# NARA | CUMULATIVE REPORT

August 2011 - March 2013

Northwest Advance Renewables Alliance

# NORTHWEST ADVANCED RENEWABLES ALLIANCE

## A NEW VISTA FOR GREEN FUELS, CHEMICALS, AND ENVIRONMENTALLY PREFERRED PRODUCTS

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NARA
Northwest Advanced Renewables Alliance

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.

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## Notice

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# NARA | ORGANIZATIONAL STRUCTURE

## August 2011 - March 2013 Cumulative Report

Northwest Advance Renewables Alliance

# Organizational Structure

## NARA Executive Committee

The Executive Committee is responsible for leading the NARA project and communicating directly with the USDA-NIFA leadership and the Advisory Board. Specific areas of leadership include working closely with the Project Area Team Leaders to approve the annual work plans and budgets; reviewing and administering subcontracts; approving scope of work for each affiliated individual institution and supervising staff members.

### NARA Executive Committee Members

**Ralph P. Cavalieri**

Executive Director and Project Director
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Dr. Cavalieri is currently Associate Vice President for Alternative Energy and Professor of Biological Systems Engineering at Washington State University. He is a Registered Professional Engineer, State of Washington. He served two terms on the Department of Energy's Biomass Research and Development Technical Advisory Committee, serves on the Board of Directors of the Washington State University Research Foundation and as the Associate Director of the Western Sun Grant Center. His research emphasis is on chemical and biochemical process kinetics and sensors.

**Michael Wolcott**

Project Co-Director
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Dr. Wolcott is a Regents Professor in Washington State University's Department of Civil and Environmental Engineering, a member of the interdisciplinary Materials Science and Engineering faculty, and director of WSU's Institute for Sustainable Design. He is an international leader in the field of natural fiber materials and biopolymers while he has led the development of advanced materials to improve durability, reduce manufacturing costs and pollution, and improve structural performance. He has previously managed nearly $20-million in funding and large research teams for numerous federal agencies, including the Office of Naval Research, the Department of Energy, the USDA, the US Forest Service, and the Federal Highway Administration.

**Linda Beltz**

Project Development Analyst
253-924-6638
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Dr. Beltz is currently Director, Technology Partnerships at Weyerhaeuser. In this role, she worked with John Tao to implement Open Innovation at Weyerhaeuser. Linda is responsible for alliances and partner activities with for-profit, non-profit, university and national labs. She is also responsible for government contracts. Linda has been with Weyerhaeuser 12 years. Prior to her current role, she led the transition for Weyerhaeuser's biofuel JV with Chevron, Catchlight Energy, and held technical and market development leadership positions in the businesses. Before joining Weyerhaeuser, Linda worked with Mead and International Paper in technical leadership, capital project, manufacturing and scientist roles.

# NARA Advisory Board

The NARA Advisory Board is composed of leaders within a variety of fields such as forestry, chemistry, and engineering.  The board's role is to provide an independent overview of NARA's progress towards completing the goals articulated in the USDA NIFA competitive grant no. 2011-68005-30416. The Advisory Board meets annually with NARA and USDA-NIFA leadership, reviews NARA quarterly and annual progress reports, and provides written recommendations to NARA and to the USDA-NIFA. The board is currently composed of six members.

## Advisory Board Members

### Terrance Cooper
### Argo Group International

Dr. Terence Cooper is CEO of Argo Group International, which provides specialized consulting services in chemical and polymer science, materials technology and market and applications development in North America, Europe and Japan. Present areas of major involvement include new product, process and market development in acrylic, methacrylic, olefinic, vinylic and styrenic copolymer systems, strategic research, development and technology portfolio analysis and environmental consulting.

### Katrina Cornish
### Ohio State University

Dr. Katrina Cornish is the leading U.S. scientific expert, and is internationally recognized as a principal authority, on alternative natural rubber production, properties and products, and on natural rubber biosynthesis in general.  As Ohio Research Scholar and Endowed Chair in Bioemergent Materials, Katrina leads a program at The Ohio State University focusing on domestic rubber production, bio-based fillers and fibers, and exploitation of opportunity feedstocks from agriculture and food processing wastes for value-added products and biofuels.

### Billy M. Glover
### Boeing

Billy Glover is the Vice President of Environment and Aviation Policy for Boeing Commercial Airplanes. In this capacity he leads an enterprise-wide team responsible for shaping global policy on critical issues affecting aviation including domestic and international policy, environmental strategy and product performance, safety and security. Prior to his current position, Glover led a cross-functional team at Boeing responsible for addressing environmental issues including aircraft noise reduction, greenhouse gas emissions, alternative fuels research, and public policy and opinion. His current team continues to provide input on key product design elements to continuously improve the environmental performance of Boeing aircraft.

### Thomas P Klin
### CH2MHill

Thomas Klin serves as Principal Technologist and Director of Aviation Environmental Services for CH2M Hill. In this capacity he oversees the execution of all environmental impact statements (EIS), environmental audits, permitting, environmental compliance and related environmental projects that enable airport development and operation. Thomas specializes in the National Environmental Policy Act (NEPA) process, environmental impact assessment and creative mitigation planning for unavoidable impacts. He also specializes in education of and consensus building between agencies involved in the airport and aviation environmental regulatory process.

### Jack N. Saddler
### University of British Columbia

Dr. John (Jack) Saddler is the endowed Professor of Forest Products Biotechnology /Bioenergy and also the former Dean, Faculty of Forestry at the University of British Columbia. He is a Fellow of the Royal Society of Canada, Canada’s highest recognition for scientists, and he has received many other awards such as the International Union of Forest Research Organizations (IUFRO’s) Scientific Achievement Award, and the Charles D. Scott award for contributions to the field of “Biotechnology for fuels and Chemicals”. Recently, Dr. Saddler received the prestigious 2009 Leadership award, presented from Life Sciences British Columbia for demonstrated leadership in the industry and given to individuals who have assisted in the creation and advancement of the broader life sciences communities over time.

### Rachael Jamison
### Washington State Department of Natural Resources

Rachael Jamison is DNR's Energy and Climate Change Policy Specialist. Her work includes forest biomass-to-energy efforts, statewide and regional bioenergy strategy, state and agency-wide climate adaptation planning and green job creation. Prior to coming to DNR, she led the Department of Ecology's Green Building Program and worked in the Department of Agriculture's Organic Food Program. Rachael is committed to finding economically viable environmental solutions to some of our most challenging environmental questions.

## Member and Affiliate Organizations

NARA members and affiliates are the institutions (universities, businesses, governmental entities, and nonprofits) that are signing parties to the NARA Non-disclosure Agreement and are expected to contribute resources, personnel, time, information and other assets to NARA in support the NARA Mission. Member institutions are also signatories to the NARA Intellectual Property Agreement.

### Catchlight Energy

Catchlight Energy's vision is to become a major integrated producer of biofuels derived from non-food sources and to deliver renewable transportation products produced from biomass in a manner that is scalable and sustainable—both environmentally and economically. For NARA, they participate with the Pretreatment Team.

### Facing the Future

Facing the Future is a national education nonprofit that develops and delivers K-12 sustainability curriculum resources that prepare K-12 students in all 50 U.S. states to become engaged, informed global citizens. As a member of NARA, Facing the Future will support the K-12 education efforts for the NARA project.

### Gevo, Inc.

Gevo is a leading renewable chemicals and advanced biofuels company. Through the NARA project, Gevo will optimize their conversion technology to convert woody biomass hydrolysate into feedstocks into isobutanol, biojet fuel and other renewable chemicals.

### GreenWood Resources, Inc.

GreenWood Resources develops and manages sustainable, environmentally certified tree farm systems for investment purposes. For NARA, they produce strategic business and financial planning for a network of commercial Douglas-fir plantations that will supplement feedstock supplied from logging residuals and thinnings from fuel-reduction operations. (Note: GreenWood Resources participation in NARA will conclude on Mary 31, 2013.)

### Montana State University

Montana State University Extension Forestry will assist with the NARA Extension Working Group by providing information about the NARA program and research updates to Montana stakeholders.

### The National Center for Genome Resources

The National Center for Genome Resources (NCGR) in Santa Fe, New Mexico, is a non-profit research institute dedicated to improving human health and nutrition through the application of genomics and bioinformatics. The NCGR assists NARA’s long term goals by providing genomic resources used to breed softwoods with traits beneficial for conversion to a biojet and co-products industry. (Note: NCGR participation will conclude at the end of Year 2 of NARA.)

### Oregon State University

Oregon State University is the state's land-grant and leading public research university. A number of NARA researchers work here and contribute primarily to the project's feedstock development and sustainability work.

### The Pennsylvania State University

Penn State is Pennsylvania's land-grant university. Research there dedicated to the NARA project investigates the social sustainability of the NARA project.

### Salish Kootenai College

Salish Kootenai College, a tribal university, provides research opportunities tied to biofuels and bio-products from woody biomass.

### US Forest Service-USDA, Forest Products Laboratory

The Forest Products Laboratory conducts innovative wood and fiber utilization research that contributes to the conservation and productivity of forest resources and sustainably to meet the needs of people for forest products. They contribute pretreatment conversion technology research to the NARA project.

### US Forest Service, Pacific Northwest Research Station

The Pacific Northwest (PNW) Research Station is one of seven research centers that are part of the USDA Forest Service. They develop and deliver knowledge and innovative technology to improve the health and use of the Nation's forests and rangelands. They contribute to NARA's outreach tasks.

### University of Idaho

Faculty in the College of Natural Resources and College of Art and Architecture participate in NARA's education and outreach tasks.

### University of Minnesota

Efforts from the University of Minnesota's Department of Bioproducts and Biosystems Engineering contribute to the NARA project by developing lignin-based co-products and contributing to the sustainability analyses.

### University of Montana

University of Montana contributes to the NARA project by identifying and collecting primary data necessary to assess the woody biomass inventory with particular emphasis on mill and logging residue and with outreach assistance.

### University of Washington

Researchers at the University of Washington lead NARA's efforts to develop a complete life cycle analysis of the wood residue to biojet and co-product process. Additionally, members from this university serve as NARA liaison with regional tribal organizations to promote educational and supply chain opportunities.

## Washington State University

Washington State University is Washington's original land-grant university and the lead institution for NARA providing  leadership, research and administrative services.

## Western Washington University

Faculty in Western Washington University's Huxley College of the Environment, along with university's Institute for Energy Studies (IES) are involved in the education and outreach goals of the NARA project.

## Weyerhaeuser

Weyerhaeuser creates sustainable solutions to the world's challenges through the development of innovative forest products that are essential to everyday lives. Weyerhaeuser NR Company provides research expertise and leadership to many aspects of the NARA project including feedstock sustainability and sourcing, phase and gate project management, techno-economic analyses and co-product development.

# NARA Management

NARA is an integrated project. An overarching challenge facing NARA is to provide a management framework that assists team cooperation, direction and achievement. NARA has implemented multiple strategies to provide administrative services and management tools to the project.

## NARA Phase-Gate model

### Description of Phase and Gate

The Phase and Gate process is a well-known project management and decision support tool that improves project execution and promotes fact-based decision making. Phase and Gate processes typically include “Phases”, where the project work is completed and “Gates” where decisions for continuation and next Phase objectives are set. Each Phase allows progression from the idea phase to implementation, where Gates ensure that the decisions to continue are based on comprehensive information. For NARA, we have developed a customized Phase and Gate process that advances the project through the steps necessary to achieve commercial readiness of a forest residuals to aviation fuels pathway: (1) Feasibility Analysis, (2) Feasibility Validation, (3) Scale Up Readiness and (4) Commercial Options. The process is designed to be adaptable for the range of academic to commercial and technical to social work encompassed within the NARA project with each phase covering key areas of: Technical, Market, Business Models / Integration, Manufacturing, Financial, Health/Safety and Intellectual Assets. Figure 1 shows the NARA Phase and Gate process.

### Objectives for NARA Phase and Gate

The Phase and Gate process is an important management element that allows NARA to:

- Coordinate team pathways and milestones in a manner that allows advancement of the project
- Identify gaps in project elements or milestones
- Realign project teams to optimize effectiveness
- Make decisions using a comprehensive fact-based gate framework

### Implementation and Results from Phase and Gate

The Phase and Gate process was developed and implemented during the first year of NARA to map critical path milestones across the project teams. During the second year, the Phase and Gate process was refined and utilized to provide important project results:

- Reorganized the pathway teams to provide seamless work integration and more complete results. Examples include (1) moving the Sustainable Production team under System Metrics, (2) providing singular accountability for LCA by aligning all LCA-related work under one leader and (3) combining Community Impact with the LCA team.
- Developed the key phase and time-based critical path milestones, by pathway, for NARA to reach its end goal of commercial readiness. One example includes identification of an overall TEA model and associated material and energy balance as critical missing elements.

- Identified critical linkages between pathway teams allowing cross-team meeting planning and information flow. One example includes extension of Biomass Modeling and Assessment needed to complete the work under Sustainable Production.
- Developed a project-wide integrated work-flow structure focused on the key project outputs (Figure 2).
- Highlighted areas of core and peripheral work, which allowed for optimized budget distribution in year 3. Examples include narrowing and reducing the focus of Feedstock Development, inclusion of pretreatment technologies deployable in regions where feedstock depots may be a preferred option, ASPEN process modeling to support the techno-economic analysis (TEA), and focus on commercially relevant, high volume lignin-based products.
- Implemented a gate decision framework for assessment and down selection of technologies. This is currently being used to reduce the number of retreatment technologies. Specifically, FPL and CLE pretreatment efforts are being consolidated in year 3 to a single “mild sulfite” down selected pretreatment. Another pretreatment gate framework will be applied to non-chemical pretreatment technologies to down select to one during year 3. Determined that two types of pretreatment technologies – chemical and non-chemical may be utilized within the regions covered by NARA, so the gate framework is to down select to one of each technology.

The Phase and Gate process continues to be evolved and implemented deeper in the NARA project. We are currently in the process of developing gate frameworks to facilitate comparison of technologies and support additional down select decisions.

## Lessons Learned

The use of a Phase and Gate process in a complex project such as NARA is both important to bring effective results, but also challenging. However, the use of this methodology in NARA has provided some important lessons:

- The Phase and Gate process is a concept that is familiar to some team members and foreign to many, especially academic participants. The earlier in the project that training on the methodology can be completed, the more team members will structure their work in a manner that corresponds to the Phase and Gate process methodology.
- Use of Phase and Gate during project planning will allow milestones to be fully aligned and coordinated to accomplish the end goal. This should result in fewer gaps and less future realignment.
- The process needs to be flexible enough to be applied to a wide variety of circumstances

## PHASE 3: SCALE UP READINESS

| | |
|---|---|
| Harvest Transport Methods | Optimized feedstock harvest, transport, & logistics for cost reduction in target regions to plant gate |
| Feedstock Spec | Optimized feedstock for lowest cost to pretreatment |
| Pretreatment Samples | Pretreatment at demonstration scale with product for 1000 gal IPK |
| 1000 gal BioJet | IBA production & separation at demonstration scale with product for 1000 gal IPK<br>1000 gal of IPK product |
| Coproduct Samples & Products | Co-products testing with customers at pilot scale |
| OPEX<br>CAPEX | Engineered & cost estimates for pretreatment scale up<br>Engineered & cost estimates for IBA scale up<br>Engineered & cost estimates for IPK scale up<br>Optimized co-products process with engineering & cost estimates |
| Carbon Inventory<br>Water Impact | Refined LCA including data for target regions - carbon, water |
| Fuels & Co-products LCA | LCA reviewed and refined based on feedback |
| OPEX<br>CAPEX | Techno-economic analysis (TEA) include detailed process and product estimates |
| Coproduct Samples & Products<br>Value Proposition | Product market sheets for priority co-products |
| Overall Community Impact<br>Regional Supply Chains | Community support issues identified & programs to enhance support / funding in place |
| East/West Pilot Supply Chains<br>Workforce | Education to address specific community issues |

## PHASE 4: COMMERCIAL OPTIONS

| | |
|---|---|
| Regional Supply Chains | Feedstock supply plan for target pretreatment sites |
| Conversion Methods<br>Regional Supply Chains<br>1000 gal BioJet<br>Coproduct Samples & Products | Pretreatment facility plan & product transport plan for selected sites<br>IBA facility plan & product transport plan for selected sites<br>IPK facility plan & product transport plan for selected sites<br>Co-products facility plan with feedstock transport plan from pretreatment / IBA processes & to product end use market |
| Fuels & Co-products LCA | Final LCA complete for selected sites<br>Environmental Preformance Datasheets complete for selected sites |
| Overall Economic Feasibility | TEA models complete for specific sites; input into commercial plan |
| Coproduct Samples & Products<br>Value Proposition | Market materials for co-products |
| East/West Pilot Supply Chains<br>Regional Asset Databases | Commercialization partners and funding sources identified for selected sites |
| Educated Workforce<br>Workforce Develop | Training program materials for skill development needs of selected site communities |

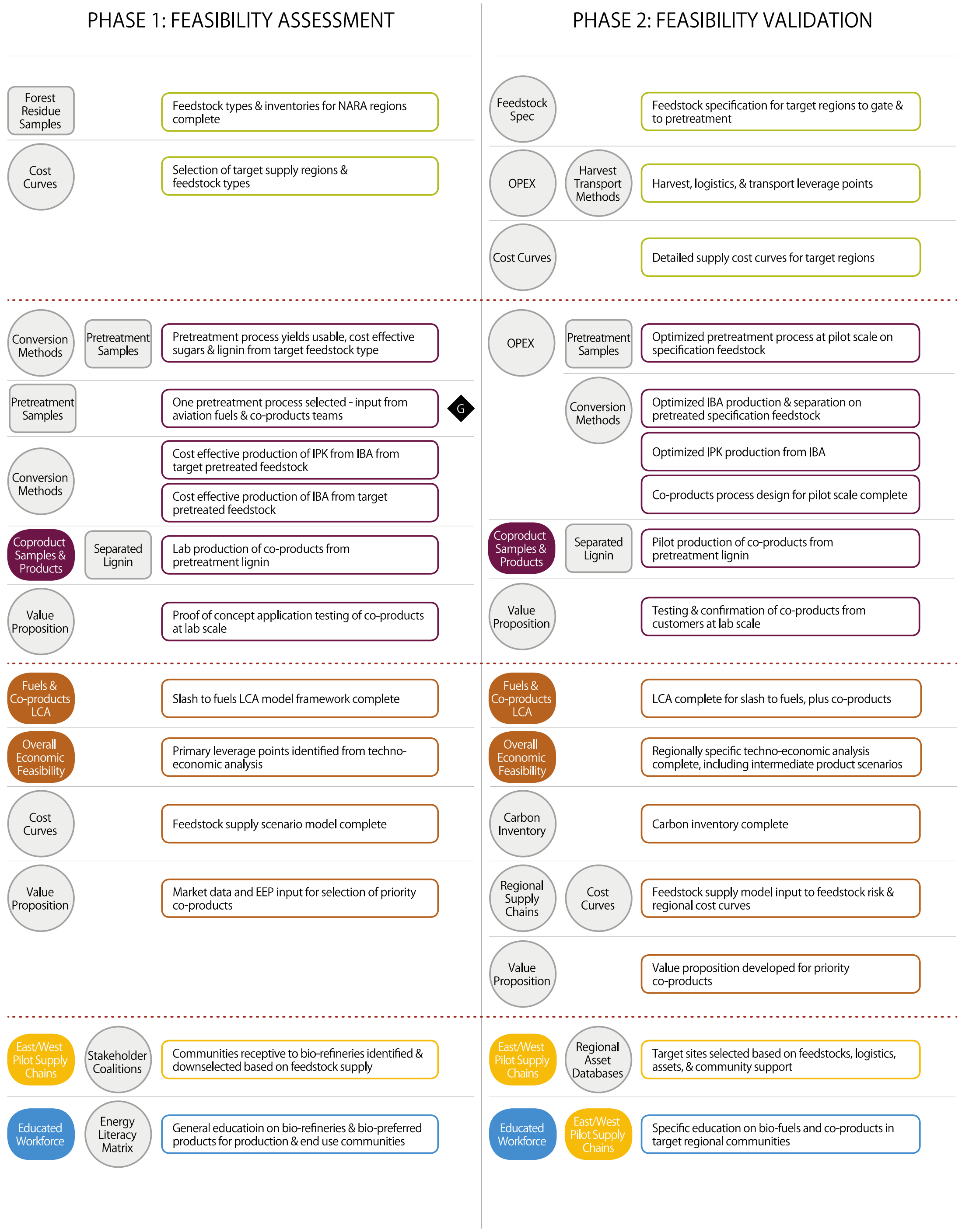


Figure 1: Schematic of NARA Phase and Gate process. Ovals indicate outcomes, elongated rectangles indicate outputs and circles indicate deliverables. Colors align with NARA programs: blue-Education, purple-Conversion, brown-Systems Metrics, gold-Outreach

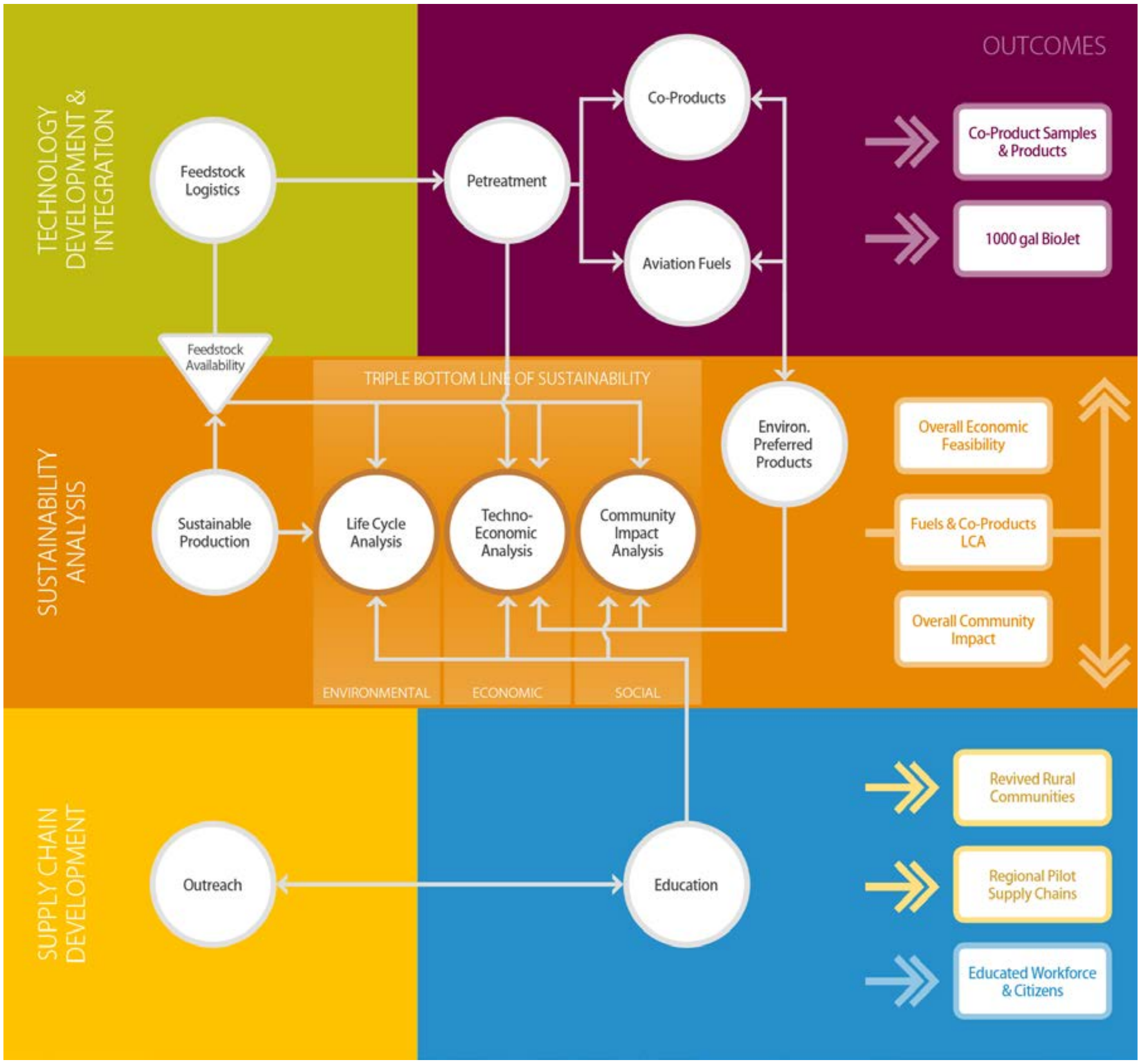


Figure 2: NARA project flow diagram with desired outcomes by project area.

## NARA Charter and Ground Rules

This document is the charter and ground rules for use in the NARA project. The Charter and Ground Rules are intended to manage processes, encourage substantive discussions, and provide an operational mechanism for assessing progress in achieving NARA's goals (link).

## Intellectual Property (IP) Management Plan and Non-disclosure Agreement (NDA)

All NARA members endorse a common Intellectual Property (IP) Management Plan and Non-Ddisclosure Agreement. The purpose of the IP Management Plan is to ensure that the protection process for all IP developed under NARA is well-defined and agreed upon in advance of the IP creation. By agreeing to the terms in advance, the companies involved are more secure of the commercial prospects for licensing/using the technology and the rights and responsibilities of the parties protecting IP are clearly defined.

The purpose for the NDA is so that the companies can talk freely and exchange ideas with the government labs and university researchers without worry that their proprietary information will be disclosed or rendered unpatentable.

## NARA staff

NARA retains five staff members to assist in administrative and creative needs. All are funded by Washington State University's administration.

| | | |
|---|---|---|
| **Charles Burke:** | Communications and Publicity Director | ccburke@nararenewables.org |
| **Janet Duncan:** | Project Coordinator | duncanj@nararenewables.org |
| **Stephen Locker:** | Web Coordinator/ Graphic Designer | slocker@nararenewables.org |
| **Julie Semler:** | Project Coordinator | JSemler@nararenewables.org |
| **Travis Woodland:** | Intellectual Property Management | t_woodland@nararenewables.org |

# Communications

NARA communicates progress to the NARA members, partners and Advisory Board in addition to regional stakeholders, the USDA-NIFA leadership and to the general public. To accomplish this, NARA hosts meetings, maintains communication tools and includes the communication services of outside partners.

## NARA Annual meeting

NARA holds an annual meeting each year in the fall. Our first annual meeting was conducted in Missoula Montana September 13-14, 2012. The next scheduled meeting will be in Corvallis Oregon September 10-13, 2013 at the LaSells Conference Center. These meetings provide an opportunity for NARA researchers to present their work to the advisory board, the USDA-NIFA leadership, partners, stakeholders and the general public.

## NARA Team Leadership Meetings

NARA is composed of eleven work teams grouped with the feedstock, conversion, systems metrics, education and outreach components of the project. Each month, team leaders and the executive committee meet via conference call to ensure that the process is focused on reaching solutions that achieve NARA goals.

