric power and dams
- Biomass adventure race
- Water resources in a changing climate

In addition to these lessons, a nine-lesson energy curricula titled Fueling Our Future: Exploring Sustainable Energy Use was published and is available in print, digital and SMART Board formats. This curricula is promoted through the Facing the Future website and through targeted teacher workshops and conferences throughout the US. To date over 200 copies have been distributed to educators. The McCall Outdoor Science School (MOSS) pilot tested the curricula to over 1500 K-12 students. Over 200 K-12 students were assessed after introduced to the curricula and showed significant increases in bioenergy knowledge, a positive attitude towards biofuels, and science processing skills. In addition, summer workshops that focused on bioenergy and climate change were provided to K-12 teachers. Fifteen teachers attended the workshop with 60 teachers following on-line (Task E-2).

A follow-up survey connected with this workshop indicates that:

- 70% of the teachers participating in our summer workshop agree or strongly agree that they understand enough about biofuels in the Pacific Northwest to have an informed opinion.
- 48% of teachers report that they have been able to incorporate biofuels into their curriculum
- 73% agree or strongly agree that they understand key parts of the supply chain.
- 82% of the teachers agree or strongly agree that they are more likely to use problem-based learning after being involved in the workshop.

All of the NARA educational deliverables, plus biofuels literacy content from non-NARA sources, are available through energyliteracyprinciples.org, which has undergone significant development this reporting period (Task O-9).

Again this year, NARA was a major sponsor for the Imagine Tomorrow program. This event engages high school students to develop creative solutions to society's energy challenges. The 2013 event showed an increase in total student teams (133 student teams in 2013 to 112 in 2012) and in teams that participated in the biofuels challenge category (18 in 2013 to 14 in 2012). An assessment was initiated that measures STEM career choices and bioenergy literacy for the Imagine Tomorrow participants. The results show that 67% of the students were extremely or very interested in pursuing a career in science (Task E-4). In 2012, due to NARA funding, Imagine Tomorrow opened the competition to teams from Montana, Idaho and Oregon. In order to promote team participation from these newly added states, NARA provides high school team training and funding. Twenty-two teachers from Montana, Idaho and Washington have participated in a webinar series to support coaching Imagine Tomorrow teams for the 2014 event (Task E-2, O-9).

UNDERGRADUATES AND GRADUATES

Programs targeted to undergraduate and graduate students provide research opportunities that contribute directly to NARA project outcomes. The Summer Undergraduate Research Experience in Biofuels (BF-SURE) is a summer (10 week) research experiences for undergraduate students that provides laboratory, fieldwork, and research skills in the broad area of biofuels and bioproducts research. In 2013, 38 students applied and nine were selected and teamed with NARA principal investigators, including placements at Weyerhaeuser, to conduct research and showcase their projects at a poster symposium sponsored by Washington State University. Demographics of 2013 applicants were 61% women, 39% men; and 11% Hispanic, 3% Native American, 34% Asian, 8% African American, 5% multicultural and 39% Caucasian. The program's popularity is increasing with over 50 applicants received for the 2014 summer season (Task E-5, E-6).

The IDX course included undergraduate and graduate students representing a variety of disciplines including engineering, environmental studies, chemistry, community planning, architecture, landscape architecture, construction management and law, to develop the western Montana corridor (WMC) and the Mid-Cascade to Pacific (MC2P) supply chain analyses described in the Supply Chain Coalitions segment of this report. (Task E-5). In addition, graduate students affiliated with MOSS, interviewed NARA researchers to develop media used to train Imagine Tomorrow teams and supplement educational materials (Task E-2).

Graduate students associated with the University of Washington and Salish Kootenai College, plus NARA SURE undergraduate students, were involved in the NARA Tribal Team. This team completed a 10-year biomass projection for the reservation of the Confederated Salish and Kootenai Tribes (CSKT) (Task T-E1, T-E6) and will expand their work opportunities with other PNW tribes and on other NARA related projects. This group will employ seven interns in summer 2014.

Lastly, for this reporting period, NARA funds have supported 69 graduate students working on tasks assigned to the NARA project.

PUBLIC BIOENERGY LITERACY

To promote bioenergy literacy opportunities to the public, NARA outreach developed multiple information delivery pieces including over 70 stories posted on NARA's online newsletter and blog plus 10 infographics. This information is distributed through the NARA website (10,866 unique visits, 60,360 pageviews, 54.48% new visits in this reporting period), affiliated organization websites, Facebook, Twitter and through targeted mailings to regional policy-makers. In addition, journalists published 31 NARA related news stories. To provide stakeholders with relevant information from NARA and other sources relating to bioenergy literacy, NARA maintains a knowledge base that is currently being transformed into a dynamic and searchable source at woodtobiofuel.org (Tasks O-1 through O-7).

Significant outputs to date for this team are listed below.

- A report "Biomass supply estimates for the Confederated Salish and Kootenai Tribes on harvest planning and management goals" has been provided to the Confederated Salish and Kootenai Tribes. (Task E-1).

- A lesson plan "The Value of a Tree: Comparing Carbon Sequestration to Forest Products" was published and is targeted to middle school students. http://www.nsta.org/store/product_detail.aspx?id=10.2505/4/ss14_037_07_27

- A nine-lesson energy curriculum titled "Fueling Our Future: Exploring Sustainable Energy Use" was published and is available in print, digital and SMART Board formats. http://www.facing-thefuture.org/CurriculaFreeUnits/BuyCurricula/tabid/550/ProductID/69/Default.aspx - .U4YVX-pRdXZV

- 2013 Imagine Tomorrow program was completed along with survey collection and analysis. This deliverable is a NARA milestone and trends suggest expanded interest in newly added states (OR, ID and MT). Imagine Tomorrow Students were surveyed after the competition with 67% of the students responding that they were extremely or very interested in pursuing a career in science (Task E-4). http://imagine.wsu.edu/past/2013/default.html

Outcomes are:

- Two undergraduate students who participated in the NARA SURE program applied and were accepted to graduate school at the University of Washington and will work with NARA researcher Dr. Ivan Easton. NARA related internship experience was an important factor in their acceptance (Task E-6).

- Over 200 K-12 students were assessed after introduced to NARA generated curricula and showed significant increases in bioenergy knowledge, positive attitude towards biofuels, and science processing skills. This deliverable is a NARA milestone and establishes a baseline used to evaluate the success of future summer programs at MOSS (Task E-2).

- Summer workshops that focused on bioenergy and climate change were provided to K-12 teachers. Seventy-five teachers participated in the workshops. A follow up survey connected with this workshop indicates that:
- 70% of the teachers participating in our summer workshop agree or strongly agree that they understand enough about biofuels in the Pacific Northwest to have an informed opinion.
- 48% of teachers report that they have been able to incorporate biofuels into their curriculum
- 73% agree or strongly agree that they understand key parts of the supply chain.
- 82% of the teachers agree or strongly agree that they are more likely to use problem-based learning after being involved in the workshop (Task E-2). http://sandbox.clearingmagazine.org/AL@.pdf