## NARA Website

The NARA website functions as the central repository for NARA information to the general public; host portals like “the energy literacy matrix” used as a data retrieval tool for educators; and contains an intranet feature used to share project information internally among NARA researchers. As of March 31, 2013, the website experienced 20,539 individual visits with 83,270 page views. Visitations were from all 50 US states and from 114 countries. NARA website is at http://nararenewables.org

## NARA Newsletters

NARA distributes a monthly newsletter written to communicate NARA’s progress to the general public and to the NARA team. Past newsletters can be viewed at http://nararenewables.org/news/newsletter

## Forest Business Network

The focus of the Forest Business Network is to help forest product businesses grow and prosper. They work strategically with the NARA Outreach team to develop stakeholder groups and disseminate information within the forestry industry. Their website is https://www.forestbusinessnetwork.com.

## Ruckelshaus Center

The Center is a joint effort of Washington’s two research universities and was developed in response to requests from community leaders. Building on the unique strengths of the two institutions, the Center is dedicated to assisting public, private, tribal, non-profit and other community leaders in their efforts to build consensus and resolve conflicts around difficult public policy issues. For NARA, the center assists the Outreach Team communicate with policy makers. They also help facilitate NARA’s internal communications. Their website is http://ruckelshauscenter.wsu.edu/

# NARA | STRATEGIC ANALYSIS

August 2011 - March 2013 Cumulative Report

Northwest Advance Renewables Alliance

# Strategic Analysis

## BACKGROUND

The USDA NIFA AFRI CAPs in Sustainable Bioenergy are charged to:

> *…facilitate the establishment of regional systems for the sustainable production of bioenergy and biobased products that: contribute significantly to reducing the National dependence on foreign oil; have net positive social, environmental, and rural economic impacts; and are integrated with existing agricultural systems. (USDA NIFA 2010)*

A key element to achieving this goal is an integrated technical pathway for economically producing biofuels and co-products. A clear challenge exists to achieve economic viability while simultaneously providing the requisite attention to the social and environmental attributes of an emerging sustainable biofuels industry. As guidance, the NARA Advisory Board and USDA leadership directed NARA to establish a focused Techno-Economic Analysis (TEA) of our conversion pathway. Having completed the initial version of the analysis, we are using the results to guide the strategic direction of our project towards realizing a "*regional system for sustainable production of bioenergy and biobased products"*.

## APPROACH

The NARA Executive Team directed establishment of a TEA founded on the National Renewable Energy Laboratory (NREL) analysis of producing cellulosic-based ethanol. (Humbird et al 2011) Our analysis therefore utilized the analytical framework of the NREL effort while revising capital expenditures, operational expenditures, and fixed costs as appropriate. As such, our analysis used revised data for feedstock handling, pretreatment, and alcohol-to-jet operations. NARA corporate members Weyerhaeuser, Catchlight Energy, TSI, and Gevo provided the relevant cost and yield data for these operations.

Several scenarios were developed for operating the plant. For purposes of brevity, this summary will focus on the "Burn Lignin" scenario that includes:

- Feedstock Preparation and Storage
- Calcium Bisulfite Pretreatment
- On-Site Enzyme Production
- Standard Gevo Isobutanol (IBA) and Iso-Paraffinic Kerosene (IPK) Production
- Multi-Fuel Boiler Burning all Production Residues with Natural Gas for Energy Balance

Assumptions in this analysis and production scenario are as follows:

- Integrated Biorefinery – 770,000 BDT/yr
- Feedstock - ground slash piles – composition from NARA FS-10

- Greenfield Capital Expenditure (CapEx) Entire Facility
- Commercial Feedstock Costs of $68/BDT delivered to mill gate
- Burn Lignin and Screen Rejects

A more detailed development of this analysis is provided in Task SM-TEA-1: Techno-Economics Analysis of the 2013 NARA Cumulative Report.

## SUMMARY OF FINDINGS

Assuming a complete greenfield construction of an integrated biorefinery, and 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 spot market cost of petroleum jet fuel (Figure 1 and Task SM-TEA-1). With optimistic estimates for improved yields throughout the greenfield operation of the process, this value might be lowered to 1.45 times the cost of the petroleum equivalent. Whereas a greenfield operation of the current process is not projected to reach cost equivalency as is, the analysis aids NARA in focusing our work on programmatic efforts that may bring us to cost parity within our current timeframe using different strategies than our initial model. It should be noted that this initial model is a “worst case” scenario for costs and does not investigate many of the production scenarios currently under investigation.

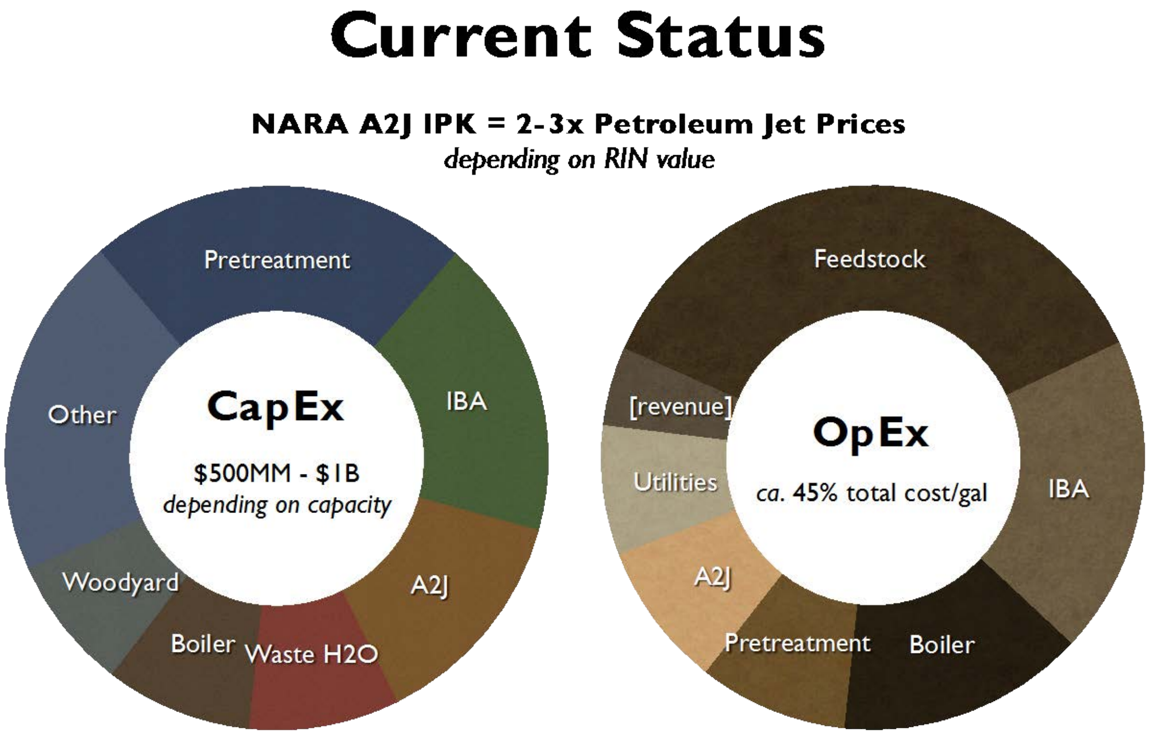


Figure 1: Summary of the current status of the techno-economic analysis for an integrated biorefinery producing biojet (IPK) using forest residuals as a feedstock and assuming a complete greenfield construction. Relative contributions of individual cost centers are provided for the

capital expenditures (CapEx) and operational expenditures (OpEx).

Interpretation of the analysis presents several highlights concerning the economic production of advanced biofuels:

1. A high CapEx for a greenfield construction of an integrated biorefinery will likely impose financing barriers for large plants.
2. The role of feedstock costs in the OpEx is critical. Even at relatively low mill gate costs for forest residuals, its role is dominant over every other cost center in the analysis.
3. Federal renewable fuel policies that influence financial incentives for production are crucial to successfully establishing an industry. In our analysis, these incentives are considered through the valuation of cellulosic and advanced biofuel RINs.

Carefully considering the three points above provides us with the opportunity to strategically position the current research efforts to reach an improved cost position within the project lifespan of NARA. The approaches will be discussed separately below.

***Reducing the capital cost of a biorefinery*** is necessary to reduce production costs as well as to improve the access to capital for producers. The high capital costs of biorefineries are an issue that is not exclusive to NARA (Table 1). Of the ten commercial cellulosic biofuels projects currently under construction (Brown and Brown 2013), the average CapEx is $10.22 per gallon of annual capacity. (Lane 2013a) This figure is on the upper range of a previously reported estimate of $6-12 per gallon of annual capacity. (Lane 2013b)

Our estimate of CapEx per rated gallon of annual capacity for the NARA integrated biorefinery is similar to these values when viewed on an equivalent ethanol basis. By removing the Alcohol-to-Jet conversion process, the NARA CapEx would be less than $20 per gallon capacity isobutanol. This value can then be converted to an equivalent ethanol production by equating energy density of the alcohols (ethanol/butanol = 0.67), resulting in a NARA CapEx at *ca.* $13 per gallon of equivalent ethanol capacity. However, the additional process of converting to biojet drives the CapEx figure to more than $27 per gallon of capacity IPK. This increase can be accounted for in part, but not entirely, through the increased energy density. The additional CapEx involved in the step to convert alcohol to jet fuel would be similar for all such conversion processes, irrespective of the alcohol used.

Regardless of the exact measure, the capital requirements for building a biorefinery to produce biojet will be expensive. Reducing this CapEx requirement will, in the short term, facilitate developing the industry by both reducing costs and increasing access to capital.

Lane (2013a) delineates several financial and technology strategies for reducing CapEx requirements. One of these, **retrofit of existing assets**, has been a basic tenant of both NARA and its biofuels partner Gevo. Existing infrastructure that has potential for retrofitting to the NARA process includes the following:

| | |
|---|---|
| **Existing or Dormant Pulp Mills** | *feedstock preparation, pretreatment vessels, wastewater treatment, energy plant, rail transportation* |
| **Existing or Dormant Ethanol Plants** | *hydrolysis and fermentation vessels, tank farms, fuels distribution* |
| **Petroleum Refineries** | *chemical processes for alcohol to jet conversion* |

The assessment of existing regional assets to be applied to the emerging biofuels industry in pilot supply chains is a key component of our Goal 3: Supply Chain Coalitions, and it is conducted by our Outreach and Education Teams.

**Table 1.** Summary of commercial cellulosic biofuels projects currently under development. Rated capacity, announced capital expenditure (CapEx) and cost per gallon of annual capacity are provided for each projects. Data is provided to compare to the NARA TEA estimates in this project report.

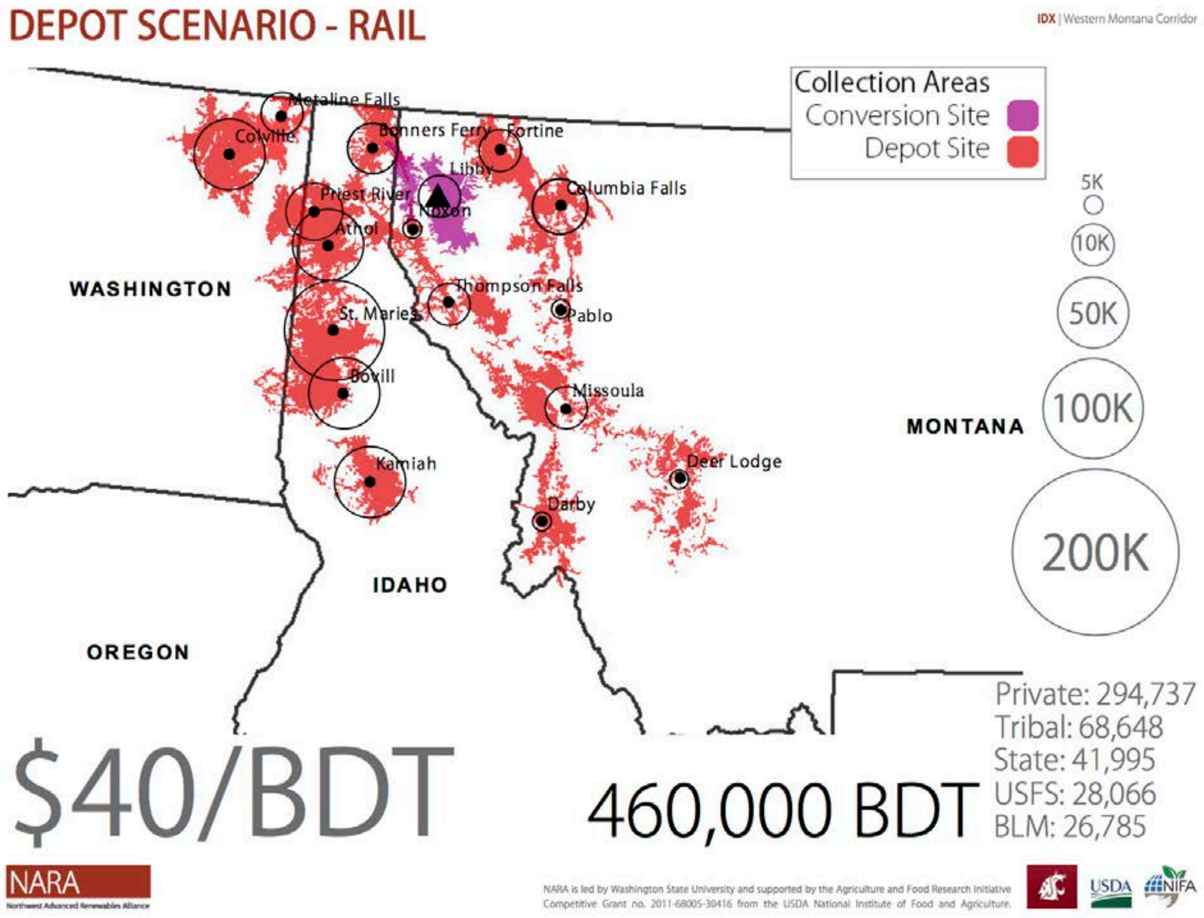
| Source | Facility | Process | Fuel Product | Feedstock | Rated Capacity (million gal/yr) | CapEx (million) | CapEx/Capacity (per gal capacity) |
|---|---|---|---|---|---|---|---|
| Brown and Brown | Kior | pyrolysis & hydrotreat | hydrocarbons | loblolly pine residuals | 41 | $350 | $8.54 |
| 2013 | ClearFuels | gasification & FT | hydrocarbons | woody biomass | 20 | $200 | $10.00 |
| | Sundrop Fuels | gasification and MTG | hydrocarbons | mixed biomass & NG | 50 | $500 | $10.00 |
| | ZheaChem | acid hydr & ac. acid syn | ethanol | poplar & ag residue | 25 | $391 | $15.64 |
| | Abengoa | enzymatic hydrolysis | ethanol | corn stover | 25 | $350 | $14.00 |
| | Beta Renewables | enzymatic hydrolysis | ethanol | Arundo donax | 20 | $170 | $8.50 |
| | DuPont Biofuels | enzymatic hydrolysis | ethanol | corn stover | 25 | $276 | $11.04 |
| | POET | enzymatic hydrolysis | ethanol | corn stover & cob | 25 | $250 | $10.00 |
| Lane 2013a | Aggregated | | | | 266 | $2,719 | $10.22 |
| Lane 2013b | Estimate | | | | | | $6 to $12 |
| NARA TEA | Integrated Greenfield | enzymatic hydr to IPK | IPK | forest residuals | 32 | $881 | $27.24 |
| | | enzymatic hydr to IBA | IBA | forest residuals | 45 | $881 | $19.39 |
| | | enzymatic hydr to IBA | EtOH Equiv | forest residuals | 68 | $881 | $13.02 |

For instance, our initial pilot supply chain analysis occurred in the Western Montana Corridor, a region with the potential to supply aviation fuels to regions east of the Cascade Mountains via the Yellowstone Pipeline. Two viable sites were delineated for redevelopment, Libby and Frenchtown, MT. These sites are both brownfields and are dormant forest products facilities with existing rail transportation, water rights, environmental permitting, and energy plants. In addition, Frenchtown was the site of a former pulp mill owned by Smurfit Stone. In addition to the previously stated assets, an existing wastewater treatment and feedstock preparation facility is in place. Although further analysis is required to value these assets, their usefulness to industrial development is readily apparent. This same effort is beginning west of the Cascade Mountains where a host of facilities exist including pulp mills, forest products depots, and ethanol plants.

***Reducing operating costs of a biorefinery*** presents greater challenges, but with $0.45 of every dollar being expended on variable operating costs, potential exists. Several tasks within the existing NARA project are already aimed at this opportunity. For instance, the Pretreatment and Conversion Teams are focused on increasing yield and decreasing chemical and energy inputs. Successes in these areas are important to decreasing the operating costs. However, the largest single cost center in the entire analysis is the feedstock cost, which in turn is dominated by transportation costs. Several variables (*e.g.* on-site drying, grinding efficiency, truck packing, etc.) are already aimed at decreasing feedstock costs, but the limits of these activities are likely to be *ca.* 20% improvements.

Dramatic reductions in feedstock costs will only be achieved by decreasing transportation distance. Unfortunately, as the size of the biorefinery increases to develop processing economies of scale, feedstock costs increase disproportionately, as the plant must source raw material over longer distances. The concept of biomass depots has been discussed recently by a number of groups and is recommended for study. (Feedstock Logistics 2010) In concept, these depots would function as concentration facilities that draw biomass from a smaller fibershed, prepare that material, and ship it to conversion facilities. In a recent feedstock sourcing study of the Western Montana Corridor (Figure 2), functioning and dormant primary wood processing facilities were identified and screened for rail sitings. These facilities automatically have regional harvest occurring, since sawlogs are typically the highest value products. Using these existing assets as potential biomass depots could supply adequate quantities of biomass at more acceptable transportation costs by transferring to rail at the depot. This analysis demonstrates that depots can increase biomass volumes at cost, but it is not as readily apparent that they can drive dramatic decreases in feedstock costs at volume. Further study will better discern this potential.

One additional approach that may be successful is to conduct more of the processing at the depot to facilitate shipping of either pretreated or saccharified feedstock. In these cases, increasing the energy density of the shipped product would additionally decrease transportation costs. However, to realize these logistical savings pretreatment methods that can be cost effectively operated at small scales are necessary.



DEPOT SCENARIO - RAIL

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.

Figure 2: Example depot model for feedstock sourcing at $40/BDT transportation costs in the Western Montana Corridor. Depot sites were located at existing or shuttered primary wood processing facilities with rail sidings and transportation routes into a hypothetical conversion site in Libby, MT. Direct delivery of feedstock into the Libby conversion is by truck.

**Biofuels has had the support of recent federal administrations and congresses.** This support has been manifested in the original Renewable Fuel Standard (RFS1), enacted under the Energy Policy Act (EPAct) of 2005, and further expanded into RFS2 under the Energy Independence and Security Act (EISA) of 2007 (EPA 2013). RFS2 sets mandates for biofuels production in the U.S., and if enforced, this mandate could assist in bringing biofuels to commercial scale much faster than if left solely to market forces.

The mechanisms by which the EPA intends to enforce the RFS mandates are Renewable Identification Numbers (RINs). RINs are unique 38-character numbers assigned to each gallon of renewable fuel and issued to biofuels producers or importers at the point of production or importation (Yacobucci 2012). A RIN market has developed for the buying, selling, and trading of RINs once they are separated at blending. RINs are valid for two years, and blenders or exporters that have met RFS mandates may opt to sell their excess RINs, or keep them for the following year's requirements, but no more than 20% of a specific year's Renewable Volume Obligation (RVO) requirements may be met by previous year's RINs (Yacobucci 2012). This could be an additional revenue stream for blenders or exporters, which could stimulate the markets to quicker biofuels adoption. Speculators may also opt to purchase RINs and resell them, something akin to a day trader on the stock market. With respect to NARA, the fact that biojet does not currently have an annual volumetric mandate under RFS means that blenders that produce jet fuel blends do not have to turn those specific RINs into the EPA to meet any volumetric obligations. These RINs could subsequently be sold on the RIN market at 100% profit to the blender. The blender could opt to use these RINs to meet other volumetric mandates under RFS if it was economically more beneficial to do so. Regardless of the specific directions, an understanding of RIN valuation and its impact on the economics of fuels production is vital to the development of the biofuels industry.

## STRATEGIC FUTURE DIRECTIONS

Given the need to decrease capital costs along with feedstock costs, we recommend focusing on the following:

- Continue seeking regional assets that might be retrofit for an emerging biofuels industry. These facilities would include primary wood processing plants for depots, pulp plants for pretreatment and hydrolysis, and ethanol plants for fermentation.
- Inventory the specific assets at these sites and value their potential using future versions of the TEA.
- Develop a process-modeling task to predict the mass and energy balance for the plants. The models should be constructed to facilitate studies addressing production scale and dispersed supply chain production (*i.e.* rather than only integrated facilities).
- Advance the logistical and economic studies of feedstock supply from solids depots (*i.e.* solids in/solids out via simple feedstock preparation) to liquids depots utilizing distributed production of sugars.
- Continue supporting pretreatment technologies that have the potential for economic viability at small scale. Wet oxidation is one such technology, but others should be sought and explored.

- Continue to monitor, reexamine, and when possible, leverage dynamic U.S. biofuels RFS, RIN, and other related policies to better understand opportunities for NARA stakeholders.

## BIBLIOGRAPHY

Brown, T.R. and R.C Brown. 2013. A review of cellulosic biofuel commercial-scale projects in the United States. Biofuels, Bioproducts, and Biorefining. In Press.

EPA. 2013. Renewable Fuel Standard (RFS). Available at United States Environmental Protection Agency: http://www.epa.gov/otaq/fuels/renewablefuels/index.htm.

Feedstock Logistics Interagency Working Group ed., 2010. Biofuel Feedstock Logistics, Biomass Research and Development Board. http://www.usbiomassboard.gov/pdfs/biomass_logistics_2011_web.pdf

Humbird, D. *et al*. 2011. Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover. Golden, CO: National Renewable Energy Laboratory. Technical Report NREL/TP-5100-47764.

Lane, J. 2013a. Biorefinery 2015 – transformations in biofuels costs, financing. Biofuels Digest. http://www.biofuelsdigest.com/bdigest/2013/03/25/biorefinery-2015-transformations-in-biofuels-costs-financing/

Lane, J. 2013b. The capex-opex fallacy, electric cars, and biofuels. Biofuels Digest. http://www.biofuelsdigest.com/bdigest/2013/01/25/the-capex-opex-fallacy-electric-cars-and-biofuels/

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

Yacobucci, B. 2012. Analysis of Renewable Identification Numbers (RINs) in the Renewable Fuel Standard (RFS). Washington, D.C.: Congressional Research Service.

# NARA Teams and Goals

## NARA Team Structure and Leadership

### Feedstock

| | |
|---|---|
| • Development | Ralph Cavalieri, Washington State University |
| • Logistics | John Sessions, Oregon State University |

### Conversion

| | |
|---|---|
| • Pretreatment | Ralph Cavalieri, Washington State University |
| • Conversion | Andrew Hawkins, Gevo |
| • Co-Products | Thomas Spink, TSI |

### System Metrics

| | |
|---|---|
| • LCA and Community Impact | Ivan Eastin, University of Washington |
| • Sustainable Production | Greg Johnson, Weyerhaeuser |
| • Environmentally Preferred Products | Paul Smith. Penn State University |
| • Techno Economic Analysis<br>Weyerhaeuser | Thomas Spink, TSI; Gevan Marrs, |

### Education

| | |
|---|---|
| • Education<br>University | Steve Hollenhorst, Western Washington |

### Outreach

| | |
|---|---|
| • Outreach | Vikram Yadama, Washington State University |

## The NARA project is designed to accomplish these five goals:

1. Develop a sustainable biojet fuel industry in the Pacific Northwest that uses residual woody biomass as feedstock.
2. Create valuable co-products made from lignin, which is an industrial byproduct of the woody biomass to biojet process.
3. Enhance and sustain rural economic development.
4. Establish supply chain coalitions within the NARA region.
5. Improve bioenergy literacy to develop a future energy workforce and enhance citizen understanding.

# NARA | GOAL ONE

August 2011 - March 2013 Cumulative Report

SUSTAINABLE BIOJET

Northwest Advance Renewables Alliance

# Goal One: 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 roadmap to sustainably 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 residue 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 residues to biojet:

1. Feedstock Logistics Team: Integrating feedstock collection, pre-processing, 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 ability for the Gevo fermentation/separation and WSU BioChemCat processes to produce aviation biofuels from representative pretreated forest residuals

The NARA feedstock team is divided into two efforts: feedstock development and feedstock logistics. **Feedstock logistics** efforts have developed models to provide the most cost-efficient collection and transport scenarios of woody biomass. To develop biomass recovery coefficients, a procedure for estimating piled and field distributed biomass has been created and validated. To develop moisture management strategies and models, six tools were evaluated for estimating moisture content in forest biomass, and moisture data from 3000 truckloads carrying forest residuals were analyzed. A communition decision support model for determining the optimal grinding, chipping, and trucking configuration has been completed (Task FL-2; each task progress is detailed in progress reports following this summary). A forest residual sourcing curve showing feedstock costs relative to conversion facility scale was developed for Washington and Oregon (Task FL-1). To evaluate chipping and grinding production to meet alternative feedstock specifications, nine candidate forest harvest residue samples from western Washington and Oregon were identified and collected in approximately 500 oven-dried (OD) quantities. Each sample was screened to remove fines, air-dried, and characterized for polysaccharide, lignin, extractives, ash and bark content. Sample aliquots were distributed to the NARA pretreatment teams for conversion tests (Tasks FL-1 and FL-2). Significant internal outputs to date for this team are listed below. Additional outputs are listed at the end of each progress report.

- Nine residual wood samples representing different species and/or processing have been coded, characterized and distributed to the Pretreatment and Aviation Biofuels teams. Downstream conversion experiments now compare results using the same samples and evaluate conversion robustness on varied residue samples (Figure 2;Task FL-1).
- It was determined that there is very high variability in key quality attributes of the most plausible softwood feedstock for commercial-scale biofuels production from forest harvest residuals. Some of these parameters (bark, species, inorganics, and particle size) can be impacted by harvesting techniques once the value of doing so is communicated to the harvesting operators (Table 1; Task FL-1).
- Feedstock sourcing analysis indicates that forest residuals have the most promising combination of quantity, quality and cost over hog fuel or pulp chips. A sourcing curve was generated for western Washington and Oregon providing a first cut estimate of feedstock costs ($66/BDT delivered) to a 770 thousand BDT/year facility (Figure 4; Task FL-1).
- The decision support model shows that for each 10% increase in grinder/chipper utilization, transport costs are reduced $0.5-$3.0/dry ton. Simulations using this decision support model will be used to inform the Timber Supply Model (Task FL-2).
- Moisture management data has been collected and will be used to predict drying rates for biomass residue piles in western Oregon (Task FL-2).

During the first two-years, the **feedstock development** effort has been refined to focus exclusively on softwood, Douglas fir, to support efforts for production of the forest residuals that are a focus of the project. Commercially viable softwood tree families have been identified. Samples and seedlings are being evaluated for chemical and growth variation. Parameters and protocols used at the WSU Phenomics Center have been established to enable non-invasive high throughput screening of softwood trees to determine their photosynthetic capacity under varied stressed conditions. For these first measurements, trees from the coast and from inland habitats were compared (44 for each habitat) and their response to drought stress analyzed (task FD-2). Fifty-five different families were selected across the range of gains for growth rate. Core samples within these tree families were obtained from a total of 700 trees from three sites. The cores were measured, weighed and shipped for chemical analysis (task FD-3). Ash, carbohydrate, lignin and extractives content were determined for the first 150 samples. In addition, these samples were evaluated for lignocellulosic recalcitrance when subjected to dilute acid pretreatment (task FD-5). To begin linking softwood characteristics to genotype, a preliminary heritability analysis was performed on the first 146 samples (task FD-3). In addition, 15 of the total 83 Forest Service Douglas-fir transcriptome samples have been obtained and analyzed with the intent to identify SNPs (single nucleotide polymorphisms) (task FD-4). Significant internal outputs to date are:

- Variability and probable heritability has been demonstrated in Douglas-fir chemical composition, photosynthetic capacity and lignocellulosic recalcitrance. This information provides a high likelihood that genetic markers can be identified for favorable conversion attributes in softwoods (Tasks FD-2, FD-3, FD-5).

The **Pretreatment Team**’s efforts have progressed with small scale optimization for SPORL, wet-oxidation, dilute acid and mild bisulfite pretreatment options on Douglas-fir wood chips (FS-01) and Douglas-fir residuals (FS-03) followed by mass balance calculations after enzymatic hydrolysis (Tasks C-P-1, C-P-2, C-P-3, C-P-4). The effects of wood chip size on mild bisulfite pretreatment outcomes and bark content on SPORL outcomes were analyzed (Tasks C-P-4, C-P-1). Significant internal outputs to date are:

- Hydrolysate from SPORL and wet-oxidation, and mild bisulfite pretreatment was distributed to and evaluated by Gevo for fermentation analysis (Tasks C-P-1, C-P-2, C-AF-1).

- Solid residue fractions containing lignin from SPORL, wet-oxidation, dilute acid, and mild bisulfite pretreatments were sent to the Co-Products Team for analysis and as reference feedstock material for co-product development.

- A peer-reviewed article was published (Lou et al., ChemSusChem, DOI: 10.1002/cssc.201200859) that demonstrates effective pretreatment at an elevated pH of 5.5 or higher. The lower severity of this process is reduced severity can significantly enhance enzymatic hydrolysis of lignocelluloses, especially substrates produced from the SPORL pretreatment. These findings contradict a well-established and widely accepted concept of "optimal pH of 4.8 – 5.0" that has been exclusively practiced in numerous laboratories throughout the world. By using pH 5.5, we can reduce cellulase loading by approximately 50%. This reduction will have a significant impact on produced fuel costs (Task C-P-1)
- Pretreatment yield efficiencies after hydrolysis provide up to 90% carbohydrate yield. (Tasks C-P-1, C-P-2, C-P-3, C-P-4)

**The NARA Aviation Biofuels Team** is focused on two fermentation technologies: Gevo's fermentation, separation, and upgrading process and WSU's BioChemCat process managed at WSU-BSEL. Gevo has analyzed pretreated hydrolysate from SPORL, wet-oxidation, and mild bisulfite pretreatments for carbohydrate and inhibitor content. Using SPORL and wet-oxidation hydrolysate from FS-03 residuals, Gevo has determined growth and fermentation performance for a wild-type ethanol producing yeast strain (for benchmark purposes) and for an isobutanol producing yeast strain. They are currently adapting yeast strains for isobutanol production using pretreated hydrolysate from sample FS-03 and have evaluated the performance of advanced strains (Task C-AF-1). Significant external outputs to date are:

- Strain adapted biocatalysts produced a nearly twofold increase in isobutanol over pre-adapted strains on diluted FS-03 pretreated hydrolysate indicating that isobutanol can be generated and that strain adaption can improve biocatalyst performance (Task C-AF-1).

WSU BSEL has optimized fermentation protocols using the BioChemCat process on FS-01 (Douglas-fir woodchips) and FS-03 (Douglas-fir residuals) wet-oxidation hydrolysate to yield volatile fatty acid platform molecules. To extract the platform molecules, a pressurized carbon dioxide extraction system was constructed and 32 trial runs were initiated to optimize the extraction protocols (Task C-AF-2) Significant external outputs to date are:

- Fermentation performance in the BioChemCat process using FS-03 hydrolysate can provide a maximum overall acetic acid yield of 65-70 g/L. The pressurized carbon dioxide extraction protocol has been optimized to remove 85% of acetic acid from water (Task C-AF-2).

## Outcomes/Impacts:

Events that cause a change of knowledge, actions or conditions for stakeholders and society.

## Training

| Name | Affiliation | Role | Contribution |
|---|---|---|---|
| Alvarez Vasco, C | WSU, BSEL | PhD Student | Assay development |
| Garcia, Karissa B | WSU, BSEL | Undergraduate | Chemical composition analysis |
| Pedro Guajardo | WSU, BSEL | Undergraduate | High throughput pretreatment |
| Scott Geleynse | WSU, BSEL | PhD student | Pretreatment and enzyme hydrolysis |
| Roland Gleisner | USFS, FPL | Tech support | Pretreatment and preprocessing |
| Shaoyuan Leu | USFS, FPL | Post Doc | Pretreatment of FS-01 and FS-03 |
| Hongming Lou | USFS, FPL | Post Doc | Enzyme and lignin interaction |
| Chao Zhang | USFS, FPL | Visiting PhD Student | Bench scale pretreatment of FS-01 |
| Haifeng Zhou | USFS, FPL | Visiting PhD Student | Enzyme and lignin interaction |
| \Rene Zamora | OSU | PhD Student | See Publication List; Task FL-2 |
| Storm Beck | OSU | MS Student | See Publication List; Task FL-2 |
| Fernando Becerra | OSU | MS Student | See Publication List; Task FL-2 |
| Dong-Wook Kim | OSU | MS Student | See Publication List; Task FL-2 |
| Francisca Belart | OSU | PhD Student | See Publication List; Task FL-2 |
| Justin Long | OSU | Res. Associate | See Publication List; Task FL-2 |
| Elvie Brown* | WSU, BSEL | Post Doc | Mass balance of DA and lignin preparation |
| Ruoshui Ma | WSU BSEL | PhD student | Lignin conversion |
| Rajib Biswas | WSU, BSEL | Post Doc | 100% |
| Keerthi Srinivas | WSU, BSEL | Post Doc | 100% |
| Nanditha Murali | WSU, BSEL | PhD Student | 50% |
| Ben Garrett | WSU, BSEL | PhD Student | 100% |

# Resource Leveraging

| Resource Type | Resource Citation | Amount | Relationship or Importance to NARA |
|---|---|---|---|
| Mond Guo | funded by DOE SBIR | | Provided assistance in lignin preparation and enzymatic hydrolysis |
| Xiaohui Ju | funded by NSF | | Provided assistance in lignin preparation and enzymatic hydrolysis |
| Grant | USDA SBIR Phase II program to Biopulping International (Contract Number: 2010-33610-21589) | $100,000 out of $400,000 | Pretreatment of Lodgepole pine and lignin characterization from lodgepole pine |
| Grant | USDA NIFA-AFRI Competitive Grant (No. 2011-67009-20056) | $100,000 out of 1,000,000 | Enzyme and lignocellulose interactions |
| Scholarship | Chinese Scholarship Council (CSC) | $40,000 | Support of Chao Zhang and Haifeng Zhou |
| Salary | US Forest Service | $45,000/year | Support of J.Y. Zhu & Roland Gleisner |
| Mond Guo | funded by DOE SBIR | | Provided assistance in lignin preparation and enzymatic hydrolysis |
| Xiaohui Ju | funded by NSF | | Provided assistance in lignin preparation and enzymatic hydrolysis |
| Grant | Collaborating with Humboldt State University on a grant proposal responding to BRDI USDA-NIFA-9008-003828. | | Proposal includes testing of alternative grate sizes and alternative screening configurations. USDA rated this as a high priority project, but funding limitations (probably our CAPs) prevented funding. DOE, a co-funder, is now reviewing this proposal. |
| | | | The OSU College of Forestry is partnering with the College of Engineering to become a Center of Excellence in Logistics and Distribution as a member of the NSF I/UCRC program. Our participation would be in forest products logistics and distribution and would leverage NARA funding. |
| DOE | | $760,000 | Equipment in the pilot facility |

# FEEDSTOCK

## Feedstock Development Team

### Task FD-2: Phenomics Analysis

| Key Personnel | Affiliation |
|---|---|
| Helmut Kirchhoff | Washington State University |

#### Task Description

Selected plant lines will be subjected to phenomics analyses. Initially, this phenomics system currently relies upon chlorophyll fluorescence analysis, a well-established and versatile tool for studying stress response in plants *in situ*. In addition to the numerous examples for annual plants, this technique has already been applied, for example, to study salt-stress responses in poplar trees. We will thus initially use chlorophyll fluorescence based phenomics as a second screening filter to identify softwood tree individuals, Douglas-fir and western hemlock, that are best adapted to their designated growth habitat. The WSU phenomics facility will speed up the selection process for three reasons: (i) Chlorophyll fluorescence screening can identify stress before it becomes visible; (ii) It is non-invasive, thus screened plants can be further used;(iii) It is fully automated and therefore allows the screening of a large number of plants. Furthermore, due to a fast detection system, screening parameters can be measured multiple times ensuring good statistics and therefore high fidelity data.

The following parameters will be examined because they are expected to be most relevant for growing trees in different designated areas such as: (i) soil composition (N-deprived soil), (ii) fertilizers (iii) salinity, (iv) drought. Softwood trees will be used which passed the first selection criteria for maximal biomass production and quality. We expect to screen about 500 individuals. For each of the four parameters, a set of the 500 selected individuals will be grown and screened in parallel (about 2000 plants total). Beside morphometric parameters (leaf size and number, chlorophyll content), the maximal photochemical quantum efficiency, photosynthetic electron flux, capacity of photoprotective non-photochemical quenching, as well as the degree of photoinhibition of photosystem II will be deduced from chlorophyll fluorescence measurements. This detailed analysis will indicate the stress status of the trees under the different environmental parameters and will allow selection of the most robust plants.

#### Activities and Results

In order to optimize the equipment and protocols used to perform phenomics experiments on trees, initial parameters were established on well-studied plants in the genus *Arabidopsis* and *Populus. Arabidopsis* mutants with reduced lignin content were studied in the initial work. Low lignin content (higher cellulose/lignin ratio) is a desirable trait for biofuel production from woody biomass. By using mutants affected in lignin biosynthesis, we aim to study the impact of low lignin content on photosynthesis. That knowledge is required for optimizing feedstock since photosynthesis forms the energy source for plant biomass. Growth curves showed that these mutants grew very similar to wild type plants indicating that reduced lignin content has no direct impact on growth. An interesting result is that the light-induced proton motive force (pmf) required for ATP production is higher in the mutants compared to their wild-type counterpart. A higher pmf in the lignin mutant is indicative for a slower consumption of ATP caused by altered lignin metabolism. Furthermore, the photoprotective mechanism (qE parameter = high energy quenching) that is activated in plants to avoid damage by high-light is less in lignin mutants. Overall, this data has given indication for feedback between lignin biosynthesis and photosynthesis. Unraveling this interrelationship can pave the way to optimize trees with high cellulose/lignin content.

Young poplars (height 1m) were used to establish optical measurements in the Phenomics Center because these types of measurements were not reported so far. After establishing the measurements, studies were focused on photosynthetic performance and on the ability to avoid photooxidative stress by activation of photoprotective processes (qE parameter). Comparison of the different poplar hybrids showed significant differences in photosynthetic parameters. The hybrids A19, A44, 1732-48, and P3 have much lower photosynthetic performance values whereas A16, 2R-35, 1732-85, and 1732-84 have higher values compared to the control trees. We could not identify a correlation between the photosynthetic performance parameter and photoprotective qE mechanism. Thus, the differences in photosynthetic performance seen in the different hybrid trees do not seem to be correlated with the ability to activate photoprotection on the level of the photosynthetic apparatus. The data indicates that the different poplar hybrids have distinct photosynthetic features.

In the Phenomics Center, we performed, for the first time, a large-scale phenotyping of Douglas-fir trees. For these first measurements, trees from the coast and from inland habitats were compared (44 for each habitat) and their response to drought stress analyzed. A main outcome of these measurements is a high variability in photosynthetic parameters as shown in Figure 1 for the Fv/Fm parameter. Furthermore, drought stress over eight days did not lead to detectable phenotypic changes (both in RGB images as well all other photosynthetic parameters), indicating a high robustness against drought stress. Finally, both coastal and inland grown plant types show no significant differences. The experiment will be repeated for longer drought period to identify individuals that can withstand drought longer and individuals that are more sensitive. The work was performed in the WSU Phenomics Center (Pullman, WA). Experiments were run by Magnus Wood (not supported by NARA). In November 2012, a new PostDoc (Ricarda Hoehner) was hired for the NARA Phenomics work.

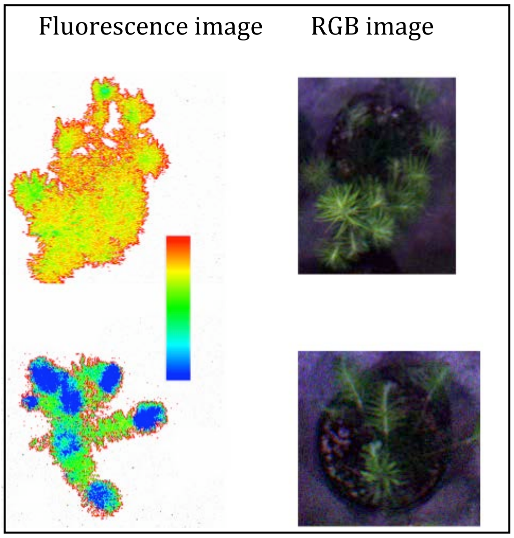


**Fig. 1**. Fv/Fm parameter on multiple Douglas-fir individuals as a response to drought stress.

## Recommendations/Conclusions

Methods to study young trees were established and first results indicate significant differences in photosynthetic performances of poplar hybrids and in Douglas-firs. Since phenomics is a new approach, the first aim was to establish the non-invasive optical screening for the plants. We could solve different practical problems (e.g. mutual obstruction of fast growing plants, parasite infestations). Developing a SNP chip for in-depth genetic analysis on Douglas-fir has high priority. In this respect, the Phenomics approach will act as a gatekeeper that can identify individuals with desired traits that should be selected for more elaborate, expensive, and time-consuming approaches (e.g. chip technologies). For example, determining plant phenotypes under drought stress can detect drought resistant and sensitive individuals. Differential genotypic analysis on these selected plants promises to unravel key genes or gene patterns that can lead to drought resistant trees and guide breeding strategies for feedstock optimization.

## Physical and Intellectual Outputs

None to report at this time

# Task FD-3: Combining Genomic and Field-based Breeding and Testing Methods to Improve Woody Feedstock Production

| Key Personnel | Affiliation |
|---|---|
| Keith Jayawickrama | Oregon State University |

## Task Description

Genetic selection and testing has been applied on timber species in the west for over 50 years. One result of that work is data and genetic gain predictions for several traits from replicated, randomized progeny tests for over 30,000 families of Douglas-fir and western hemlock. A range of phenotypic variation, and some level of genetic control, has been demonstrated between families for every trait studied, so we can expect variation and genetic control in traits pertaining to biofuel production. Another result is that over 150,000 timberland acres are reforested annually with seedlings from open-pollinated seed orchards, thus delivering real genetic gains (in whatever traits are selected for) to operational plantations in the west.

Over the last decade, the cost of using genomic and marker-based tools to complement field-based breeding and testing has dropped rapidly in forest tree species. These tools have the potential to improve the efficiency, speed of delivering genetic gain, especially given the long times needed for field-based breeding, as well as to reduce cost. Recent advances by the Conifer Translational Genomics Network (a multi-institution project for major US conifers) can be put to use in this project. We propose as an expanded/strengthened Task 2 (Identify single nucleotide polymorphisms [SNP] genotypes) to use the power of both of these approaches in tandem, with a state-of-the art genotyping array based on SNP technology for marker-based selection of phenotypes conducive to production of biofuels from woody residuals as a value added trait of trees selected for production of lumber and other products of saw logs.

The specific objectives of this project are: (1) Quantify the phenotypic variation in biofuel production potential in a subset of Douglas-fir and western hemlock families, pre-selected for commercially important traits such as rapid growth, adaptability, wood specific gravity and wood stiffness; (2) Identify SNP genetic markers in Douglas-fir associated with useful variations in biofuel production potential; and (3) Make selections for increased biofuel production in woody residuals of trees developed for use as saw logs using a combination of phenotypic and SNP genetic marker data.

## Activities and Results

The progeny test populations most suitable for sampling should: (1) have advanced-generation high-genetic gain germplasm, (2) have trees large enough to obtain amounts of wood needed for chemical analysis, (3) have good maps and access information, and (4) be available and accessible to OSU researchers and contractors. Two second-generation populations, T96 and CL98, established by Plum Creek Timber Company in 1996 and 1999 respectively, were selected. Various sampling tools (cordless drills, gas-powered drill, 5mm, 10mm and 12 mm manual corers) were compared and the 10 and 12mm manual corers with extensions were selected to produce the core samples.

Fifty-five (55) different families were selected across the range of gains for growth rate from the T96 population. Samples within these tree families were obtained from a total of 700 trees from three sites. The cores were measured, weighed and shipped to Xiao Zhang's lab at Washington State University. Enough sample quantity was obtained to provide 10g of dry wood for analysis. The final set of 150 cores were dried and ground in a Wiley mill at OSU to free up time for the Zhang lab to expedite analysis.

Preliminary analyses on the first 146 samples showed very high heritabilities (abbreviated $h^2$). A heritability of 0 means there is no genetic control, a heritability of 1.0 means variation in the trait is totally genetic. These results strongly indicate that Douglas-fir would respond to genetic selection for these 3 traits.

| | Klason_Lignin | Holocellulose | Extractives |
|---|---|---|---|
| Narrow-sense individual $h^2$ | 0.823 ± 0.200 | 0.778 ± 0.1949 | 0.000 ± 0.000 |
| Broad-sense individual $h^2$ | 0.823 ± 0.200 | 0.778 ± 0.1949 | 0.650 ± 0.349 |

We selected 30 more families and 3 woods run lots from the CL98 series, located and visited the Moon Creek progeny test site near Fairview, and collected a first batch of samples.

We started collaborating with Helmut Kirchhoff's lab to pursue phenomics work with Douglas-fir, with emphasis on drought tolerance. Two sets of containerized seedlings were sent to the lab, one from a moister coastal breeding zone and the other from a drier inland southern Oregon breeding zone. The objective of this pilot study is to get baseline parameters for Douglas-fir. Three different parameters (false color Fv/Fm, NPQ, PhiII) were evaluated after 8 days without water. In this preliminary study the two populations did not appear different.

The second phase was to leverage a Douglas-fir Drought-Tolerance study with the USDI BLM, and sow seedlings from 107 elite families (originating from across western Oregon and western Washington) and two woods run lots for detailed analysis (including fluorescence assay) by the Kirchhoff lab. We visited the BLM nursery at the Sprague seed orchard near Pleasant Valley to coordinate the sowing of these drought tolerance study seedlings. The seedlings have germinated and are in the process of being transplanted to the 615A cavities.

## Sub-Task 2. Identify single nucleotide polymorphism (SNP) genotypes

James Cook, Callum Bell, and Glenn Howe (OSU faculty member) reviewed and updated plans for genotyping Douglas-fir. James Cook requested and obtained approval from NARA Leadership team and WSU leadership for modification to the budget allocation (emphasizing softwoods instead of poplar).

Gave input to NCGR on obtaining Douglas-fir sequence data from Rich Cronn (USDA PNW Research Station, Corvallis). Continued to update research priorities based on genotyping and genomic selection research published in early 2013. Began simulation work to devise an efficient multi-generation sampling strategy to obtain the maximum information from future sample collection and genotyping work. Opportunities to form a Douglas-fir genotyping consortium are being explored, with the objective of lowering genotyping costs by capturing economies of scale.

## Recommendations/Conclusions

As expected, study of chemical composition and degree of biomass recalcitrance at the individual-tree level is time-consuming and not feasible for a large number of programs (although it yields the maximum data from the genetic analysis viewpoint). However, the individual-tree data from T96 is necessary to calculate heritabilities, correlations between traits, and potential genetic gains for these traits. Large variations have been found between trees and families for the traits of interest and it is apparent the traits will respond to genetic selection.

Sample collection from the CL98 series was completed and samples were processed and shipped to WSU/Tri-Cities for wood chemistry analysis by the end of April. Wood samples from future progeny test series will be bulked by family, reducing the number of samples by a factor of 8-10. This will allow us to work through many more programs in years 2-5 than in the first year. We delivered bulked samples from the second population (CL98) by the end of April 2013. However, once we identify the families in each program with the most desirable fuel properties, we would like to have individual samples analyzed within these few top families to find the individuals with the best properties and propagate them by grafting. This will allow for future seed production. This will include more advanced-generation programs for Douglas-fir and also one western hemlock program.

We expect to deliver about 1,000 seedlings from 107 families and two unimproved controls for the drought tolerance study to the Kirchhoff lab by September 2013.

Personnel and resources are in place to move forward rapidly on the SNP genotyping program. We envision developing a sampling strategy with the aid of the simulation mentioned above, and starting tissue collection and DNA extraction before the end of year 2. Inferring from two recent publications on Douglas-fir, we may able to move forward in short order with existing SNP databases to build a chip and then to start genotyping.

## Physical and Intellectual Outputs

### Research Presentations

Alvarez-Vasco, C.A, X. Zhang, K.J.S. Jayawickrama and K.B. Garcia. 2013. Phenotypic variations of biomass recalcitrance in Douglas fir families. Poster accepted by the 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29-May 2, 2013.

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. High throughput analysis of biomass recalcitrance of Douglas fir families. Panel presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. Variation in Chemical Composition and Biomass Recalcitrance of D. fir Families. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Jayawickrama, K.J.S., T. Ramaraj, and C.J. Bell. 2012. Marker-aided selection for biofuel production potential in Douglas-fir. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Task FD-4: Genetic Variation Underlying Amenability to Pretreatment/Bioconversion

| Key Personnel | Affiliation |
|---|---|
| Callum Bell | National Center for Genome Resources |

## Task Description

NCGR (National Center for Genomic Resources) will build an updated reference transcriptome for Douglas-fir. We will draw on the two existing references (Howe et al., Wegrzyn et al.) plus newly available single-ended 101 base pair Illumina reads from a collection of 83 trees (US Forest Service). NCGR will apply its Batched Parallel Assembly (BPA) software to these Illumina reads. The workhorse of the assembly is the ABySS assembler, which applies a De Bruijn graph approach. The ABySS kmer pool is fed into an overlap consensus using Mira to further contiguity and collapse redundancy. If the pool is very large (>several million sequences), a cd-hit-est can be performed to reduce the set to the best two cluster representatives. The final synthetic-EST set is then deredundified further using cd-hit-est if desired, and is fed into alignment using BWA. The existing reference transcriptome contigs can be fed into the BPA pipeline at the Mira stage, which will yield a new transcriptome reference that unifies the available resources.

SNP (Single Nucleotide Polymorphism) discovery and prioritization (Task FD-4.4) will be done by alignment of the newly available Illumina sequence reads to the updated reference transcriptome, and identification of mismatches. NCGR will do this by applying Alpheus, its high-throughput alignment and variant detection pipeline. Alpheus is a parallelized workflow that aligns short reads to the reference using the GSNAP algorithm, and parses the output to tabulate all variants that are discovered along with supporting statistics such as the number of reads having a variant, variant nucleotide quality, and sequence coverage at the variant position. Threshold heuristics are then applied to arrive at a draft set of putative variants that have strong support. Alpheus will be supplemented by bioinformatics methods already applied in Douglas-fir genetics (Howe et al.) to arrive at a candidate set of new SNPs ready for validation. The goal is to supplement the existing SNP set with new polymorphic variants, with the particular goal of having SNPs in every Douglas-fir gene.

## Activities and Results

An updated transcriptome assembly for Douglas-fir is now available from the USDA Forest Service (Table 1). It was assembled from 36 of the Forest Service transcriptome samples. This reference is stranded and twice the size of the previous two references available.

NCGR has gained access to sequence reads for 15 of the total 83 samples that the Forest Service maintains. We intend to use all 83 samples in our comprehensive transcriptome reference, but a trial assembly was performed to determine whether the efforts would still be valid after the release of the Forest Service's new reference. The first eight samples received were assembled using NCGR's BPA software (Table 1). We expect the size of the assembly to increase as data from additional samples are introduced into the assembly.

The ability to align sequence reads to a reference is critical in SNP identification. This quality was assessed in both the new Forest Service reference and our trial assembly (Table 1). On average, 6% more reads aligned to NCGR's trial reference than to the Forest Service reference. This could amount to a substantial number of reads over the entire set of 83 samples. We still recognize that SNP identification would benefit from an updated, comprehensive transcriptome assembly for Douglas-fir.

Table 1. Summary statistics for current Douglas-fir transcriptome references.

| Reference | No. Contigs | Total bases (Mb) | N50 (Kb) | Mean % of reads aligned |
|---|---|---|---|---|
| FS (short read) | 39,000 | 36.5 | 1.3 | - |
| JGI (454) | 25,000 | 32.5 | 1.6 | - |
| FS (w/UC-Davis, stranded) *NEW | 90,730 | 78.1 | 1.2 | 78 |
| NCGR (trial, 8 sample) | 41,140 | 38.7 | 1.8 | 84 |

## Recommendations/Conclusions

NCGR is ready to start assembling the Douglas-fir transcriptome once data from all 83 samples are made available. When the assembly is complete, we are prepared to identify SNPs using our variant-detection pipeline, Alpheus. Two recent publications make further reevaluation of the project necessary:

Glenn T Howe, Jianbin Yu, Brian Knaus, Richard Cronn, Scott Kolpak, Peter Dolan, W Walter Lorenz and Jeffrey FD Dean. 2013. A SNP resource for Douglas-fir: de novo transcriptome assembly and SNP detection and validation. BMC Genomics 14:137.

Müller T, Ensminger I, Schmid KJ. 2012. A catalogue of putative unique transcripts from Douglas- fir (*Pseudotsuga menziesii*) based on 454 transcriptome sequencing of genetically diverse, drought stressed seedlings. BMC Genomics. 13(1):673.

Between them, these studies may provide sufficient SNPs to create a useful genotyping resource without further bioinformatics work on the Forest Service sequence reads. We are in the process of reevaluating the available resources and formulating a new plan. There may be the opportunity to join an international consortium, which has the potential to reduce costs by gaining access to bulk discounts through Illumina. At the same time we should not ignore new technologies such as genotyping-by-sequencing (GBS).

## Physical and Intellectual Outputs

### Research Presentations

Jayawickrama, K.J.S., T. Ramaraj, and C.J. Bell. 2012. Marker-aided selection for biofuel production potential in Douglas-fir. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Task FD-5: Screen and Identify Suitable Plant Feedstocks for Large Scale Pretreatments to Produce High Yield Sugar and High Quality Lignin

| Key personnel | Affiliation |
|---|---|
| Xiao Zhang | Washington State University |

## Task Description

Biomass recalcitrance, a collective term describing the resistances of biomass material toward mechanical and/or biochemical deconstructions, is the major barrier hindering the development of an economically viable biomass conversion process. Softwood is the largest biomass feedstock in the Pacific Northwest. However the biomass recalcitrance variations among different softwood species and families are not known. The first objective of the task is to determine the biomass recalcitrance variations among Douglas-fir families and to screen and identify the “most” and “least” Douglas-fir lines.

The genetic influence on biomass recalcitrance is a poorly defined area. Elucidating potential genetic factors influencing biomass recalcitrance can provide breakthrough understanding to the selection and breeding of “ideal” biomass feedstock for biofuel and bioproducts conversion. Approximately 3,000 Douglas-fir lines of different families will be tested for biomass recalcitrance. The work will generate a significant amount of information and allow detailed genetic analysis to identify potential genetic trait(s) controlling biomass recalcitrance. Our second objective is to provide biomass recalcitrance information from different Douglas-fir families to the genetic analysis group (Keith Jayawickrama, Callum Bell, Helmut Kirchhoff) to elucidate and understand the genetic influence on biomass recalcitrance.

To attain a comprehensive understanding of biomass recalcitrance, we devised a three-step screen protocol (Figure 1). The first step is a high throughput chemical compositional analysis to determine the amount of total carbohydrate and lignin in the different Douglas-fir families. Douglas-fir core samples (approximately 20cm length × 1cm diameter) were taken from breast height of each Douglas-fir tree lines (age 16 yr). The samples were ground and passed through a 1 mm screen on a Wiley mill. Wood particles with sizes between 20-60 mesh were collected for the analysis. We chose to determine klason lignin, holocellulose and acetone extractives to represent the chemical compositions of the samples. The klason lignin was determined following Tappi standard assay (T222) with 100mg wood samples. The holocellulose content was determined by using acid chlorite treatment of wood samples. The amount of holocellulose represents total carbohydrate content. The acetone extractives content was obtained by extraction of wood in acetone solvent for four hours. The acetone extraction, acid chlorite treatment and 3% acid hydrolysis were carried out in an Ankom 200 fiber analyzer incubator where 24 sample analyses can be processed simultaneously.

Biomass recalcitrance can be attributed to both chemical and physical/structural recalcitrance. The ultimate goal of biomass conversion is to attain an efficient and high yield conversion of wood carbohydrate to biofuel. While a feedstock with higher holocellulose content can potentially provide more sugar for fuel production, its physical characteristics, such as density, fiber length and cell wall thickness, also have a significant impact on the susceptibility toward subsequent pretreatments to release the chemical components. The second step of the protocol is the pretreatment screening of Douglas-fir lines. Two pretreatment chemistries were applied, diluted acid (DA) and alkaline hydrogen peroxide (HP) pretreatment. DA is one of the most common biomass deconstruction methods used on all types of biomass. In a typical DA process, biomass hemicelluloses are preferentially hydrolyzed while most of the cellulose and lignin remain in solid substrate. Alkaline hydrogen peroxide pretreatment of Douglas-fir family lines was used to compare between different pretreatment conditions. HP pretreatment is expected to target on lignin degradation to improve substrate digestibility to the enzyme. Pretreatment of different Douglas-fir family lines were carried out in tube reactors, a modified procedure adapted from the National Renewable Energy Laboratory (NREL). Twenty-four samples were pretreated at the same time in the tube reactor placed in an oil bath. Both water soluble fractions (WSF) and solid fractions after the pretreatment were collected. The WSFs were analyzed for releasing sugars and soluble phenolic compounds measured by high throughput microplate assay. These results provided information on recalcitrance of each Douglas-fir family lines toward carbohydrate and lignin removal during pretreatment. The holocellulose and lignin remaining in the solid substrates were also determined. The solid substrates were subjected to enzymatic hydrolysis in the third step. A relatively excessive amount of enzyme (~50mg cellulose per gram of cellulose) was applied to hydrolyze these substrates and glucose released after 72 hours of hydrolysis was determined. High enzyme dosages were applied to minimize the effect of potential enzyme dosage limitation while maximizing the effect of substrate digestibility differences among different Douglas-fir lines.

NREL has developed a high throughput screening method based on suing microtiter plate assisted by robotics to determine the sugar released from combined pretreatment and hydrolysis. A large amount of sample analyses can be performed, however, relatively limited information can be obtained. Our screen method can provide a more comprehensive understanding and quantification of biomass differences among different samples, which are critical to the subsequent genetic analysis to identify potential genetic traits associated with biomass recalcitrance.

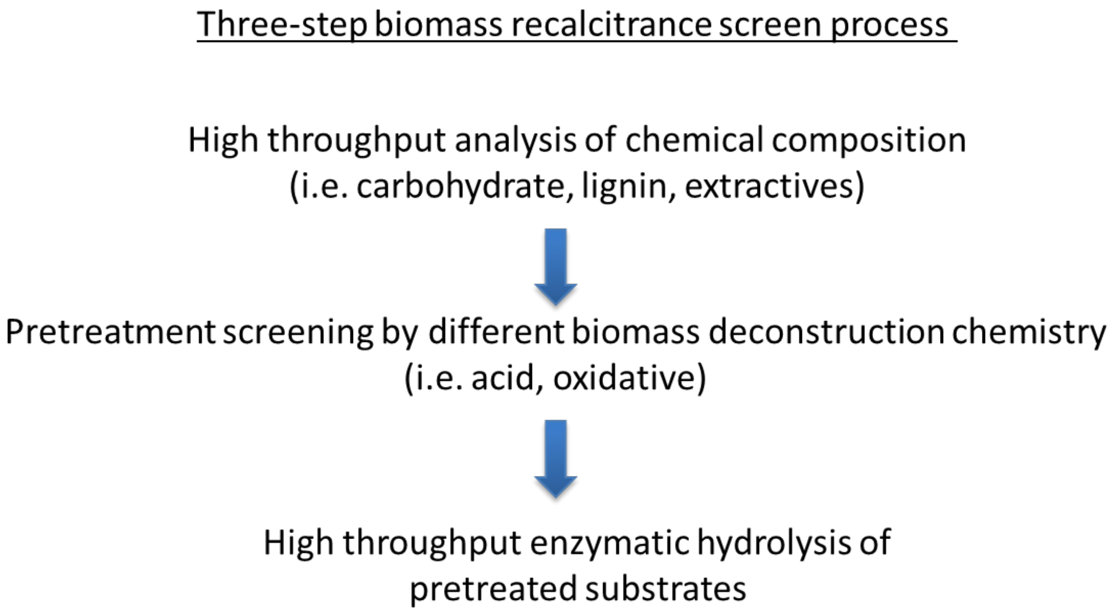


Figure 1: A three-step screen protocol to determine the degree of biomass recalcitrance of softwood

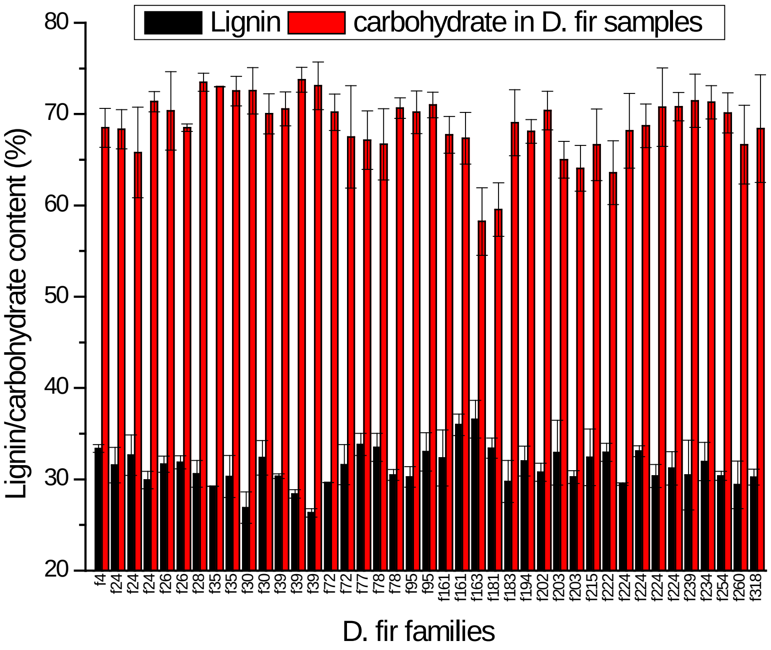
## Activities and Results

At the beginning of the project, the work was focused on developing a reliable screen protocol and refining each assay step. This development also included working with Oregon State University to standardize the tree sampling procedure to obtain representative and sufficient samples for analysis. A significant amount of replicated experiments were carried out to verify the results obtained from this screening method and comparing this method with standard or conventional testing protocols for chemical analysis (lignin and sugar analysis), pretreatment and enzymatic hydrolysis.

Since June 2012, ~ 500 core samples from different Douglas-fir family lines (from different families or same families planted in different locations) were received. A detailed analysis of the first batch, 150 samples analysis, was completed. A significant variation in chemical composition was observed in different Douglas-fir family lines. Lignin, holocellulose and extractive amounts varied between 26-38%, 54-76% and 0.6-5% respectively (Figure 2). Dr. Jayawickrama conducted an initial heritability analysis and the results suggest that the variations in lignin and holocellulose content are under strong genetic control. This analysis will be confirmed once we complete the remaining samples from the initial 500 Douglas-fir phenotypes.

To identify suitable pretreatment conditions for Douglas-fir lines, more than 20 different pretreatment conditions from each of DA and HP chemistry were first evaluated on FS01, a reference Douglas-fir sample used by the NARA pretreatment team. Diluted acid pretreatment of Douglas-fir using 4% sulfuric acid (w/w on wood) for 30 minutes at 180°C and alkaline peroxide pretreatment of Douglas-fir at 180°C for 30 minutes using 4% hydrogen peroxide (w/w on wood) were selected. These are the relatively mild pretreatment conditions to produce substrates with moderate substrate digestibility. A significant variation on solid substrate yield from diluted acid pretreatment of different Douglas-fir lines was observed between 58% - 71% (Figure 3). The holocellulose content in pretreated Douglas-fir lines varied from 50-58%. The holocellulose content after HP pretreatment was higher, ranging from 60-70%. The variation in the solid substrate yield difference after HP pretreatment appears to be less significant compared to diluted acid pretreatment. It is interesting to find a huge difference among the digestibility of different Douglas-fir family lines after pretreatment (Figure 4). The conversion yield from diluted acid pretreatment differs from approximately 19% to almost 50%. This variation appeared to be the most significant among other parameters. This suggests that biomass recalcitrance is not determined by a single biomass property. It was also interesting to find that some Douglas-fir lines exhibited low recalcitrance toward both pretreatment methods (e.g. 3996, 4665) while other showed different levels of recalcitrance toward different biomass deconstruction methods. A number of highly recalcitrant and less recalcitrant Douglas-fir lines were identified. We are currently investigating the relationships between the substrate digestibility and other parameters (composition, pretreatment yield, etc.).

A: lignin and carbohydrate



B: Acetone extractives content

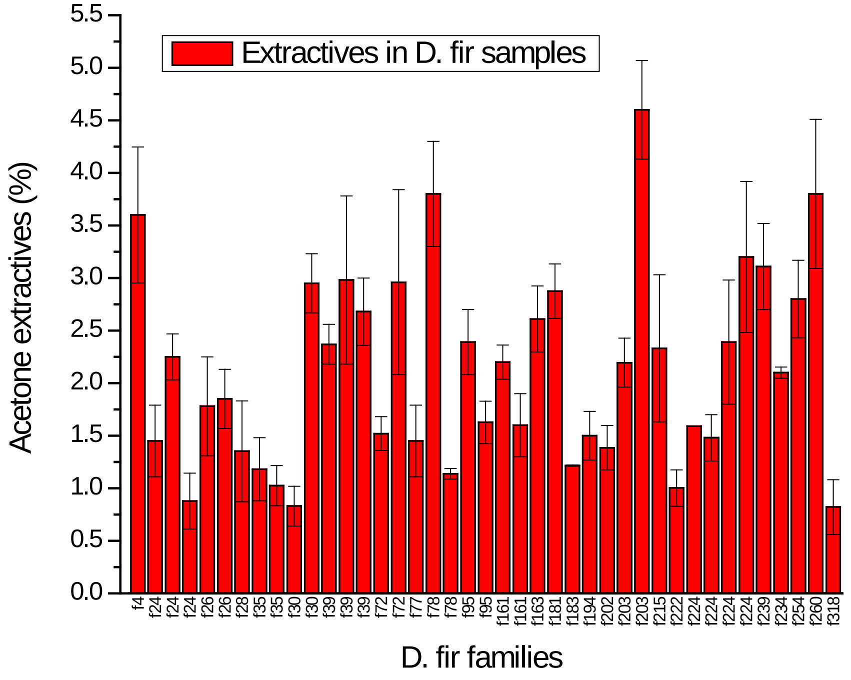
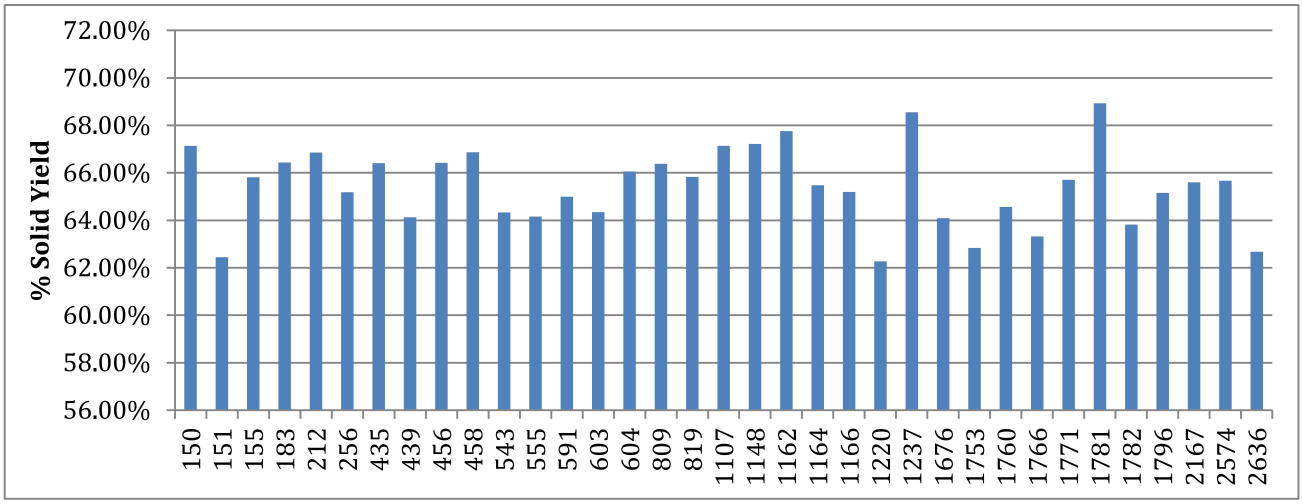


Figure 2: The chemical compositional of different Douglas-fir samples



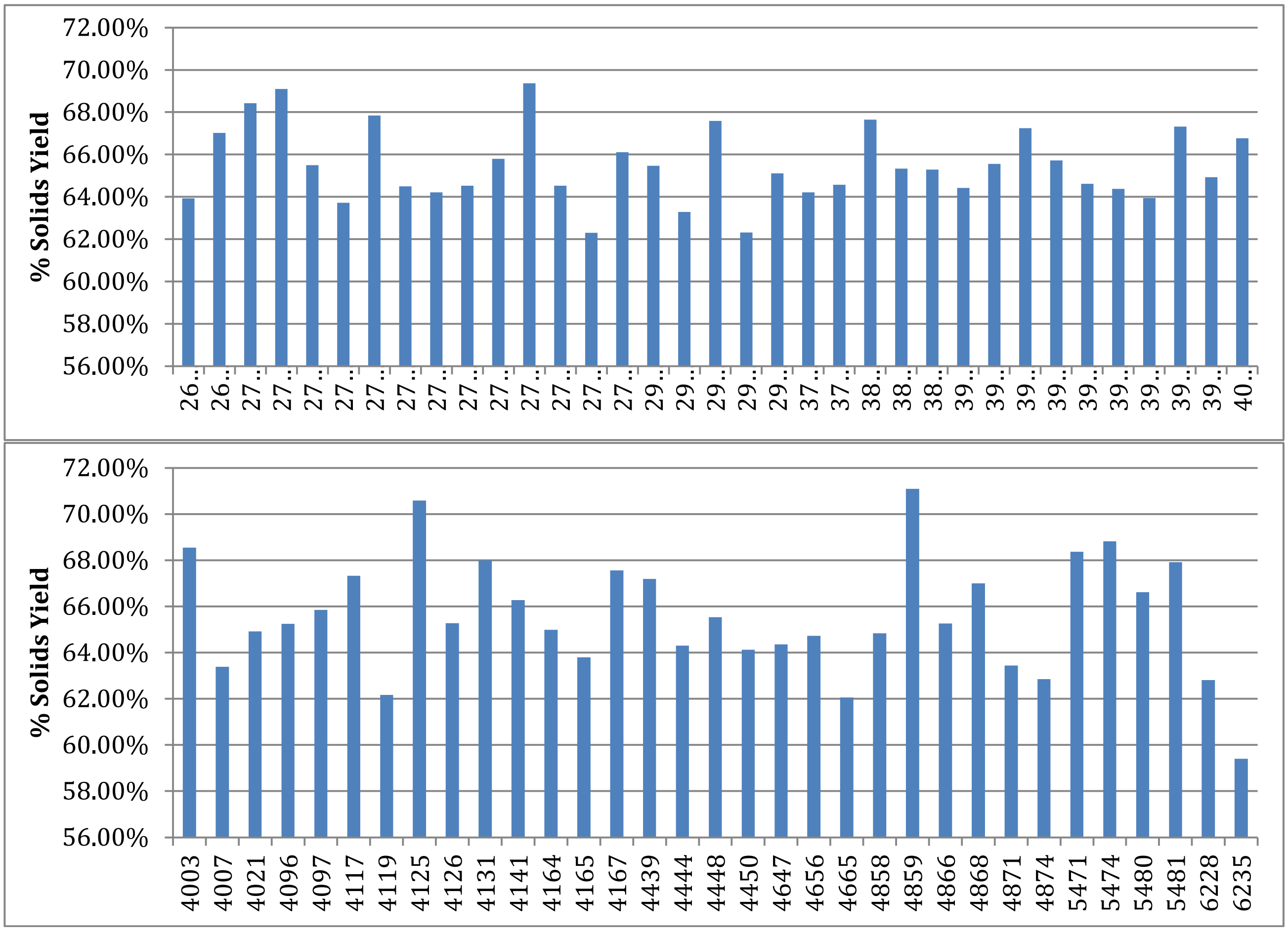
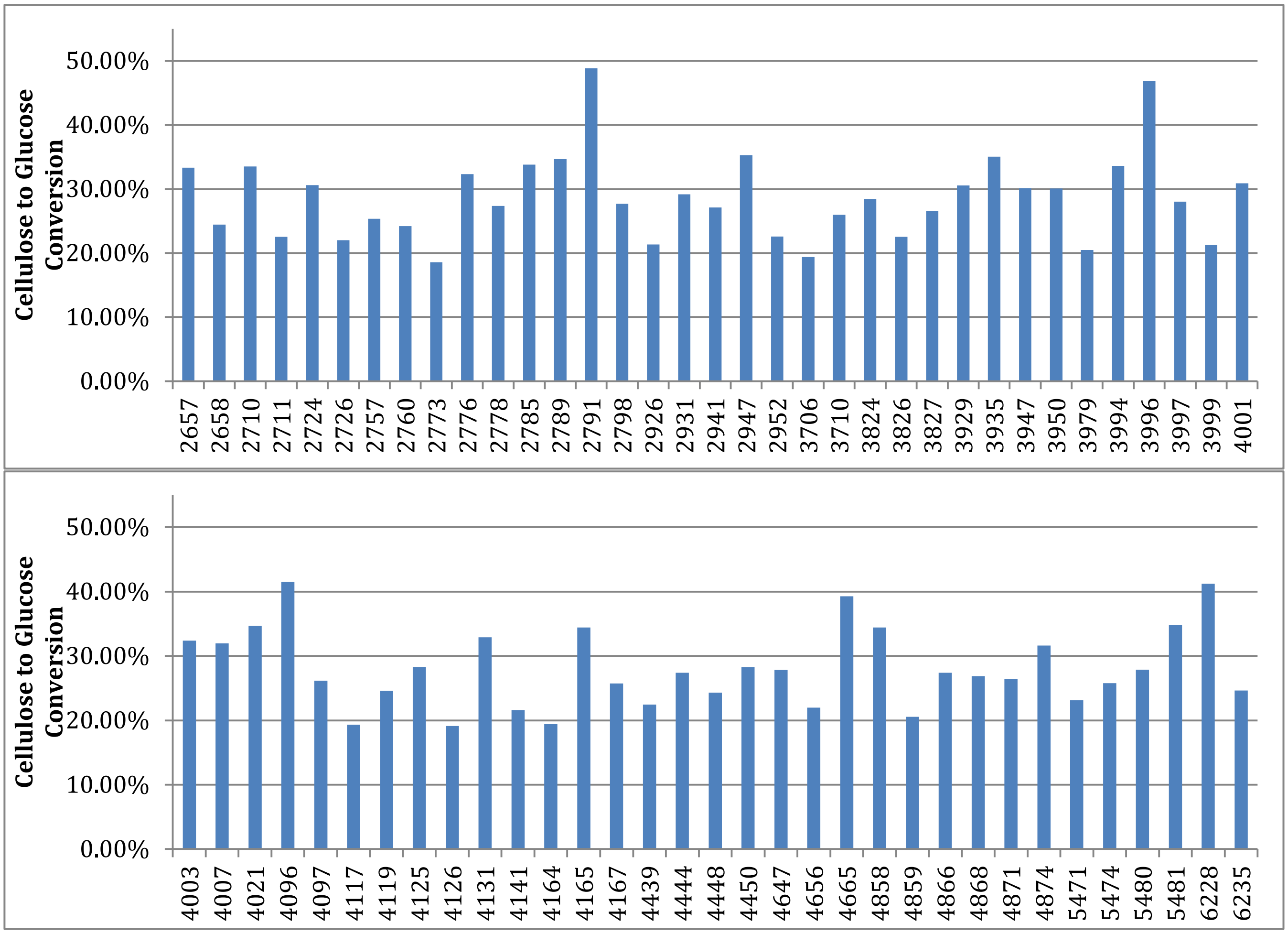


Figure 3: the pretreatment yield of D. fir line after diluted acid pretreatment. (Average: 65.50% Standard Deviation: 1.99%, sample ID is shown on X –axis)

A: Hydrolysis Yield – Dilute Acid (Average: 28.27%, Standard Deviation: 5.96%)



B: Hydrolysis Yield – Alkaline Peroxide (Average: 15.87%, Standard Deviation: 4.21%

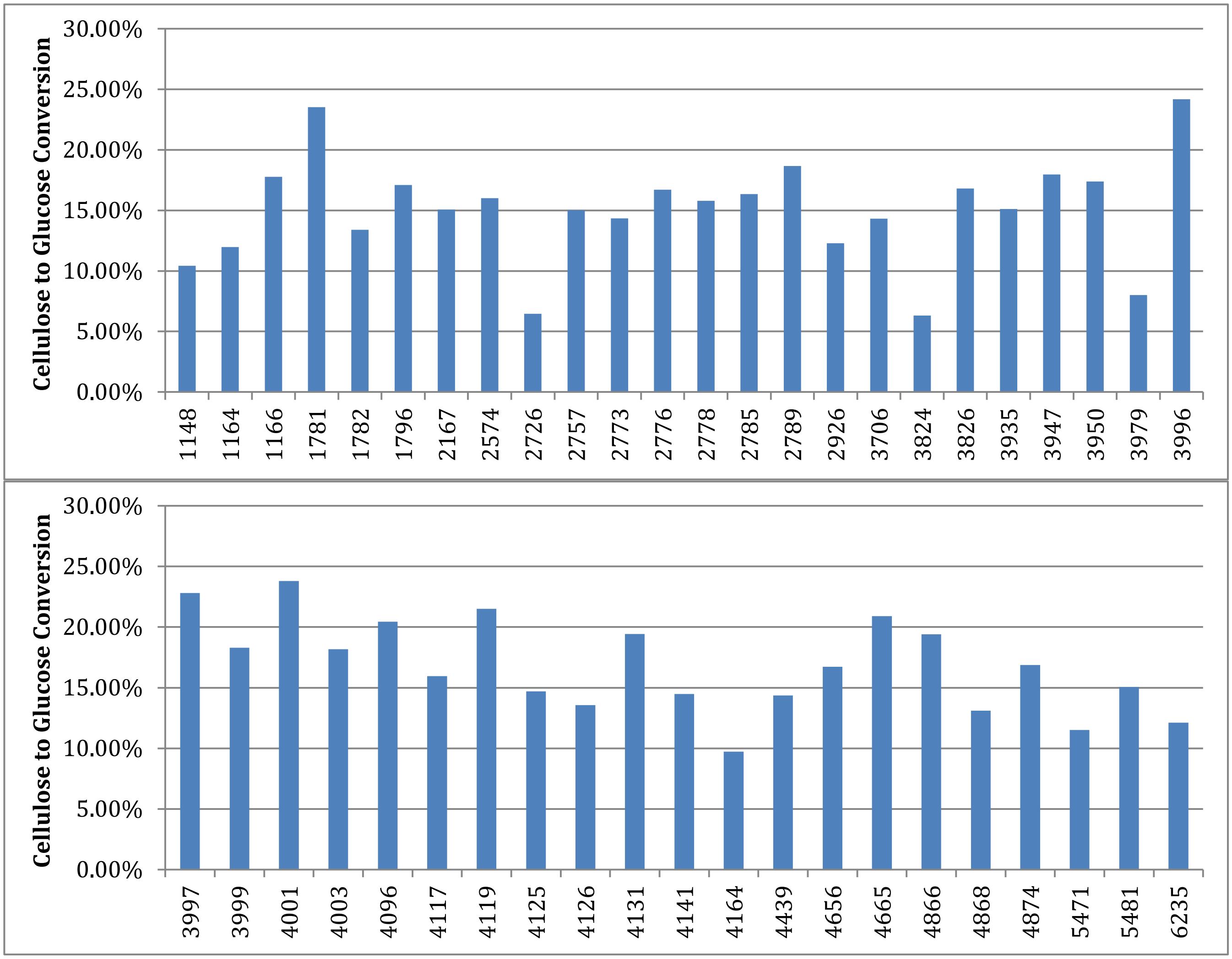


**Figure 4**: Cellulose to glucose conversion yield obtained from cellulase hydrolysis of diluted acid (A) and alkaline peroxide (B) pretreated D. fir family lines (Average: 28.27%, Standard Deviation: 5.96%, sample ID is shown on X –axis)

## Recommendations/Conclusions

A systematic research approach is taken to gain a comprehensive understanding of biomass recalcitrance variation of Douglas-fir from several aspects, including chemical composition, pretreatability and digestibility. A large amount of information has been gathered from this first one-and-half year study. The results have shown that the traits associated with biomass recalcitrance were highly variable among different Douglas-fir families. Initial heritability analysis has suggested that genetic control may have a strong influence on some of the “biomass recalcitrance traits” of Douglas-fir families. Douglas-fir family lines with relatively high or low recalcitrance are identified and the information will be provided for subsequent genetic analysis. This research task can help us gain a comprehensive understanding of the recalcitrance of softwood toward biomass conversion. Continued gathering this information from the other Douglas-fir family lines will likely lead to a breakthrough understanding of the underlining genetic control of biomass recalcitrance and provide insight to feedstock selection and breeding for biofuel production.

## Physical and Intellectual Outputs

### Conference Proceedings and Abstracts from Professional Meetings

Carlos A. Alvarez-Vasco, Xiao Zhang, Keith J. S. Jayawickrama and Karissa B. Garcia “Phenotypic variations of biomass recalcitrance in Douglas fir families”, 35th Symposium on Biotechnology Application on Fuels and Chemicals, April 2013 Portland

### Research Presentations

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. High throughput analysis of biomass recalcitrance of Douglas fir families. Panel presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. Variation in Chemical Composition and Biomass Recalcitrance of D. fir Families. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

### Trainings, Education and Outreach Materials

Pedro Guajardo was awarded the Auvil Scholarship for his work with NARA.

# Feedstock Logistics TEAM

## Task FL-1: Feedstock Sourcing

| Key Personnel | Affiliation |
|---|---|
| Gevan Marrs | Weyerhaeuser |

### Task Description

Weyerhaeuser and Oregon State University will work cooperatively to quantify costs and quantities of key Pacific Northwest candidate feedstocks by region; determine feedstock key quality parameters, variation and impact on conversion processes; perform analysis to select optimum feedstock sourcing strategies, and develop and test feedstock supply chain improvements to reduce costs and increase value.

Weyerhaeuser will concentrate on the supply chain from young, intensively managed plantations of Douglas-fir in western Oregon and Washington, primarily pre-commercial thinnings. Many of these stands have good access on favorable terrain, but are not currently being utilized; others are on steep terrain, posing greater utilization challenges. Unlike forest residuals from regeneration activities, residuals from pre-commercial thinnings are not currently at roadside. Because of high handling costs, forest owners currently either thin-to-waste or delay thinning, losing potential forest growth. Cost-efficient stump-to-truck collection and comminution systems for young managed stands could contribute significantly to a bioenergy industry. Weyerhaeuser is in strong position to design and implement studies in young managed stands with their well-distributed ownership of Douglas-fir plantations in Oregon and Washington. We will leverage existing harvesting equipment manufacturers to test and document the application of small-tree supply chains that have been successful elsewhere and test modifications of those techniques for our regional conditions and multi-product markets. Weyerhaeuser will: work with the conversion group to match feedstocks from young plantations with required specifications for conversion; document the costs and productivity of existing small-tree supply chains; test and document improvements in the supply chain; estimate potential regional supplies and costs for use in regional biomass modeling; and coordinate with the sustainable production group on long term site productivity studies.

### Activities and Results

Although a preliminary analysis of likely feedstock that balances available quantities of Pacific Northwest softwood against cost and quality indicated that forest harvest residuals (“FHR”) were the most plausible candidate for sourcing the NARA project (Figure 1), to get broadly representative materials for all pretreatment pathways with minimum variability and contaminants, Douglas-fir pulp chips were obtained from a pulp mill chip pile and prepared, characterized and distributed to teams as a starting common reference sample.

Eight candidate FHR samples were obtained from operating harvests in western Washington and Oregon. Each sample of about 500 OD pounds was screened to remove fines (which contain a high level of bark and inorganics contaminants), air-dried, fully characterized, and aliquots of chosen samples delivered to pretreatment teams for conversion tests. Figure 2 shows a comparison of one of the major quality attributes—polysaccharides content. As expected, samples with higher bark content tended to have more fines produced, and thus higher fines screening rejects, which of course drives up feedstock cost to conversion mouth.

Quantification of key quality attributes confirmed that not only was there a high degree of variability between FHR samples, there seemed to be considerable opportunity to influence several key factors (bark content, species, and inorganic contamination) once harvesters were aware of desired quality attributes. Figure 3 shows how one main factor—bark content—is broadly correlated to total polysaccharides content, and thus to conversion process yield where fermentation of monosaccharides is the route to biofuels.

A final (largely unexplored to date) controllable factor is how the feedstock is particulated from forest to conversion mouth. Many early NARA feedstock samples were being ground for power combustion and the resulting fines resulted in far too much material loss for biofuels.

Our latest large-scale (~4 OD tons) of NARA FHR reference sample was collected to reduce bark content and fines generation in the woods. Subsequent mill screening and re-sizing of the oversize particles led to a much improved feedstock quality and cost for our subsequent work. (see FS-10 in Figure 3). Table 1 lists the key quality attributes of all NARA feedstocks to date.

In concert with the techno-economic analysis (TEA) task, it was necessary to set a conversion plant scale, which trades off rising feedstock cost against reduced unit capital costs with increasing facility scale. Preliminary FHR availabilities were obtained by county for all NARA states and contiguous 3-to-5 county blocks chosen in each of western Washingtion and Oregon, as well as one in Montana and Idaho, for which the data showed more than 1million BDT/yr FHR availability. A harvesting and hauling model was constructed leading to construction of sourcing curves for western Washington and Oregon (Figure 4).

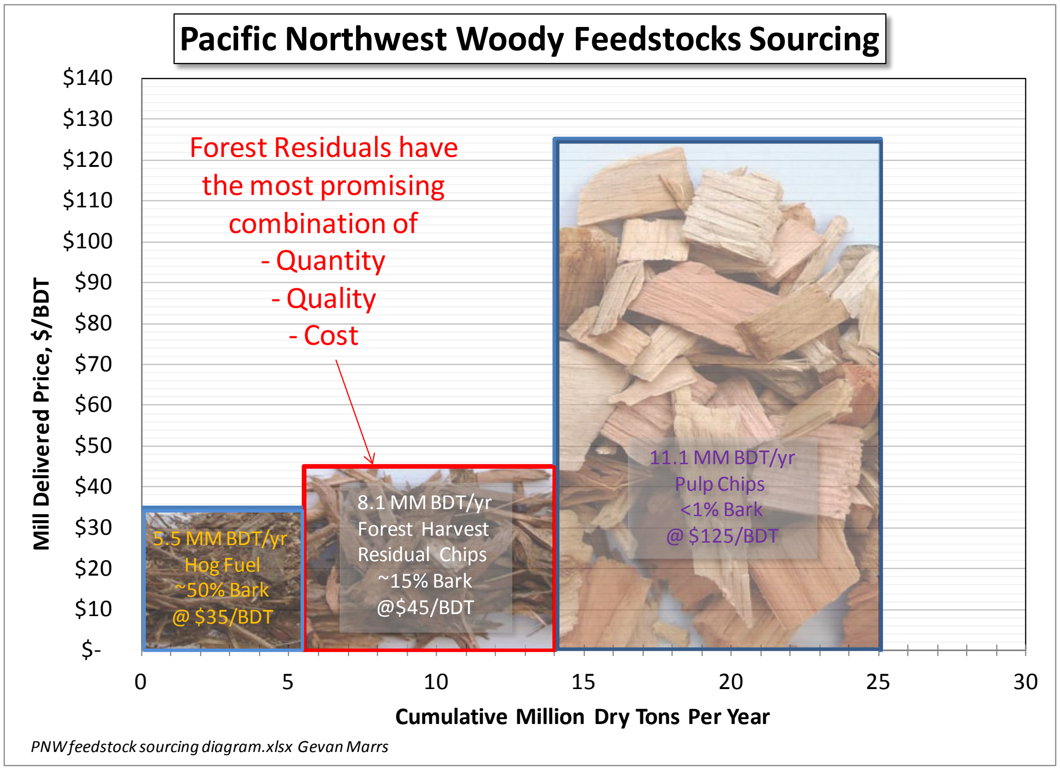
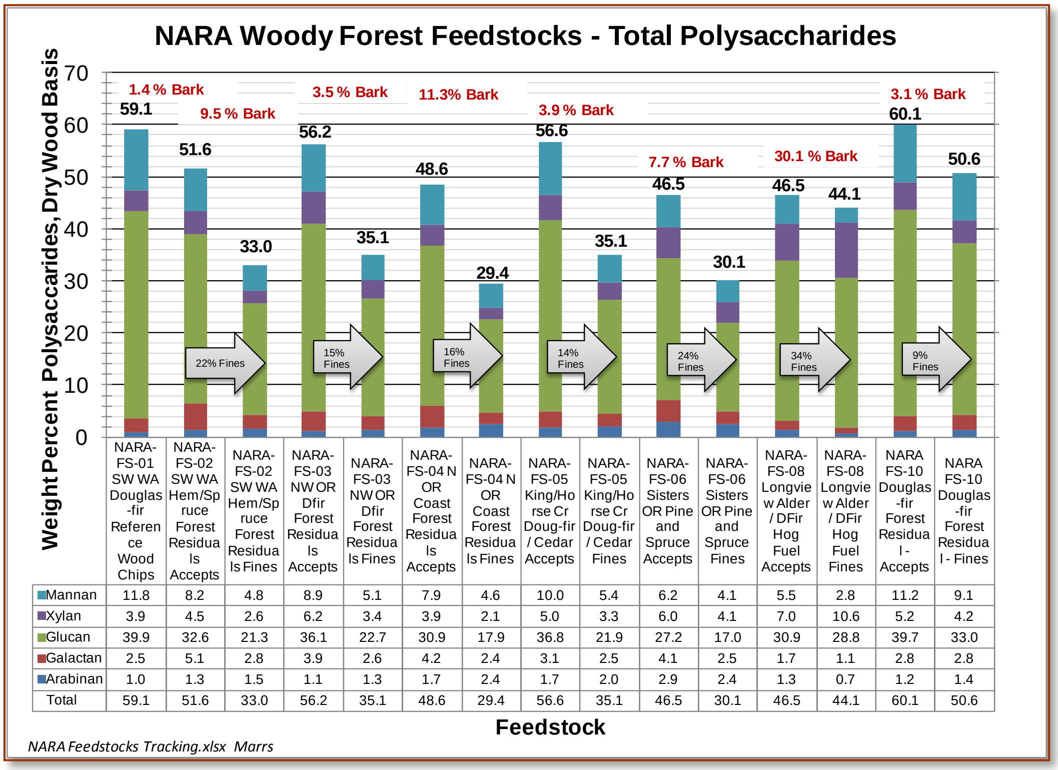


Figure 1. Preliminary estimates of quantities and costs for three basic softwood feedstock categories in the NARA PNW region.



| | NARA-FS-01 SW WA Douglas-fir Reference Wood Chips | NARA-FS-02 SW WA Hem/Spruce Forest Residuals Accepts | NARA-FS-02 SW WA Hem/Spruce Forest Residuals Fines | NARA-FS-03 NW OR Dfir Forest Residuals Accepts | NARA-FS-03 NW OR Dfir Forest Residuals Fines | NARA-FS-04 N OR Coast Forest Residuals Accepts | NARA-FS-04 N OR Coast Forest Residuals Fines | NARA-FS-05 King/Horse Cr Doug-fir / Cedar Accepts | NARA-FS-05 King/Horse Cr Doug-fir / Cedar Fines | NARA-FS-06 Sisters OR Pine and Spruce Accepts | NARA-FS-06 Sisters OR Pine and Spruce Fines | NARA-FS-08 Longview Alder / DFir Hog Fuel Accepts | NARA-FS-08 Longview Alder / DFir Hog Fuel Fines | NARA FS-10 Douglas-fir Forest Residual - Accepts | NARA FS-10 Douglas-fir Forest Residual - Fines |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mannan | 11.8 | 8.2 | 4.8 | 8.9 | 5.1 | 7.9 | 4.6 | 10.0 | 5.4 | 6.2 | 4.1 | 5.5 | 2.8 | 11.2 | 9.1 |
| Xylan | 3.9 | 4.5 | 2.6 | 6.2 | 3.4 | 3.9 | 2.1 | 5.0 | 3.3 | 6.0 | 4.1 | 7.0 | 10.6 | 5.2 | 4.2 |
| Glucan | 39.9 | 32.6 | 21.3 | 36.1 | 22.7 | 30.9 | 17.9 | 36.8 | 21.9 | 27.2 | 17.0 | 30.9 | 28.8 | 39.7 | 33.0 |
| Galactan | 2.5 | 5.1 | 2.8 | 3.9 | 2.6 | 4.2 | 2.4 | 3.1 | 2.5 | 4.1 | 2.5 | 1.7 | 1.1 | 2.8 | 2.8 |
| Arabinan | 1.0 | 1.3 | 1.5 | 1.1 | 1.3 | 1.7 | 2.4 | 1.7 | 2.0 | 2.9 | 2.4 | 1.3 | 0.7 | 1.2 | 1.4 |
| Total | 59.1 | 51.6 | 33.0 | 56.2 | 35.1 | 48.6 | 29.4 | 56.6 | 35.1 | 46.5 | 30.1 | 46.5 | 44.1 | 60.1 | 50.6 |

*NARA Feedstocks Tracking.xlsx  Marrs*

Figure 2. Compilation of one key quality attribute (polysaccharides) for NARA feedstocks sampled to date.

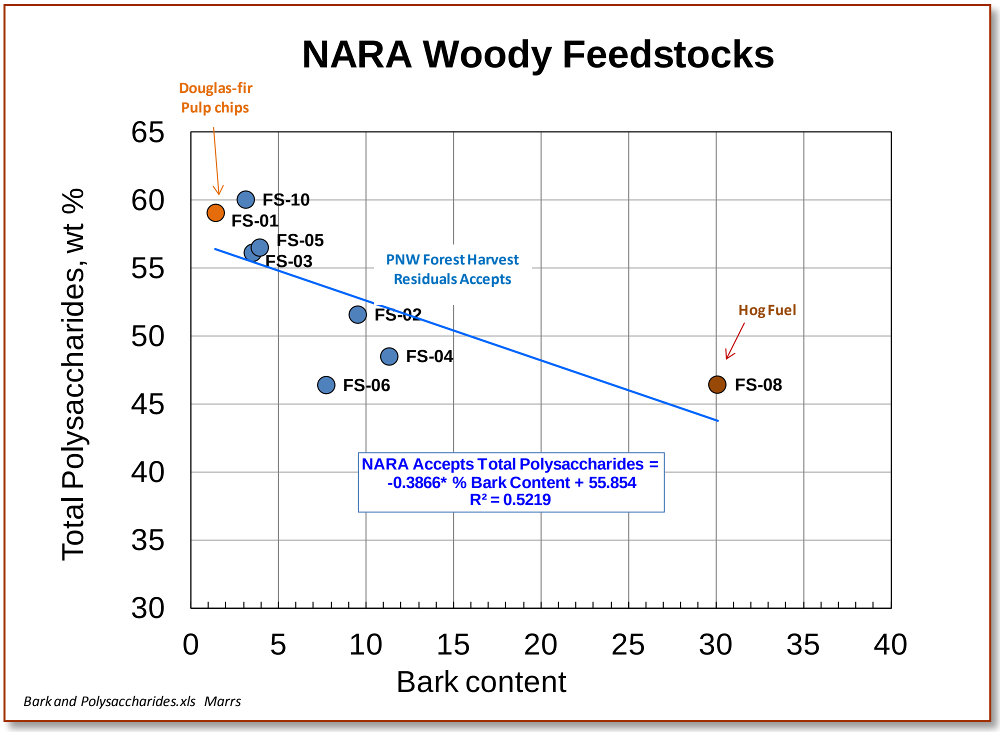


Figure 3. A key quality parameter—bark content—can vary widely depending upon harvesting and is strongly related to process conversion yield potential.

Table 1. Quality attributes of NARA feedstock samples.

| Summary Chemical Analyses NARA Feedstocks | | | | | | | | | | Qualtiy Aspects NAF | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feedstock | Total Polysaccharides | Hexose Polysaccharides | Pentose Polysaccharides | Lignin, Acid-Insoluble (Klason) | Acid-soluble Lignin | Hot Water Extractives | Ethanol Extractives | Ash | **Total** | Percent Fines Reject | Bark Content | Ash % |
| NARA-FS-01 SW WA Douglas-fir Reference Wood Chips | 59.07 | 54.2 | 4.91 | 26.83 | 0.28 | 2.11 | 1.63 | 0.20 | **90.1** | | 1.4% | 0.20 |
| NARA-FS-02 SW WA Hem/Spruce Forest Residuals Accepts | 51.63 | 45.8 | 5.82 | 32.23 | 0.50 | 5.22 | 2.81 | 1.45 | **93.8** | | 9.5% | 1.45 |
| NARA-FS-02 SW WA Hem/Spruce Forest Residuals Fines | 32.97 | 28.9 | 4.08 | 44.17 | 0.87 | 6.92 | 4.93 | 10.48 | **100.3** | 22.0% | UNK | 10.48 |
| NARA-FS-03 NW OR Dfir Forest Residuals Accepts | 56.18 | 48.87 | 7.31 | 29.63 | 0.44 | 3.71 | 2.52 | 1.24 | **93.7** | | 3.5% | 1.24 |
| NARA-FS-03 NW OR Dfir Forest Residuals Fines | 35.10 | 30.4 | 4.73 | 41.60 | 0.74 | 5.55 | 4.01 | 15.27 | **102.3** | 14.8% | UNK | 15.27 |
| NARA-FS-04 N OR Coast Forest Residuals Accepts | 48.55 | 43.0 | 5.59 | 35.37 | 0.63 | 4.91 | 3.09 | 2.37 | **94.9** | | 11.3% | 2.37 |
| NARA-FS-04 N OR Coast Forest Residuals Fines | 29.38 | 24.9 | 4.50 | 44.80 | 1.10 | 6.07 | 6.47 | 8.47 | **96.3** | 16.1% | UNK | 8.47 |
| NARA-FS-05 King/Horse Cr Doug-fir / Cedar Accepts | 56.56 | 49.8 | 6.72 | 29.00 | 0.43 | 5.11 | 2.49 | 1.65 | **95.2** | | 3.9% | 1.65 |
| NARA-FS-05 King/Horse Cr Doug-fir / Cedar Fines | 35.10 | 29.8 | 5.30 | 40.30 | 0.83 | 7.49 | 6.16 | 15.20 | **105.1** | 13.9% | UNK | 15.20 |
| NARA-FS-06 Sisters OR Pine and Spruce Accepts | 46.45 | 37.6 | 8.89 | 33.90 | 0.58 | 5.43 | 5.11 | 2.82 | **94.3** | | 7.7% | 2.82 |
| NARA-FS-06 Sisters OR Pine and Spruce Fines | 30.12 | 23.7 | 6.42 | 43.47 | 0.84 | 7.08 | 6.29 | 12.70 | **100.5** | 24.5% | UNK | 12.70 |
| NARA-FS-08 Longview Alder / DFir Hog Fuel Accepts | 46.48 | 38.1 | 8.37 | 34.90 | 0.88 | 5.52 | 3.14 | 5.76 | **96.7** | | 30.1% | 5.76 |
| NARA-FS-08 Longview Alder / DFir Hog Fuel Fines | 44.10 | 32.8 | 11.28 | 37.73 | 1.20 | 5.79 | 2.48 | 8.92 | **100.2** | 33.6% | UNK | 8.92 |
| NARA FS-10 Douglas-fir Forest Residual - Accepts | 60.09 | 53.74 | 6.35 | 27.53 | 0.44 | 3.37 | 2.14 | 0.44 | **94.0** | | 3.4% | 0.44 |
| NARA FS-10 Douglas-fir Forest Residual - Fines | 50.60 | 44.9 | 5.66 | 32.23 | 0.56 | 4.34 | 4.33 | 1.97 | **94.0** | 9.0% | UNK | 1.97 |

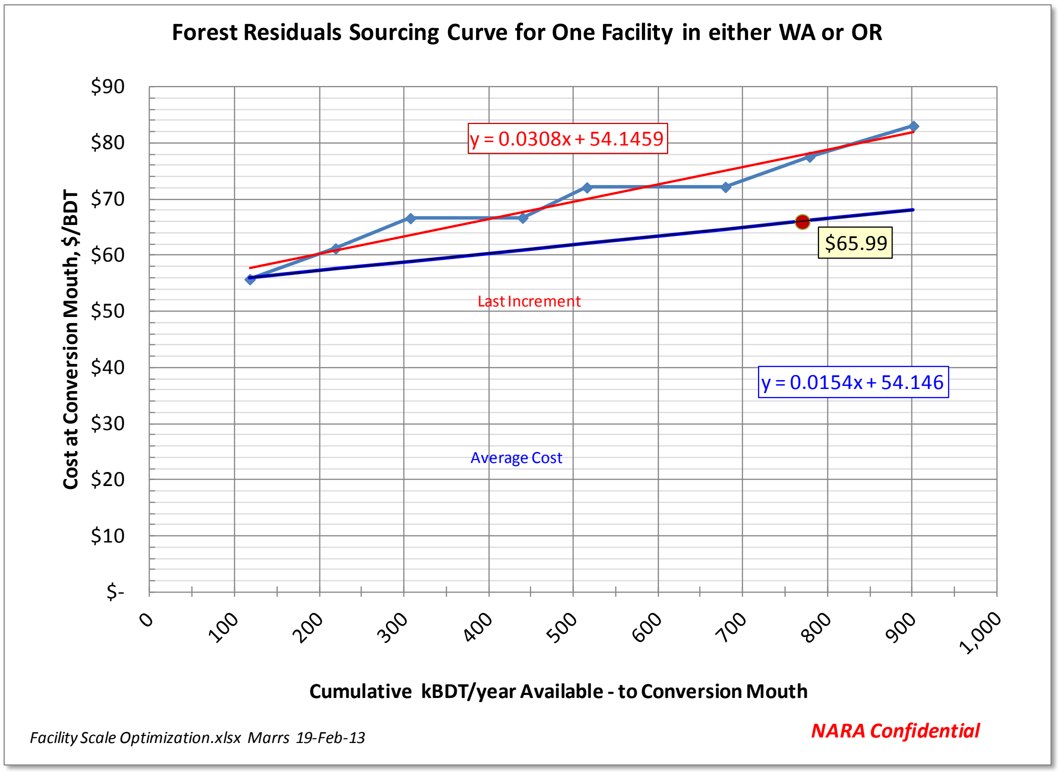


Figure 4. Feedstock sourcing curve for western WA or OR estimates average feedstock cost to a 770 thousand BDT/yr facility at approximately $66/BDT.

## Recommendations/Conclusions

Our work to date demonstrates that there is a very high variability in key quality attributes of the most plausible softwood feedstock for a scale biofuels production—forest harvest residuals. Many of this (bark, species, inorganics, particle size) can be impacted by harvesting techniques once the value of doing so is communicated to the harvesting operators. One aspect—optimizing the location, methods, and degree(s) of particle-size reduction and matching to the conversion process sensitivities—is largely unexplored and is not well-defined based upon prior art (like pulp mill procedures, for example). This area has considering financial impact on overall process economics and should be investigate further in coming project years. Additionally, while the initial focus has been on the regions with the highest availability of FHR feedstock at scale, and existing harvesting operations from which to readily obtain samples, work should be directed toward quantifying the opportunity and quality for softwood feedstocks in the Montana corridor.

## Physical and Intellectual Outputs

### Physical

- Nine different NARA feedstocks were sampled at varying scales (from 500 to 10,000 OD lbs), prepared by size screening, air-dried, fully characterized, and distributed as required for the various pretreatment teams for conversion tests.
- Preliminary feedstock sourcing curves, showing rising cost with conversion facility scale, were prepared and delivered to the TEA group, providing one key manufacturing cost input.

### Research Presentations

Marrs, G. 2012. Feedstock sourcing – quality and impacts. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Marrs, G. 2012. Feedstock sourcing – quantity and cost. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Task FL-2: Logistics Decision Support and Improvement

| Key Personnel | Affiliation |
|---|---|
| John Sessions | Oregon State University |
| Kevin Boston | Oregon State University |
| Loren Kellogg | Oregon State University |
| Glen Murphy | Oregon State University |

## Task Description

We will: synthesize existing feedstock supply chains for collection, preprocessing, storage, and transport to support model development; develop biomass efficiency recovery factors linked to forest type and harvest methods; quantify grinding and chipping production costs and their ability to meet alternative feedstock specifications; develop and test operational strategies and decision support systems to reduce moisture content for long distance wood transport; work with trailer manufacturer partners to demonstrate advanced trailer configurations to increase load efficiency and performance of chip vans on highway and on forest roads to improve access, reduce weight, and increase capacity; compare mobile versus stationary chipping/grinding strategies under a range of field conditions and operating strategies; evaluate any new processes for worker health and safety.

## Activities and Results

Task FL-2.1 develops biomass recovery coefficients for Oregon, Washington, Idaho and Montana. A procedure for estimating piled and field distributed biomass has been developed and validated. Packing estimates, the percentage of solid wood in a cubic foot of space, have been collected from 15 sites in western Oregon and Washington. Five additional sites have been identified in eastern Oregon. Sites are being identified in Idaho and Montana in coordination with the University of Montana BBER group. Finally, the prototype of the biomass recovery by species and silvicultural prescription has been developed and prototyped.

Task FL-2.2 develops moisture management strategies and models. We completed the evaluation of six tools (2 acoustic, 2 conductance, and 2 capacitance) for estimating moisture content in three forms of woody biomass (small roundwood logs, chips and hogfuel) in six species (Douglas-fir, ponderosa pine, western hemlock, poplar, garryana oak, and madrone). Criteria for evaluating the tools included accuracy, efficiency and mechanical reliability. All tools required calibration (often species specific). Validation of the three best performing tools in Douglas-fir indicates that the tools are accurate below 35% MC (wet basis). This suggests they could be used for making threshold transportation decisions, i.e., determining when to haul. We have completed a forecasting model for air-drying rates of Douglas-fir in Oregon. Analysis of data from 3000 truckloads of forest harvesting residuals delivered to a cogeneration plant at Eugene, Oregon indicates moisture content varies as a function of season of harvest and season of piling. Preliminary data analysis also suggests that a significant number of truck loads are being delivered underweight. Low bulk density and large trailer access may be limiting transportation efficiency.

Task FL-2.3 refines collection and transport models for regional modeling. A decision support model for determining the optimal grinding/chipping equipment/trucking configuration for comminution has been completed. Field studies needed to develop and validate this model included mobile chipping and stationary grinding at 12 sites in Oregon and Washington. Actual grinding and chipping utilization rates varied widely (20% to 80% utilization) depending upon truck availability and road configurations (Figure 1). We found that each 10% increase in grinder/chipper utilization could reduce costs \$0.5-\$3.0/dry ton (Figure 2). Upper limits on grinder utilization depended upon the road and landing configuration. Simulations using this decision support model will be used to inform the Timber Supply Model.

Task FL-2.4 evaluates chipping and grinding production to meet alternative feedstock specifications. Grindings from eight geographic areas in western Washington, western Oregon and eastern Oregon were collected and transported to the Weyerhaeuser Technical Center for characterization by the Feedstock Sourcing team. One additional example of chips from a mobile chipper operating in Douglas-fir forest harvest residuals was sent to the Forest Products Laboratory. In addition, forest residuals from 55 sites were characterized under a companion study at Oregon State University (Smith, Sessions, et al. Forest Products J, manuscript accepted). Study of residue characteristics from the 55 samples (Figure 3) is being used to design structured tests for Summer, 2013 to increase uniformity, reduce moisture content, reduce ash content, and increase dry bulk density. Bark and ash are concentrated in the Fines Fraction.

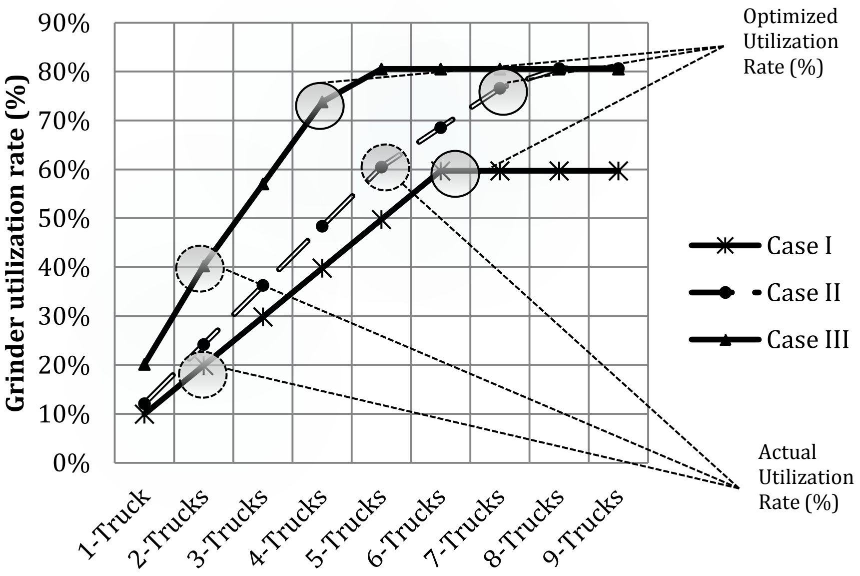


Figure 1. Grinder utilization rate as a function of truck availability showing actual utilization and utilization under the combination of trucks that provided the lowest comminution plus transportation costs (Zamora et al., manuscript in review)

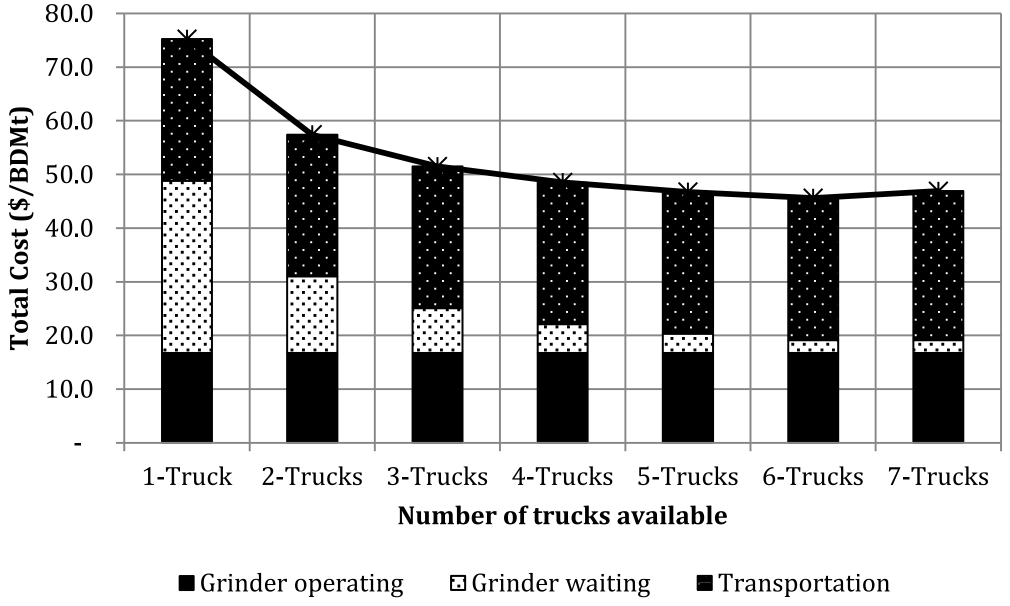


Figure 2. Delivered wood cost ($/dry metric tonne) for Case II as a function of truck availability (Zamora et al., manuscript in review)

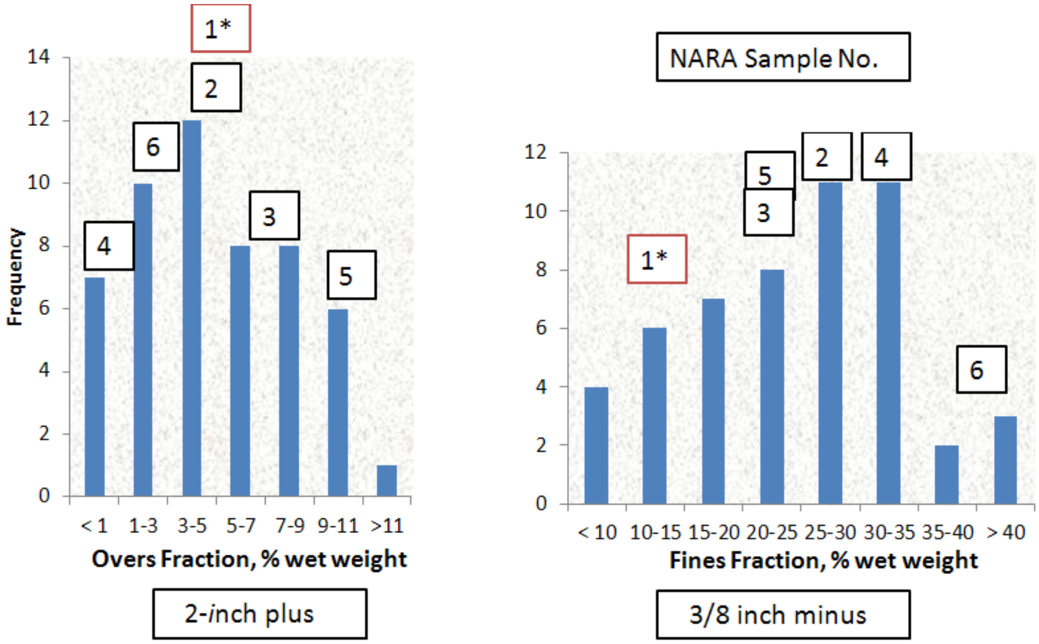


Figure 3. Example of wide variation in ground and chipped materials from forest harvest residue operations in Washington and Oregon (Smith, Sessions, et al, manuscript in review). Data points from six of the NARA sites illustrate the similar variation in materials within the NARA samples and the larger data set.

## Recommendations/Conclusions

Currently, we are approximately 40% complete with our survey of volume and locations of piles. In the next quarter, we will focus our efforts in western Washington and east of the Cascades. We are seeing a significant variability by logging system with shovel logging producing more, smaller piles scattered throughout the unit. As expected, cable logging produces fewer piles near the landings.

Managing moisture is one of the keys to improving the economic feasibility of woody biomass use. Transportation costs and market values of woody biomass are strongly linked to the amount of moisture in the woody biomass. We have developed drying rate models for small logs for two species that have been stored in-forest. We have assembled data that should allow prediction of drying rates for biomass residue piles in western Oregon. We have identified tools that could be used in-forest for determining when moisture contents have dropped below 35% (wet basis), a potential transportation decision threshold. Our emphasis next year will be on determining the effect of harvesting season on initial residue moisture contents, the effect of residue pile design on drying rates, and building an economic model that can tell us the optimal storage time balancing cost savings against capital, interest and risk costs.

Our next steps are to complete the biomass recovery coefficients and collection and transportation cost models for the feedstock supply model. By August we will be able to provide recovery coefficients, comminution and transportation costs to the Feedstock Supply modeling group that will be used to develop supply curves for forest residuals to alternative locations in the NARA region.

The decision support models show the economics of comminution and transport rely heavily on operational planning, moisture management and access for large trailers. Next year we will complete the moisture management models, implement structured tests to determine the effects of grinder grate (screen size), moisture content, chipper bit configuration, and piece size on feedstock characteristics, and investigate alternatives for increasing dry bulk density.

## Physical and Intellectual Outputs

### Physical

- Fifteen sites were sampled to inventory the volume and location of piles
- 156 logs from 6 species were collected and their moisture content repeatedly measured over a five month period using 6 tools to identify suitable tools for in-forest moisture management
- Approximately 50 tons of Douglas-fir and 35 tons of hybrid poplar were bundled and air-drying rates determined as a function of drying location within Oregon, length of drying time, and season when drying began.
- A database of 3000 trailer loads of forest residuals were analyzed for moisture content as a function of harvest and piling variables.
- Eight 500 pound forest residuals from different geographic zones in Oregon and Washington were collected and sent to the Weyerhaeuser Technology Center (WTC) for characterization
- One 14,000 pound forest harvest residue of Douglas-fir was sent to WTC in January, 2013 to be used as the reference Douglas-fir sample for laboratory testing
- A Decision Support System was developed that forest planners can use for optimizing comminution and transport decisions.
- 11 manuscripts were developed by project personnel to reach professional audiences.

### Refereed Publications (accepted or completed)

Smith, D., J. Sessions, K. Tuers, D. Way and J. Traver. 2013. Characteristics of forest derived woody biomass collected and processed in Oregon. Forest Products J. Manuscript accepted.

Kim, D-W. and G. Murphy. 2012. Forecasting air drying rates of Douglas-fir and hybrid poplar biomass in Oregon, USA. International Journal of Forest Engineering. Manuscript accepted.

Sessions, J., K. Tuers, K. Boston and R. Zamora. 2013. Pricing Forest Biomass for Power Generation. West J. of Applied Forestry. 28(2):51-56.

Zhang, C., J.Y. Zhu, R. Gleisner, and J. Sessions. 2012. Fractionation of Forest Residues of Douglas-fir for Fermentable Sugar Production by SPORL Pretreatment. BioEnergy Research. 5(4):978-988. DOI: 10.1007/s12155-012-9213-3.

Long, J. and K. Boston. An evaluation of measurement techniques for estimating the volume of piled logging residue. Western Journal of Applied Forestry. Manuscript in review.

Beck, S. and J. Sessions. Ant Colony Optimization for Forest Road Access Decisions for non-conventional products. Croation J. of Forest Engineering. Manuscript in review.

Clark, J., Sessions, J. and R. Zamora. Optimizing Knife Change Times for Forest Biomass Chipping Operations. Biomass and Bioenergy. Manuscript in review,

Zamora, R., P. Adams, and J. Sessions. Ground-based thinning on steep slopes in Western Oregon: Soil compaction and disturbance effects. Western J. of Applied Forestry. Manuscript in review.

Zamora, R., K. Boston, and J. Sessions. Activity-Based Stochastic Simulation of Mobile Chipper Productivity.European J. of Operational Research. Manuscript in review.

Zamoa, R., J. Sessions, and G. Murphy. Economic impact of truck-machine interference in forest biomass recovery operations on steep terrain. Forest Products J. Manuscript in review.

Leu, Shao-Yuan, R. Gleisner, R., J.Y. Zhu, J. Sessions, and G. Marrs. Robust Enzymatic Saccharification of a Douglas-fir forest harvest residue by SPORL. Submitted to Biomass and Bioenergy.

## Research Presentations

**Posters:**

Zamora, R., K. Boston, and J. Sessions. 2012. Activity-Based Stochastic Simulation of Mobile Chipper Productivity. Prepared for 2012 Annual Meeting for the Northwest Advanced Renewables Alliance (NARA), Sept. 13-14, Missoula, MT. Also presented November 13, 2012 at Northwest Bioenergy Research Symposium, Seattle, WA.

Zamora, R. and J. Sessions. 2012. Economic Optimization of Forest Biomass Processing and Transport: A Decision Support System. Prepared for 2012 Annual Meeting for the Northwest Advanced Renewables Alliance (NARA), Sept. 13-14, Missoula, MT. Also presented November 13, 2012 at Northwest Bioenergy Research Symposium, Seattle, WA.

Zamora, R., B. Flint, J. Sessions, L. Kellogg, and P. Adams. 2012. Ground-Based Thinning on Steep Slopes in Oregon: Productivity, Economics and Soil Compaction Effects. Prepared for 2012 Annual Meeting for the Northwest Advanced Renewables Alliance (NARA), Sept. 13-14, Missoula, MT. Also presented November 13, 2012 at Northwest Bioenergy Research Symposium, Seattle, WA.

Zamora, R. and J. Sessions. 2012. Characteristics of NARA Forest Residue Sites. Prepared for 2012 Annual Meeting for the Northwest Advanced Renewables Alliance (NARA), Sept. 13-14, Missoula, MT. Also presented November 13, 2012 at Northwest Bioenergy Research Symposium, Seattle, WA.

Zhu, J, Y., C. Zhang, J. Sessions, and R. Gleisner. 2012. Fractionation of Douglas-fir Forest Residues for Efficient Sugar Production. Prepared for 2012 Annual Meeting for the Northwest Advanced Renewables Alliance (NARA), Sept. 13-14, Missoula, MT.

Buffum, M., G. Murphy, F. Belart, F. Becerra and B. Do. 2012. Assessing moisture content in biomass piles. NARA Summer Undergraduate Research Experience. Washington State University, Pullman WA. August 2.

Do, B., G. Murphy, F. Belart, F. Becerra and M. Buffum. 2012. Assessing risks of arson in biomass piles. NARA Summer Undergraduate Research Experience. Washington State University, Pullman WA. August 2.

**Presentations:**

Sessions, J. 2012. Perspectives and Priorities for Bioenergy Research at Oregon State University. Presentation at Northwest Bioenergy Research Symposium, Seattle, WA. November 14. Invited Opening Plenary Presentation.

Beck, S. and J. Sessions. 2012. Ant Colony Optimization for Road Maintenance Decisions. Presentation at Council on Forest Engineering. New Bern, North Carolina. September 10-11.

Belart, Francisca and G. Murphy. 2012. Forecasting and monitoring moisture of woody biomass in Ireland and Oregon. Presentation at Council on Forest Engineering. New Bern, North Carolina. September 10-11.

Murphy, Glen. 2012. Forecasting and monitoring moisture of woody biomass in Ireland and Oregon. Precision Forestry Symposium, Mount Gambier, Australia, 28th March 2012.

Sessions, John. 2012. Project overview to Dan Biggs, Tillamook County Economic Development Council and Assistant OSU Provost, March 22.

Sessions, John. 2011. Invited overview of the NARA project to a group of forest industry leaders and the Presidents of Oregon State University and University of Oregon in Corvallis on September 29, 2011.

Sessions, John. 2011. Invited overview of the NARA project to Oregon delegation staffers at a meeting at the College of Forestry on December 5, 2011.

## Other Publications

Zamora, R. 2011. Production and time study of the BRUKS mobile chipper in southwest Oregon. Report prepared and submitted to industrial cooperator.

## Thesis and Dissertations

Becerra, Fernando. 2012. Evaluation of Six Tools for Estimating Woody Biomass Moisture Content. MS thesis. Completed December 13, 2012. Glen Murphy, Advisor.

Kim, Dong-Wook. 2012. Modeling air-drying of Douglas-fir and hybrid poplar biomass in Oregon. MS thesis. Completed June 6, 2012. Glen Murphy, Advisor

# CONVERSION

## Pretreatment Team

### Task C-P-1: Pretreatment to Overcome Recalcitrance of Lignocellulose

| Key Personnel | Affiliation |
|---|---|
| Junyong (J.Y.) Zhu | USFS Forest Products Lab |

### Task Description

SPORL has demonstrated robust performance to remove recalcitrance of woody biomass, including softwood species. SPORL outperforms competing technologies in terms of sugar/ethanol yield and energy efficiency/net energy output (Zhu et al., Applied Microbiology and Biotechnology, 86:1355-1365, 2010; Tian et al. Bioresource Technology 101:8678-8685; Lan et al., Bioresource Technology, 127:291-297, 2013). The major work for the proposed study is to demonstrate the performance of the SPORL using Douglas-fir as well as Douglas-fir forest residues with relatively high lignin contents, and its scalability at two pilot plant facilities for 1000 gallon biojet fuel production. The focus of the study is on low cost and low value Douglas-fir forest residues to improve economics and sustainability. The *specific objectives* are: (1) to optimize SPORL pretreatment conditions for Douglas-fir and Douglas-fir forest residues under laboratory bench scale conditions based on sugar yield after subsequent enzymatic saccharification; (2) to conduct SPORL pretreatments of Douglas-fir forest residues using the FPL pilot scale pulping facility to realize first step scale-up study, to determine optimal conditions based on total sugar yield after subsequent enzymatic saccharification under high solids loadings of approximately 20%; (3) to conduct large scale, approximately ten tons of wood, production of SPORL substrate at an Industrial scale facility potentially one-step production process under optimal conditions through preliminary large scale production study at FPL; (4) to work with Washington State University, Weyerhaeuser and Gevo for large scale biojet fuel production and lignin co-product development form SPORL hydrolysates and lignin fractions.

### Activities and Results

We have completed SPORL pretreatment optimization using clean Douglas-fir wood chips (FS-01) at a laboratory bench scale of 150 g. We conducted pretreatment optimization at two temperatures of 180ºC and 165ºC. The main findings were pretreatment at low temperature of 165ºC with longer time of 75 min significantly reduced inhibitor formation under equivalent cellulose saccharification efficiency and sugar yield. We have examined the experimental data using a kinetic model we developed previously (Zhu et al., *Process Biochemisty*, **47**:785, 2012) and identify the difference in reaction kinetics between hemicellulose hydrolysis and sugar degradation. At the optimal condition (165ºC for 75 min, acid and sodium bisulfite charges on wood of 2.2 and 10wt%, respectively, with liquid to wood ratio of 3:1) identified based on total sugar yield as well as inhibitor formation. We achieved total monomeric sugar yield of 505.2 g/kg wood with total furan concentration in the hemicellulosic sugar stream of approximately 2 g/L. Enzymatic hydrolysis glucose yield is 86% theoretical at a cellulase loading of 15 FPU/g glucan or 0.058 mL/g solid substrate of CTec2.

Several pretreatment runs at 2 kg scale were produced at the identified optimal condition. The resultant solid substrate and the pretreatment hydrolysate that contains the hemicellulosic sugars and lignosulfonate were sent to Gevo for fermentation and to Weyerhaeuser for lignin co-product development.

We also studied the effect of bark on SPORL pretreatment. We investigated the potential to fractionate bark and ash by using physical fractionation based on size. We found that physical fractionation is very effective with excellent selectivity to reduce bark and ash content in the forest residues (Figure 1; Zhang et al., BioEnergy Research 5(4):978). For the sample studied, a 2 mesh screen can retain 60% of the total mass but only contain approximately 30-35% of the bark and ash. When comparing chipping and ground in harvesting forest residues, it appears that physical fractionation is more effective for grounding obtained forest residue to reduce bark and ash content. This is critical to reduce dead load shipping and processing and upgrading feedstock to improve economics.

We also completed SPORL pretreatment optimization using a Douglas-fir forest residue (FS-03) at laboratory bench scale of 150 g. This residue has very high lignin content of 32.3% with glucan content of only 37.7% based on our laboratory analysis. The optimal condition based on total sugar yield as well as inhibitor formation were same as using clean Douglas-fir wood chips, i.e. 165ºC for 75 min, acid charges on wood of 2.2, but sodium bisulfite charge increased to 12%. We achieved enzymatic hydrolysis glucose yield of 345 g/kg or equivalent to 82.3% theoretical at CTec 2 dosage of 15 FPU/g glucan. Total furan formation was 4.5 g/L. This level of furan concentration is still manageable for fermentation. A mass balance analysis is shown in Figure 2.

Again, several pretreatment runs at 2 kg scale were produced at the identified optimal condition. The resultant solid substrate and the pretreatment hydrolysate that contains the hemicellulosic sugars and lignosulfonate were sent to Gevo for fermentation.

We also made a significant finding: using an elevated pH 5.5 or higher can significantly enhance enzymatic hydrolysis of lignocelluloses, especially substrates produced form SPORL pretreatment (Figure 3; Lou et al., ChemSusChem, DOI: 10.1002/cssc.201200859). This contradicts a well-established and widely accepted concept of "optimal pH of 4.8 – 5.0" that has been exclusively practiced in numerous laboratories throughout the world. By using pH 5.5, we can reduce cellulase loading by approximately 50%.

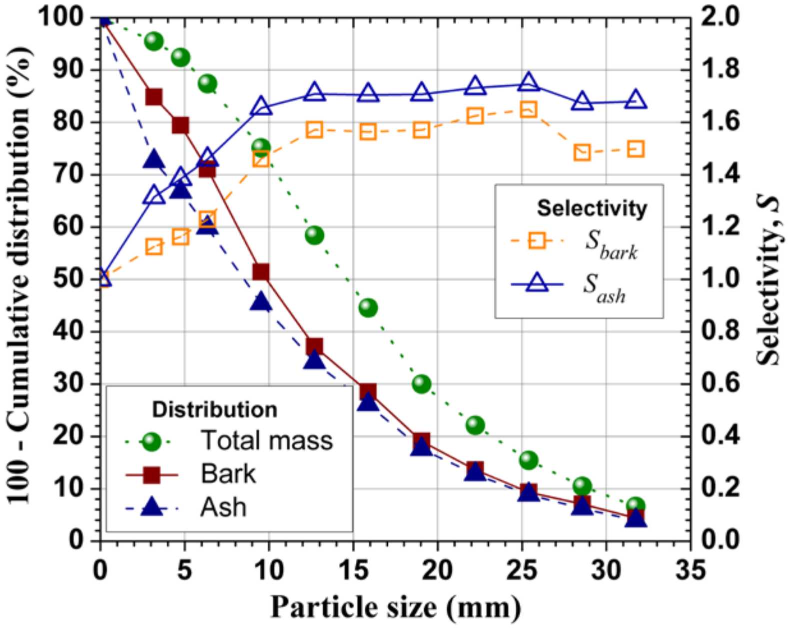


Figure 1. Accumulative (from the largest fraction) distributions of oven dry total mass, bark, and ash and sieving selectivities over bark and ash by particle/chip size of a chipped Douglas-fir forest residues.

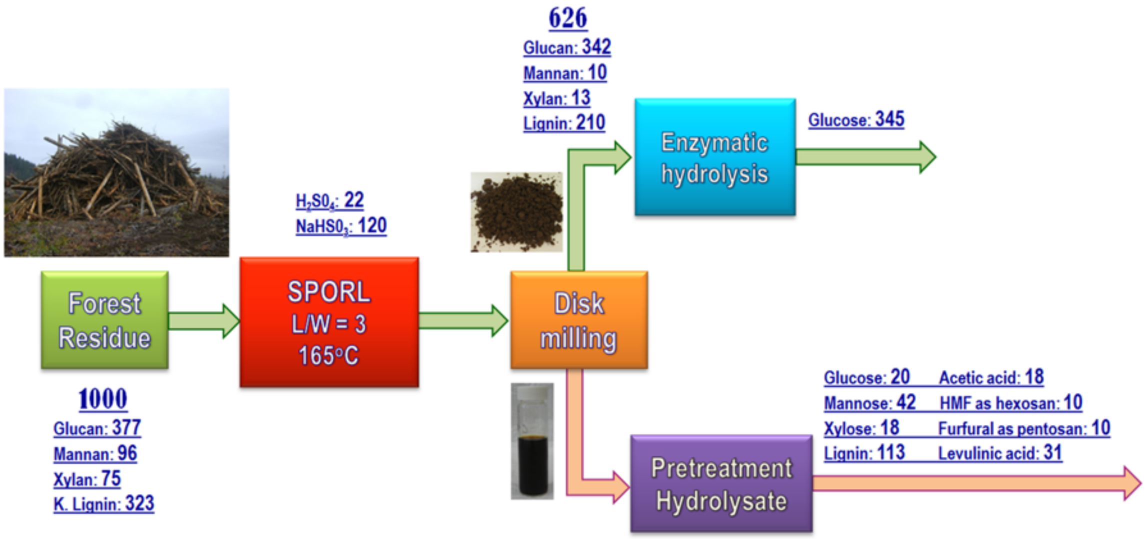


Figure 2 Overall mass balance of the optimal run at T = 165ºC, t = 75 minutes, B = 12 %, and A = 2.2 % with liquid to solid ratio of 3:1. All numbers are expressed in grams.

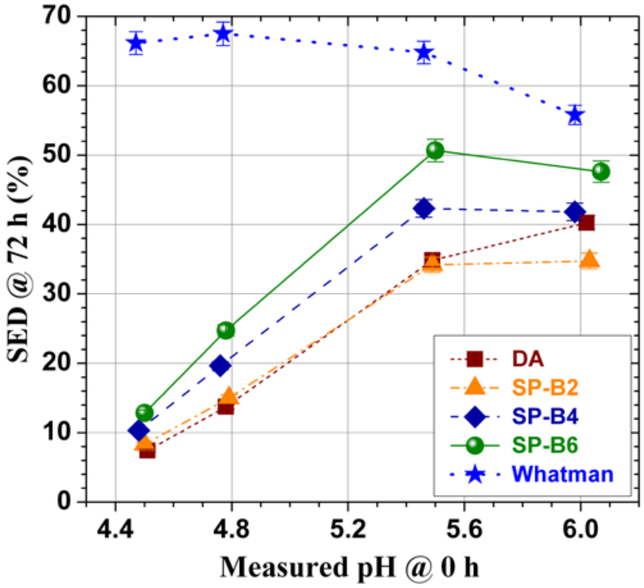


Fig. 3 Effects of pH on enzymatic saccharification of four lignocelluloses and Whatman paper. SP stands for SPORL and DA stands for dilute acid pretreatment

## Recommendations/Conclusions

Based on the results obtained so far that include sugar yield, enzymatic saccharification efficiency, cellulase loading, inhibitor formation, and fermentation data from Gevo at the relatively low pretreatment temperature of 165ºC, we are very confident that SPORL pretreatment is very effective to deal with Douglas-fir forest residue, a very recalcitrant feedstock, but is one of the only two most viable and lost cost feedstock based on a recent National Council Report (*http://www.nap.edu/catalog.php?record_id=13105*). In our initial proposal, Douglas-fir was selected as the main feedstock for the project. With the compelling data obtained, we are shifting our focus to forest residues to make this project much closer to a realistic forest biorefinery.

In the next step, we will work on the following issues:

(1) We will scale up studies to a 50 kg scale at the Forest Products Laboratory. This is critical to achieving the project goal of 1000 gallons of biojet fuel production
(2) We will further improve pretreatment to reduce inhibitor formation and improve hemicellulosic sugar yield. We have several novel approaches to address this issue.
(3) We will coordinate and work with our partners to move the project forward on several fronts: feedstock upgrade with Weyerhaeuser and Oregon State University; fermentation with Gevo; lignin co-product development with Weyerhaeuser and Washington State University, etc.
(4) We will look into several opportunities for a 10 ton pretreatment facility and site.

## Physical and Intellectual Outputs

### Physical

- 6 kg pretreated FS-01 and FS-03 solid samples were sent to GEVO
- 5 L hemicellulosic sugar streams from FS-01 and FS-03 were sent to GEVO
- 400 g lignosulfonate were sent to Weyerhaeuser
- 400 g hydrolysis lignin residue were sent to Weyerhaeuser
- 20 g hydrolysis lignin residue were sent to Washington State University
- 50 kg scale demonstration site was established

### Refereed Publications (accepted or completed)

Zhang, C., C.J. Houtman, J.Y. Zhu, 2013. Maximize Enzymatic Saccharification and Minimize Sugar Degradation in SPORL Pretreatment of Douglas-fir at a Low Temperature: A Kinetic Approach. *Bioresource Technology* (in Preparation).

Leu, S.-Y., Gleisner, R., J.Y. Zhu**,** Sessions, J., Marrs, G., 2013. Robust Enzymatic Saccharification of a Douglas-fir Forest Harvest Residue by SPORL, *Biomass and Bioenergy* (submitted)

Lou, H., J.Y. Zhu, T.Q. Lan, H. Lai, and X. Qiu., 2013. pH-Induced Lignin Surface Modification to Reduce Nonspecific Cellulase Binding and Enhance Enzymatic Saccharification of Lignocelluloses. *ChemSusChem*, DOI: 10.1002/cssc.201200859

Leu, S-Y. and J.Y. Zhu. 2013. Substrate-Related Factors Affecting Enzymatic Saccharification of Lignocelluloses: Our Recent Understanding. *BioEnergy Research*. DOI: 10.1007/s12155-012-9276-1

Zhang, C., J.Y. Zhu, R. Gleisner, and J. Sessions. 2012. Fractionation of Forest Residues of Douglas-fir for Fermentable Sugar Production by SPORL Pretreatment. *BioEnergy Research*. 5(4):978-988. DOI: 10.1007/s12155-012-9213-3

### Conference Proceedings and Abstracts from Professional Meetings

Zhang, C., Mann, D., Zhu, J.Y., Sessions, J., Marrs, G. 2013. Upgrading Forest Residues of Douglas-fir through Physical Fractionation for Fermentable Sugar Production. Abstract of the 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

Leu, S.-Y., Zhang, C., Zhu, J.Y., 2013. Sugar production from forest residue of Douglas-fir using SPORL pretreatment: in comparison with bark-free wood chips. Abstract of the 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

Lou, H., J.Y. Zhu, T.Q. Lan, H. Lai, and X. Qiu., 2013. pH-Induced Lignin Surface Modification to Reduce Nonspecific Cellulase Binding and Enhance Enzymatic Saccharification of Lignocelluloses. Abstract of the 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

## Research Presentations

Zhang, C., Mann, D., Zhu, J.Y., Sessions, J., Marrs, G. 2013. Upgrading Forest Residues of Douglas-fir through Physical Fractionation for Fermentable Sugar Production. Oral presentation at 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

Lou, H., J.Y. Zhu, T.Q. Lan, H. Lai, and X. Qiu., 2013. pH-Induced Lignin Surface Modification to Reduce Nonspecific Cellulase Binding and Enhance Enzymatic Saccharification of Lignocelluloses. Poster presentation at 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

Leu, S.-Y., Zhang, C., Zhu, J.Y., 2013. Sugar production from forest residue of Douglas-fir using SPORL pretreatment: in comparison with bark-free wood chips. Poster presentation at the 35th Symposium on Biotechnology for Fuels and Chemicals, Portland, OR, April 29 – May 2.

Zhu, J.Y., 2012. Biofuel Production from Woody Biomass: Net Energy Production Evaluations. Plenary session of 3rd International Energy Congress, 2012 AIChE Annual Meeting, Pittsburgh, PA, October 28-Nov. 2.

Zhang, C., Zhu, J.Y., Sessions, J., 2012. Fractionation of Forest Residues of Douglas-fir for Fermentable Sugar Production by SPORL Pretreatment, presented at the 2012 AIChE Annual Meeting, Pittsburgh, PA, October 28-Nov. 2

Zhu, J.Y., 2012. What we learned from (sulfite) pulping – sulfite pretreatment (SPORL) process", Canadian National Science and Engineering Research Council (NSERC) Bioconversion Network Pretreatment Workshop, Invited Plenary Presentation, University of British Columbia, Vancouver, BC, Canada, June 4-6

Zhu, J.Y. 2012. On sulfite pretreatment to overcome recalcitrance of lignocelluloses (SPORL) for robust bioconversion of woody biomass. Presented at the 243rd ACS National Spring Meeting, San Diego, CA, March 25-29, 2012.

Zhu, J.Y., 2012. Fundamentals and practices for efficient production of biofuel from lignocelluloses. Presented at the 243rd ACS National Spring Meeting, San Diego, CA, March 25-29, 2012.

Zhu, J.Y., C. Zhang, S-Y. Leu and R. Gleisner. 2012. Sugar production from Douglas-fir by SPORL pretreatment. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Task C-P-2: Dilute Acid Pretreatment of Softwood and Lignin Products Development

| Key Personnel | Affiliation |
|---|---|
| Xiao Zhang | Washington State University |

## Task Description

Task C-P-2.1 is to assist in optimizing large scale pretreatment and lignin product development. In our earlier work, we demonstrated a novel lignin conversion pathway to produce high value phenolic compounds and carboxylic acids. A PCT patent is currently in application "METHODS TO CONVERT LIGNIN TO PHENOLIC AND CARBOXYLATE COMPOUNDS" US-842432-01-US-PCT and has been licensed to intellectual ventures. As shown in Figure 1, lignin can be oxidized by organic peroxyacids or hydrogen peroxide in the presence of certain catalysts to a mixture of low molecular weight phenolic compounds and dicarboxylic acids under mild conditions (atmospheric pressure and reaction temperature up to 90°C). This oxidative lignin degradation method can convert lignin to a number of valued added products and precursors for adhesive, animal feed, polymer and hydrocarbon fuel applications.

Task C-P-2.2 is to study diluted acid pretreatment of Douglas-fir wood and forest residues. This is a new task started in August 2012. There are three components to this task:

**1. We will optimize diluted acid pretreatment for carbohydrate and lignin recovery.**
The reference Douglas-fir wood chips and residues will be pretreated by diluted acid at a series of conditions (temperature 180—230°C, acid concentration 1-4% and time 30 -90 minutes, different wood to liquid ratios, etc.). The mass balance before and after pretreatment will be determined. The hydrolysability of pretreated substrates will be investigated by using Novozymes Cellic® CTec-II enzyme preparation. The optimized pretreatment conditions will be determined based on both mass recovery yield and substrate hydrolysability.

**2. We will prepare pretreated substrate and hydrolysate for Gevo fermentation testing.**
Once the optimized pretreatment conditions are identified, we will prepare pretreated substrates and hydrolysates from the four softwood samples for Gevo to test fermentation for butanol production. We will assist Gevo to determine the potential inhibitory compounds present in diluted acid pretreated substrate/hydrolysate and optimize the fermentation parameters.

**3. We will prepare and separate diluted acid lignin for co-products development.**
Separate 300 grams of diluted acid lignin will be prepared from pretreated substrate and provided to the co-products teams to test potential applications. We will work with the co-products team on lignin characterization and lignin depolymerization/modification to maximize their values for co-products application.

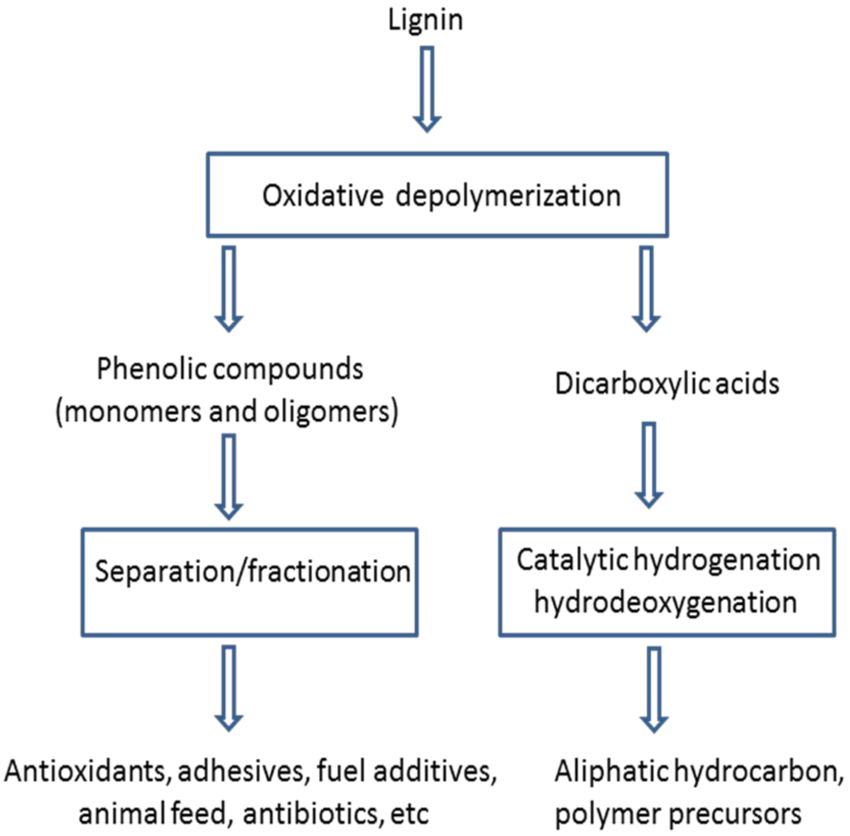


Figure 1. Oxidative conversion of lignin to value added products and fuel precursors.

## Activities and Results

### Task C-P-2.1 is to assist in optimizing large scale pretreatment and lignin product development.

This task is not scheduled to start until the third year (FY2014) of the project. However, during our recent study, we have found a catalyst that has high selectivity to convert lignin to carboxylic acids. As shown in Figure 2, the softwood lignin was first depolymerized to small molecular phenolic compounds such as vanillic acid and benzoic acid. Increasing reaction time led to the high selectivity toward dicarboxylic acids formation predominantly C4 and C3 acids. We have identified that niobium based catalysts (Cu, Fe, Mn, niobates) can selectively convert lignin to phenolic compounds while a catalyst belongs to a group of sulfide minerals can selectively convert lignin to dicarboxylic acid. The reaction mechanism of the latter reaction is proposed and described in a manuscript under preparation.

### Task C-P-2.2 is to study diluted acid pretreatment of Douglas-fir wood and forest residues.

Hemicellulose, which typically accounts for up to 25% of lignocellulosic biomass, is an underutilized component in many biomass conversion processes. A clear understanding of the hemicellulose degradation pathways during different pretreatment conditions can help improve the utilization of hemicellulose. The effect of different diluted acid pretreatment conditions (temperature 180°C-200°C, time 30-90 minutes, acid loading 1-4% gram per gram biomass) on Douglas-fir hemicellulose degradation was first investigated using FS-01 samples. O-acetyl-galactoglucomannan and arabino-4-O-ethylglucuronoxylan are the main constituents of Douglas-fir hemicellulose. As shown in Figure 3, glucose, mannose, xylose, 5-hydroxymethylfurfural (HMF), furfural, levulinic acid (LEV) and formic acid (FA) are the main degradation compounds solubilized during diluted acid pretreatment. The pretreatment time, temperature and acid concentration all have significant effect on softwood hemicellulose degradation. It was found that at 180°C, softwood hemicelluloses were predominantly converted to monosaccharides and their dehydration products, HMF and furfural. However, increasing the pretreatment temperature to 200°C resulted in the further degradation of these compounds to organic acid with a significant amount of levulinic acid and formic acid produced. Controlling the diluted acid pretreatment condition can allow the high yield conversion of hemicellulose to different degradation compounds (Figure 4). For example, maximum concentrations of LEV and FA were detected in the soluble fraction during diluted acid pretreatment of Douglas-fir at 200°C for 90 minutes using 4% (w/w) sulfuric acid which on a weight basis, correlated to approximately 36.0 g of LEV and 17.5 g of FA produced from each 100 g hemicellulose presented in Douglas-fir.

The mass balance of diluted acid pretreatment of FS-01 and FS-03 samples was determined (Figures 5 and 6). Pretreatment was carried out at 195°C using 1% sulfuric acid (w/w) for 30 minutes. As shown in Figure 5, 317.31 kg of glucose can be obtained as monosaccharide from 1000 kg of FS-01. In addition, another 88.94 kg of other sugars (mannose, xylose, galactose) can be obtained. The total sugars available for fermentation is approximately 406 kg. Most of the lignin, after diluted acid pretreatment, is collected in the residues after enzymatic hydrolysis. From 1000kg of FS-01, 256kg of lignin can be obtained as a solid residual after enzymatic hydrolysis. The FS-03 has a lower glucan content and higher lignin content compared to FS-01 (Figure 6). A lower glucose recovery was obtained after dilute acid pretreatment and subsequent enzymatic hydrolysis. From 1000 kg FS-03, 218.3 kg of glucose were obtained as monosaccharide available for fermentation. Also, 73.9 kg of other sugars were recovered in the water soluble fraction. Similar to the FS-01, the recovery yield on lignin in the residual solid is high. Approximately 300 kg of lignin can be obtained from FS-03 after dilute acid pretreatment and subsequent hydrolysis.

Several batch-scale diluted acid pretreatments of Douglas-fir were carried out on FS-03 using 1% H2SO4 for 30 minutes at 195°C. The pretreated solid substrates were hydrolyzed by Novozymes Cellic® CTec-II enzyme preparation. After the hydrolysis, the hydrolysate was separated after centrifugation and solid residues were collected and washed. The washed residues were vacuum dried and approximately 800 grams (o.d) of the resulting residues (DA-HydR) were sent to the co-products team.

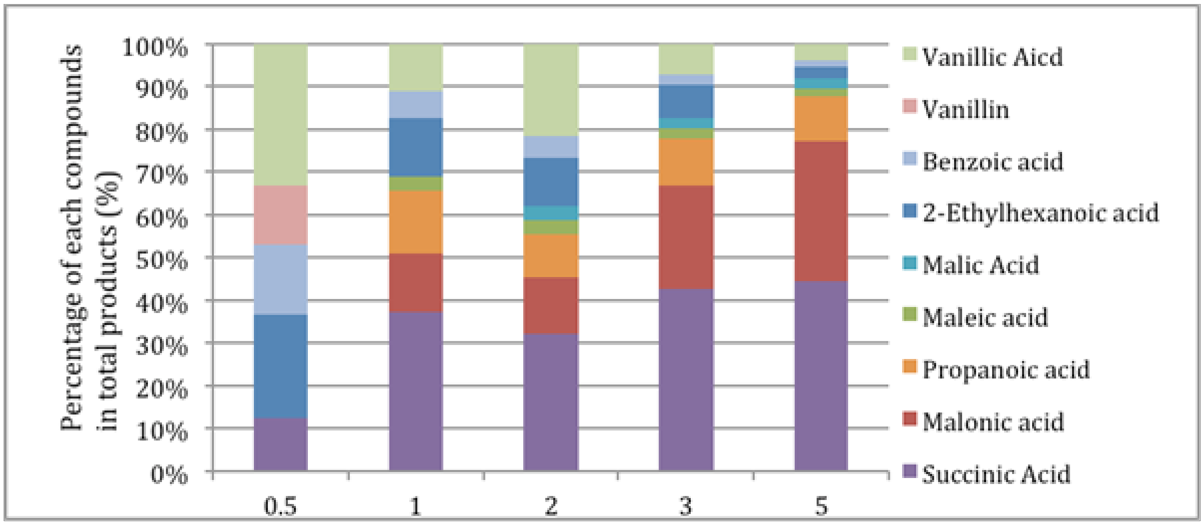


Figure 2: Time dependent reaction products detected during oxidative conversion of softwood lignin (spruce)

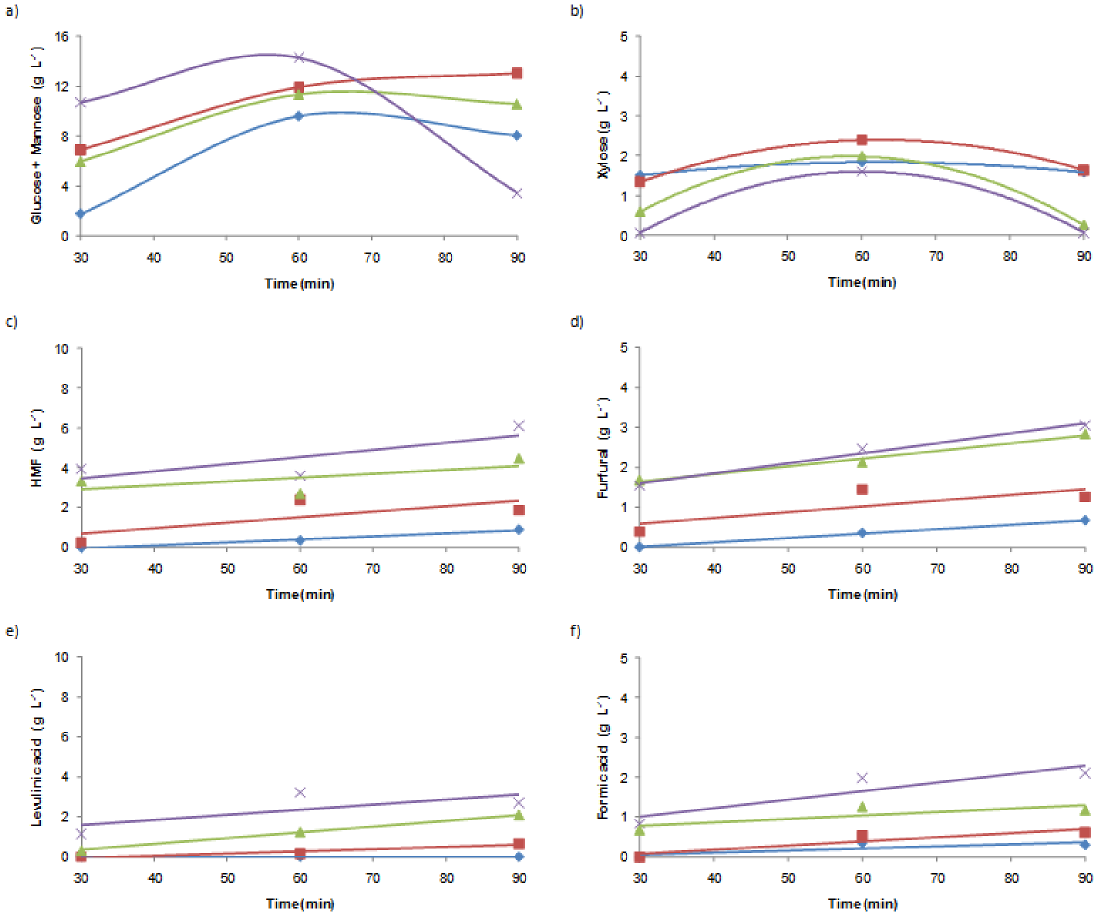


Figure 3: Sugar and decomposition products concentration in WSF during D.A pretreatment of D. fir at180°C: a) Glucose + Mannose, b) Xylose, c) HMF, d) Furfural, e) Levulinic acid, f) Formic acid. Sulfuric acid concentrations: 0% ♦, 1% ■, 2%▲, 4% X.

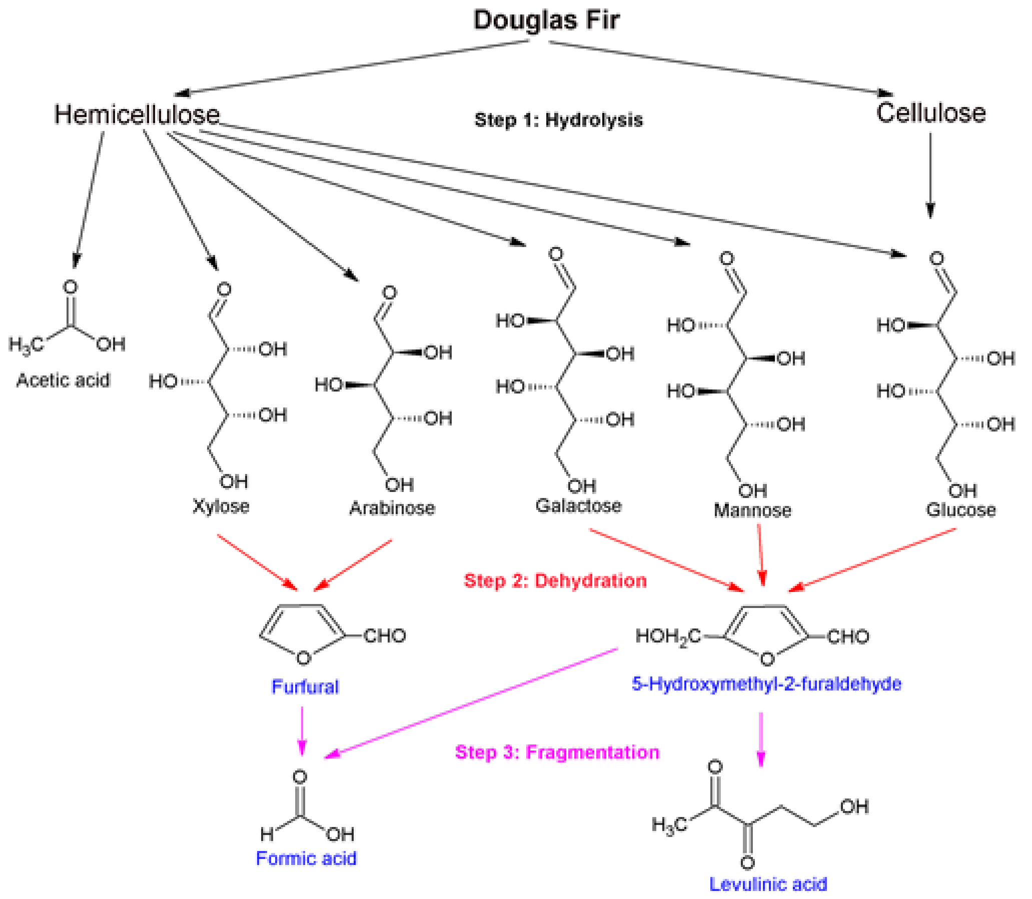


Figure 4: Hemicellulose degradation pathways during diluted acid pretreatment of D. fir.

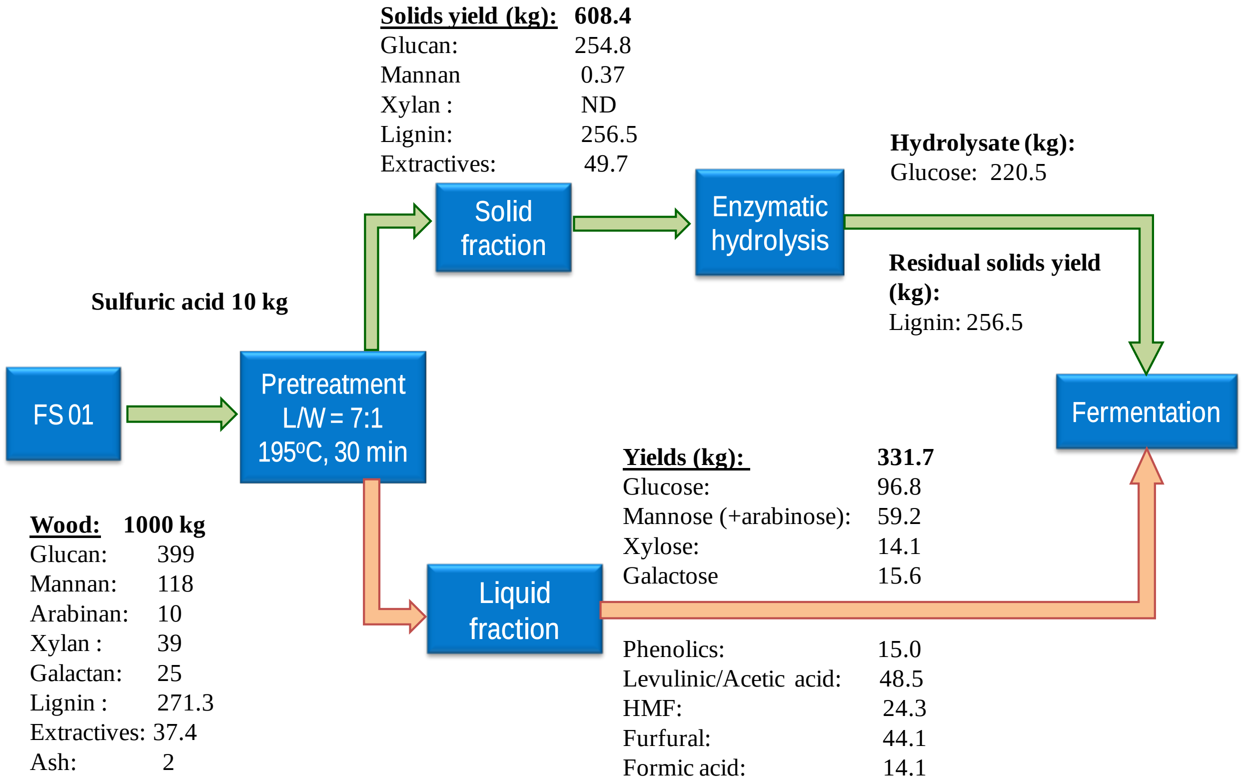


Figure 5: Mass balance of FS01 after diluted acid pretreatment.

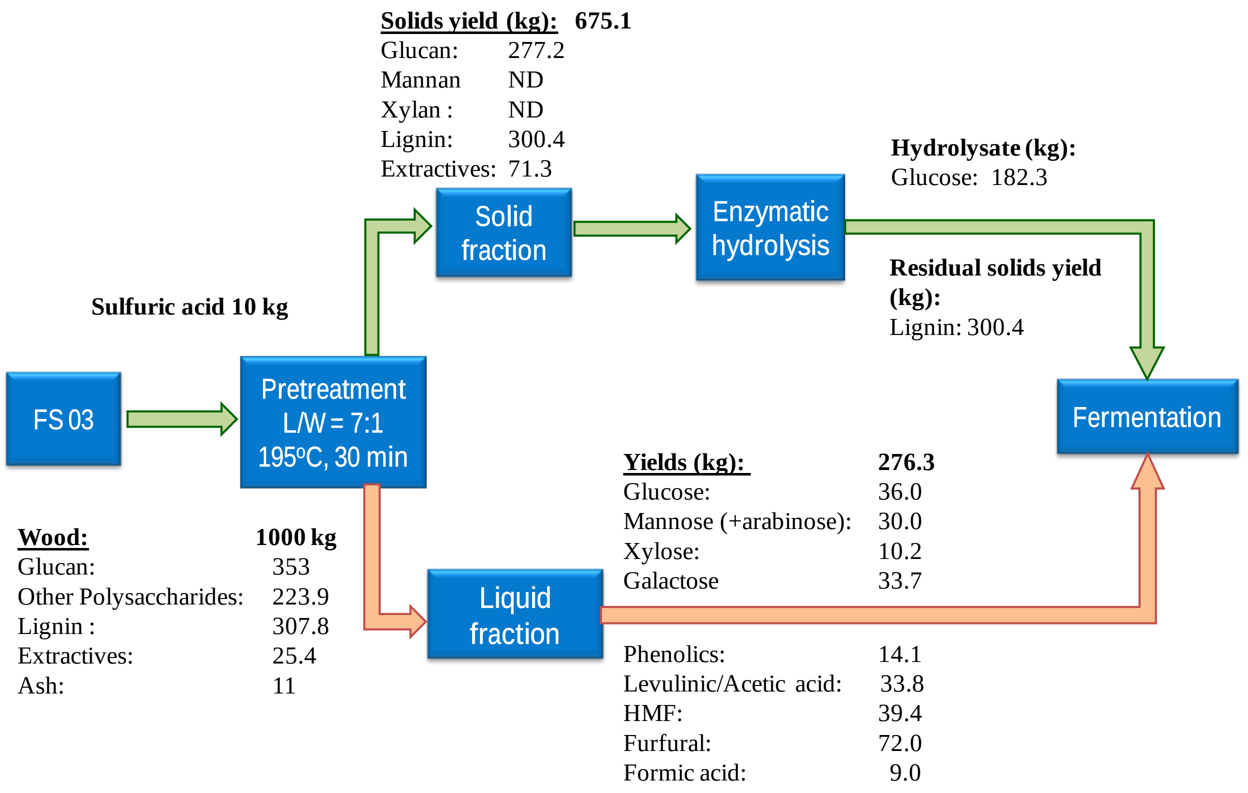


Figure 6: Mass balance of FS03 after diluted acid pretreatment.

## Recommendations/Conclusions

Diluted acid presents a relatively simple and low cost pretreatment method and can achieve a high recovery of lignin product with low sulfur and ash. We are investigating diluted acid pretreatment of other Douglas-fir residues and preparing a large batch of dilute acid hydrolyzate from FS-10.

Oxidative degradation of lignin provides a novel and green conversion pathway to produce value added chemicals in high yield. Catalysts with high selectivity to produce either phenolic compounds or dicarboxylic acid were discovered. We plan to start to apply these oxidative chemistries to convert NARA lignin to value added chemicals and polymer precursors.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Alvarez-Vasco, C., and X. Zhang. Elucidate hemicellulose degradation pathways during acid and alkaline pretreatments of softwood: new insight to the production of green chemicals from biomass hemicellulose (submitted)

### Conference Proceedings and Abstracts from Professional Meetings

Alvarez-Vasco, C., and X. Zhang. 2012. Understanding the pretreatment chemistry of softwoods. Oral presentation at AICHE Annual Meeting. Pittsburg PA, November 1, 2012.

### Research Presentations

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. High throughput analysis of biomass recalcitrance of Douglas fir families. Panel presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Alvarez-Vasco, C., M. Guo, E. Brown and X. Zhang. 2012. Diluted acid pretreatment of Douglas fir. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Alvarez-Vasco, C., K. Garcia, K. Jayawickrama, E. Brown and X. Zhang. 2012. Variation in Chemical Composition and Biomass Recalcitrance of D. fir Families. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Pedro Guajardo, Alvarez-Vasco, C, Xiao Zhang "Diluted acid and peroxide pretreatments of Douglas fir biomass" NARA SURE

### Intellectual Property

PCT patent application, "METHODS TO CONVERT LIGNIN TO PHENOLIC AND CARBOXYLATE COMPOUNDS" US-842432-01-US-PCT, Xiao Zhang licensed to intellectual ventures

## Task C-P-3: Preparation of Pretreated Biomass

| Key personnel | Affiliation |
|---|---|
| Brigitte Ahring | Washington State University |

### Task Description

Using an innovative wet explosion pretreatment process, we have prepared pretreated samples (up to 100 kg) from feedstocks supplied by Weyerhaeuser in accordance with the specific task of the project (Task C-P-3.1). The specific operational conditions varied during pretreatment of the different biomass materials included temperature, pressure and oxygen level. The pretreatment process is fully instrumented and allows for full resolution of the optimal pretreatment conditions for the specific woody biomass feedstock. During the year of 2013, the pretreatment team has been strengthened by implementation of a post doc fellow, along with a full time technician. This has allowed us to start making full mass balances over the pretreatment feed stock materials and further to evaluate the conditions for optimal enzyme hydrolysis of pretreated materials from an economic perspective. The WSU BSEL group will continue to consult with the different NARA partners to ensure that the material delivered meets their needs. The group will further evaluate the samples produced for release of C5 and C6 sugars using commercial enzyme products as well as the level of inhibitory compounds such as HMF, furfural and acetic acids. Furthermore, the quality of the lignin product produced is an important part of a successful NARA pretreatment process. Conversion results from the fermentation as well as co-product experiments needs to be reported back to WSU BSEL to adjust the pretreatment so that an optimal pretreatment process can be obtained (Task C-P-3.2). In the coming year we propose to optimize coordination to ensure that we will have the fully optimized process developed for both biojet fuel and lignin-products as results of NARA.

### Activities and Results

During our preliminary work, we found that pretreatment of Douglas fir was possible at high dry matter content. However, very high dry matter concentrations were not included in the initial pretreatment optimization as equipment related challenges could cause delays. The first part of our study dealt with examining the optimal pretreatment conditions in relation to temperature, time and oxygen loading on the feedstock FS-01. Table 1 summarizes the Wet Explosion Pretreatment conditions tested along with the results obtained. By using the highest initial sugar release, the pretreatment conditions were identified for an enzymatic hydrolysis optimization using dosage response methodology. A summary of the dosage response study is given in Table 2 and Figure 1 using pretreatment conditions of 185C, 25 min, 7.5% oxygen.

Product balances for all the individual process steps were conducted on FS-01 using optimal conditions for initial sugar release after pretreatment and sugar release during enzymatic hydrolysis (conditions for FS-01). Results are shown in Figure 2. The first work on FS-03 showed that the pretreatment conditions would need to be further optimized compared to the results obtained with FS-01. During the optimization period, we were able to increase the sugar yield of FS03 from the original 62% to close to 87% of total sugar released after enzymatic hydrolysis. Unfortunately, the team ran out of FS03 feedstock before the final mass balance could be closed.

Experimental work on FS-10 (replacing FS-03) has begun and will be conducted during second quarter of 2013. From the initial experiments, it is obvious that pretreatment of FS10 will be less challenging when compared to FS03.

Using the optimal pretreatment conditions for FS-01 samples of hydrolysate and residual lignin fractions have distributed to both Gevo and Weyerhaeuser. To ease the work of Gevo samples of up to 50 kg of size are pretreated, enzymatic hydrolyzed in our pilot plant and separated using our screw press and centrifuge yielding a hydrolysate with low concentrations of fibers. The solids containing the lignin residue was frozen along with the clarified hydrolysate and shipped to Weyerhaeuser and Gevo for further work. Two samples of FS-03 have further been shipped to Gevo. The first sample contained higher amounts of inhibitors as the last sample, which was run at more optimal conditions. Lignin samples from these runs have been shipped to Weyerhaeuser for further distribution and testing. The pretreatment team is awaiting feedback from partners to make the necessary adjustments of the conditions so that the samples produced meet the optimal conditions for the biofuels/co-product team.

Table 1. Different Wet Explosion pretreatment conditions and resulting sugar release

| Pretreatment Conditions | Cellobiose (g/L) | Glucose (g/L) | Xylose (g/L) | Galactose (g/L) | Arabinose (g/L) | Mannose (g/L) | HMF (g/L) | Furfural (g/L) | Acetate (g/L) |
|---|---|---|---|---|---|---|---|---|---|
| DF-PT-1 185C, 25m, 53 psi O2 | 1.16 | 9.55 | 7.27 | 5.7 | 2.18 | 13.97 | | | |
| DF-PT-2 185C, 25m, 73 psi O2 | 1.2 | 11.53 | 8.23 | 6.56 | 2.52 | 16.44 | 2.798 | 0.522 | 5.238 |
| DF-PT-3 175C, 25m, 53 psi O2 | 1.48 | 5.2 | 6.87 | 5.03 | 2.31 | 9.81 | | | |
| DF-PT-4 175C, 25m, 73 psi O2 | 1.31 | 6.96 | 7.39 | 5.47 | 2.15 | 11.74 | | | |
| DF-PT-5 195C, 25m, 53 psi O2 | 0.67 | 9.52 | 4.07 | 3.94 | 1.14 | 10.98 | | | |
| DF-PT-6 195C, 25m, 73 psi O2 | 0.69 | 11.05 | 3.97 | 4.16 | 1.24 | 11.13 | | | |

Table 2. Summary of sugar release after enzymatic hydrolysis

| Table 3. Sugars (g/L) | G+C | Xylose | Galactose | Arabinose | Mannose |
|---|---|---|---|---|---|
| C (20mg/g glucan) + H (2mg/g glucan) | 70.1 | 7.7 | 5.9 | 2.1 | 16.9 |
| Cellulase only (20mg/g glucan) | 68.8 | 8.5 | 7.0 | 2.0 | 19.4 |
| Hemicellulase only (2mg/g glucan) | 23.4 | 8.7 | 6.1 | 2.2 | 17.7 |
| C (60mg/g glucan) + H (6mg/g glucan) | 121.6 | 7.6 | 5.3 | 1.9 | 17.6 |
| Cellulase only (60mg/g glucan) | 83.8 | 6.1 | 2.8 | 0.7 | 12.2 |
| Hemicellulase only (6mg/g glucan) | 36.1 | 10.4 | 8.4 | 3.7 | 21.3 |
| C (20mg/g glucan) + H (10mg/g glucan) | 82.4 | 8.0 | 6.2 | 1.7 | 18.2 |
| Cellulase only (20mg/g glucan) | 68.8 | 8.5 | 7.0 | 2.0 | 19.4 |
| Hemicellulase only (10mg/g glucan) | 45.5 | 9.3 | 7.7 | 3.4 | 19.5 |
| C (60mg/g glucan) + H (30mg/g glucan) | 142.8 | 7.1 | 5.6 | 1.5 | 17.5 |
| Cellulase only (60mg/g glucan) | 83.8 | 6.1 | 2.8 | 0.7 | 12.2 |
| Hemicellulase only (30mg/g glucan) | 64.7 | 8.4 | 5.9 | 2.8 | 17.3 |
| C (20mg/g glucan) + H (6mg/g glucan) | 79.5 | 8.1 | 5.9 | 1.9 | 17.9 |
| Cellulase only (20mg/g glucan) | 68.8 | 8.5 | 7.0 | 2.0 | 19.4 |
| Hemicellulase only (6mg/g glucan) | 37.8 | 10.0 | 8.2 | 3.5 | 21.0 |
| C (60mg/g glucan) + H (18mg/g glucan) | 134.1 | 7.7 | 5.9 | 1.7 | 18.3 |
| Cellulase only (60mg/g glucan) | 83.8 | 6.1 | 2.8 | 0.7 | 12.2 |
| Hemicellulase only (18mg/g glucan) | 53.3 | 9.3 | 8.5 | 2.6 | 19.6 |
| C (40mg/g glucan) + H (4mg/g glucan) | 99.8 | 7.7 | 5.7 | 1.8 | 18.1 |
| Cellulase only (40mg/g glucan) | 95.7 | 8.1 | 5.7 | 1.7 | 18.6 |
| Hemicellulase only (4mg/g glucan) | 30.9 | 8.5 | 5.7 | 2.6 | 16.8 |
| C (40mg/g glucan) + H (20mg/g glucan) | 106.3 | 7.5 | 4.8 | 1.8 | 16.4 |
| Cellulase only (40mg/g glucan) | 95.7 | 8.1 | 5.7 | 1.7 | 18.6 |
| Hemicellulase only (20mg/g glucan) | 61.4 | 9.3 | 7.8 | 3.4 | 19.5 |
| C (40mg/g glucan) + H (12mg/g glucan) | 103.3 | 7.9 | 6.9 | 1.5 | 17.3 |
| Cellulase only (40mg/g glucan) | 95.7 | 8.1 | 5.7 | 1.7 | 18.6 |
| Hemicellulase only (12mg/g glucan) | 48.1 | 8.8 | 6.3 | 2.1 | 18.5 |

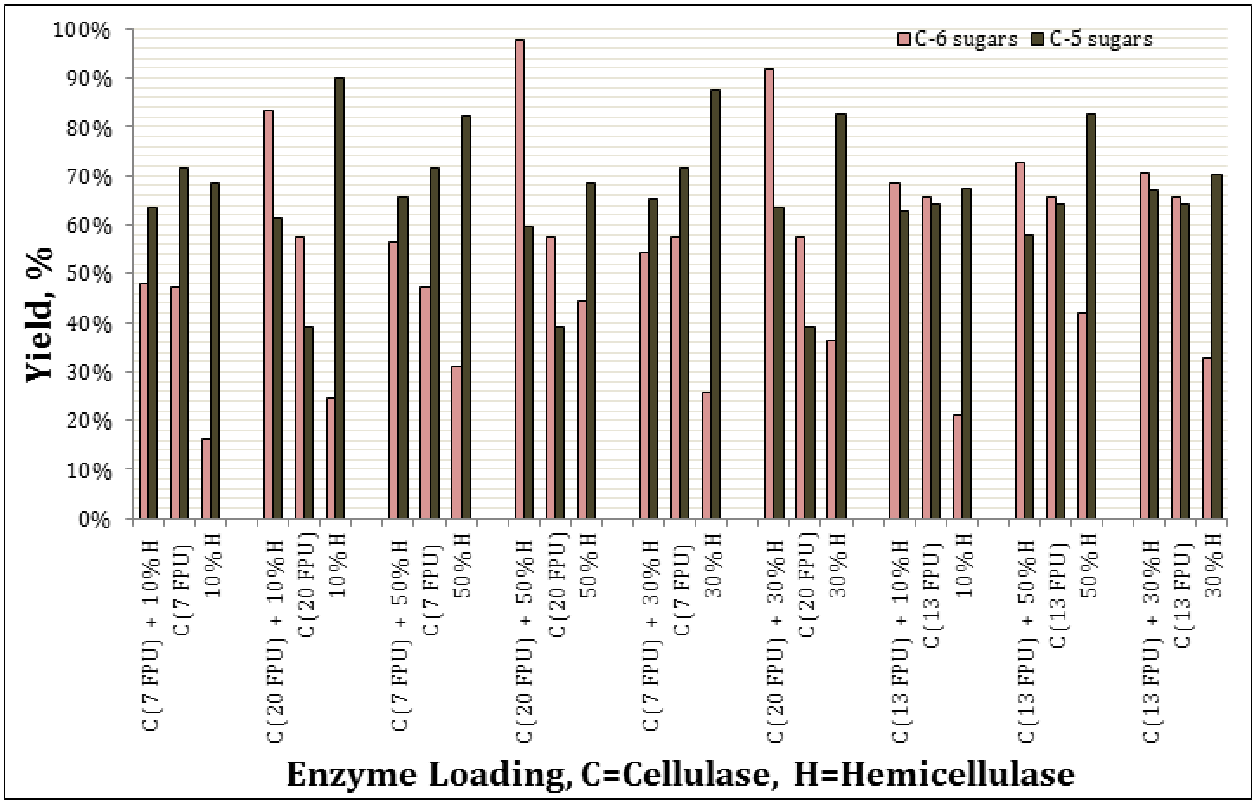
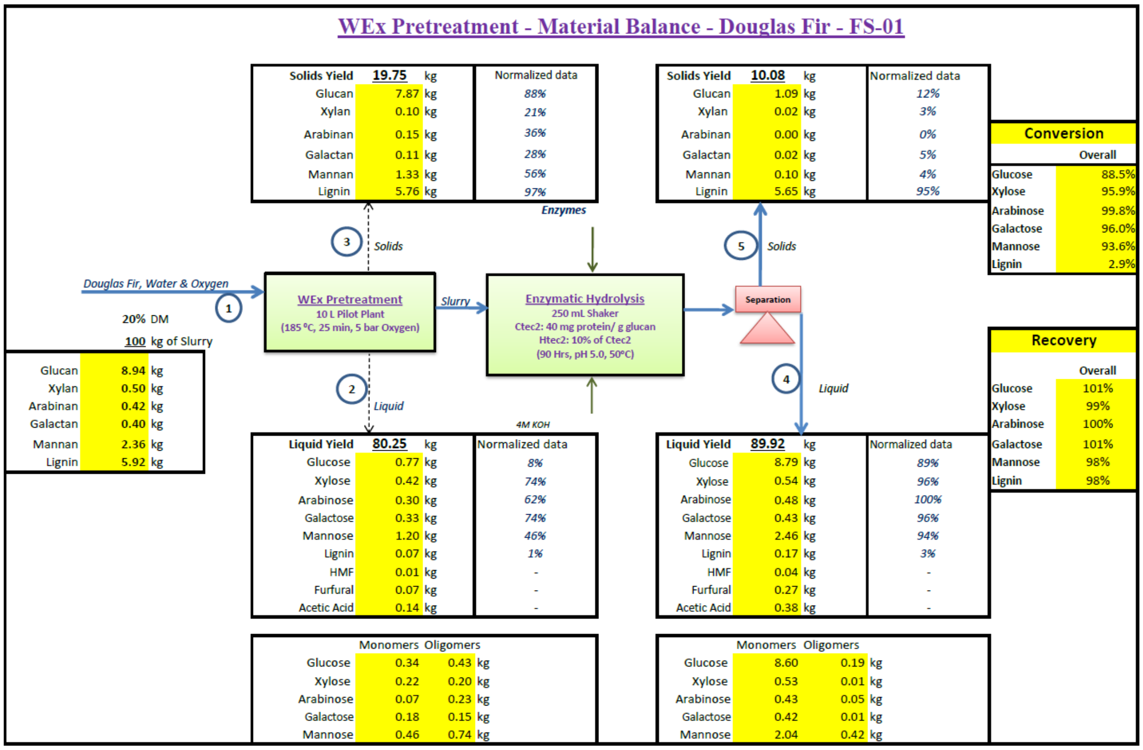


Figure 1. Calculated yield’s obtained.



| | | |
|---|---|---|
| Glucan | 8.94 | kg |
| Xylan | 0.50 | kg |
| Arabinan | 0.42 | kg |
| Galactan | 0.40 | kg |
| Mannan | 2.36 | kg |
| Lignin | 5.92 | kg |

| Solids Yield | 19.75 | kg | Normalized data |
|---|---|---|---|
| Glucan | 7.87 | kg | 88% |
| Xylan | 0.10 | kg | 21% |
| Arabinan | 0.15 | kg | 36% |
| Galactan | 0.11 | kg | 28% |
| Mannan | 1.33 | kg | 56% |
| Lignin | 5.76 | kg | 97% |

| Solids Yield | 10.08 | kg | Normalized data |
|---|---|---|---|
| Glucan | 1.09 | kg | 12% |
| Xylan | 0.02 | kg | 3% |
| Arabinan | 0.00 | kg | 0% |
| Galactan | 0.02 | kg | 5% |
| Mannan | 0.10 | kg | 4% |
| Lignin | 5.65 | kg | 95% |

| Liquid Yield | 80.25 | kg | Normalized data |
|---|---|---|---|
| Glucose | 0.77 | kg | 8% |
| Xylose | 0.42 | kg | 74% |
| Arabinose | 0.30 | kg | 62% |
| Galactose | 0.33 | kg | 74% |
| Mannose | 1.20 | kg | 46% |
| Lignin | 0.07 | kg | 1% |
| HMF | 0.01 | kg | - |
| Furfural | 0.07 | kg | - |
| Acetic Acid | 0.14 | kg | - |

| Liquid Yield | 89.92 | kg | Normalized data |
|---|---|---|---|
| Glucose | 8.79 | kg | 89% |
| Xylose | 0.54 | kg | 96% |
| Arabinose | 0.48 | kg | 100% |
| Galactose | 0.43 | kg | 96% |
| Mannose | 2.46 | kg | 94% |
| Lignin | 0.17 | kg | 3% |
| HMF | 0.04 | kg | - |
| Furfural | 0.27 | kg | - |
| Acetic Acid | 0.38 | kg | - |

| | Monomers | Oligomers | |
|---|---|---|---|
| Glucose | 0.34 | 0.43 | kg |
| Xylose | 0.22 | 0.20 | kg |
| Arabinose | 0.07 | 0.23 | kg |
| Galactose | 0.18 | 0.15 | kg |
| Mannose | 0.46 | 0.74 | kg |

| | Monomers | Oligomers | |
|---|---|---|---|
| Glucose | 8.60 | 0.19 | kg |
| Xylose | 0.53 | 0.01 | kg |
| Arabinose | 0.43 | 0.05 | kg |
| Galactose | 0.42 | 0.01 | kg |
| Mannose | 2.04 | 0.42 | kg |

| Conversion | |
|---|---|
| | Overall |
| Glucose | 88.5% |
| Xylose | 95.9% |
| Arabinose | 99.8% |
| Galactose | 96.0% |
| Mannose | 93.6% |
| Lignin | 2.9% |

| Recovery | |
|---|---|
| | Overall |
| Glucose | 101% |
| Xylose | 99% |
| Arabinose | 100% |
| Galactose | 101% |
| Mannose | 98% |
| Lignin | 98% |

Figure 2: Mass balance – FS-01

## Recommendations/Conclusions

The following parameters were found to give the highest digestibility of FS-01 and FS-03:

**Pretreatment:**

Dry content = 25% (not optimized)

Temp = 185C (optimized)

Time = 25min (optimized)

Oxygen loading = 7.5% of DM (optimized)

**Enzyme hydrolysis (for over 95% sugar release from pretreated biomass):**

20% DM (not optimized)

40mg EP/Cellulose CTec2 + 10% HTec2 V/V of Ctec2 (optimized)

50°C (optimized)

90h (optimized)

pH=5.0 (optimized)

A major study was done on FS-01 to determine the “sweet spot” where sugar yield and enzyme load is optimized for cost (paper submitted). This study shows that the enzyme load can be decreased to 15 mg EP/ Cellulose CTec2 + 10% HTec2 V/V of Ctec2 with an overall sugar yields of 83%. It is obvious from this study that the cost of sugars is optimized at a yield of sugars that is less than the maximum obtainable. Due to the differences seen in biomass performance during pretreatment, it is recommended that a full optimization study is performed whenever new biomasses are used.Going forward, an optimization study on FS-10 has been planned as well as sample distribution to the partners. Commissioning of the fully equipped Washington State University pilot plant is close and this will allow us to produce much larger samples to meet any needs of the NARA partners.

## Physical and Intellectual Outputs

### Physical

Table 4: Samples for partners

| | | |
|---|---|---|
| Gevo | 3/14/2012 | FS-01-Hydrolysate |
| Gevo | 3/14/2012 | FS-01-PT sample |
| Gevo | 12/26/2012 | FS-03-Hydrolysate |
| Gevo | 2/18/2013 | FS-03-Hydrolysate |
| Weyerhaeuser | 1/21/2013 | FS-03 Lignin |
| Weyerhaeuser | 2/18/2013 & 4/16/2013 | FS-03 Lignin |

### Refereed Publications (accepted or completed)

None. However, one paper has been submitted to a peer-reviewed journal summarizing results from FS-01 parameter optimization experiments.

### Research Presentations

Ahring, B., D. Rana, V. Rana K. Srinivas and P. Teller. 2012. Breaking the barriers of Douglas fir softwood to biofuels using wet explosion pretreatment. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

## Task C-P-4: Mild Bisulfite Pretreatment of Forest Residuals

| Key Personnel | Affiliation |
|---|---|
| Dwight Anderson | Catchlight Energy |

### Task Description

Catchlight Energy will identify the pretreatment parameters that give the greatest sugar yield for the Mild Bisulfite Pretreatment on a NARA feedstock such as FS-03. Lignin co-product value has the potential for significant contribution to overall economics, so Catchlight Energy will also produce samples to enable the identification of economic opportunities with co-products.

In Year 1, Catchlight Energy participated as a non-funded Member by providing pretreatment data for a NARA feedstock (FS-01) to enable an economic comparison of pretreatments. Catchlight Energy had also provided initial lignin samples to the Co-Products team. Catchlight Energy contributed additional lignin samples from FS-03 to the Co-Products team at Catchlight Energy's own expense.

Year 2 research will focus on optimizing Mild Bisulfite pretreatment of softwood forest residues. Pretreatment runs will be conducted in the one cubic foot batch pilot digester at Weyerhaeuser Technology Center. The feedstock of choice will be softwood residues such as FS-10. The subtasks are: a) Identify Mild Bisulfite Pretreatment conditions that optimize the yield of fermentable sugars in the selected feedstock. b) Produce additional samples of lignosulfonate and residual lignin beyond what would be previously provided by Catchlight Energy funding for analysis by the Co-Products team.

### Activities and Results

Mild Bisulfite Pretreatment shows promise to be able to use typically-sized wood chips. This not only reduces the cost associated with more aggressive feedstock processing, but it opens up the possibility of using equipment that is used in existing pulp and paper operations. The task of optimizing Mild Bisulfite Pretreatment began in March 2013. It is focused on the Douglas-fir forest residual reference sample collected from Washington and Oregon in January 2013. This feedstock is a strong candidate for a first commercial plant. The results of the first two pretreatment runs indicate that it is possible to do Mild Bisulfite pretreatment without size reduction of the wood chips other than what is typically practiced in the pulp and paper industry.

A number of parameters in the pretreatment and subsequent processing affect optimization. An experimental plan was developed to begin with Catchlight Energy's current pretreatment parameters and find successively more cost-competitive alternatives. Parameters to be addressed include chip size, chemical concentration, time/temperature, and enzyme optimization.

Chip size is an important characteristic. Many pretreatments require significant feedstock size reduction. This poses two challenges.

- It requires additional capital and energy. Extremely finely-ground wood can require significant energy.

- A high fines content limits equipment selection choices. Wood digesters are mature technology, well-suited to many pretreatment chemistries. The most cost-effective designs cannot tolerate large amounts of fines in the feedstock.

At the same time, however, penetration of wood chips by pretreatment chemistry can be adversely affected by chips that are too large, or by too high a fines content. Excessive fines in a wood chip feedstock consume a disproportionate amount of the pretreatment chemistry compared to typically sized chips in the same feedstock. For these reasons, development work at Catchlight Energy has previously used a reduced chip size with fines removed. This is made by re-chipping wood chips so they pass through a 0.75 inch diameter round hole screen, then discarding the 1/8" fines. These are referred to as the "Reduced-Size Chips" in Table 1. By comparison, the NARA Reference Chips (NARA's FS-10 Combined Accepts) was screened through a 1.75 inch gyratory screen and recombined with overthicks that were milled to <1.5 inches. Fines were not removed, and comprised 9% of the feedstock. Thus, the NARA Reference Chips are less ideal but more practical than the Reduced-Size Chips.

Catchlight Energy has previously found good hydrolysis performance at pulp yields near 75%. The concern was that the more realistic NARA Reference Chips would have too high a yield and too low a chemical consumption compared to the Reduced-Size Chips. Table 1 indicates, however, that the larger chips did not have a higher yield at similar pretreatment conditions, and each cook consumed the same amount of chemical. Thus, future optimization can center on the more practical NARA Reference Chips.

**Table 1:** Pretreatment Results for Differently-Sized Chips

| | **Reduced-Size Chips (0.75" screen)** | **NARA Reference Chips (1.75" screen)** |
|---|---|---|
| Percent Dry Matter | 90.56% | 88.92% |
| Ca bisulfite,on wood | 11.76% | 11.20% |
| Free $SO_2$, on wood | 4.99% | 4.75% |
| Time to Temperature | 45 minutes | 55 minutes |
| Time at Temperature | 75 minutes | 75 minutes |
| Temperature | 165°C | 165°C |
| Pulp Yield on Wood | 68.1% | 65.7% |
| $SO_2$ consumed during cook | 62.1% | 61.4% |

## Recommendations/Conclusions

The Mild Bisulfite pretreatment appears compatible with practical chip sizes that are customarily used in the pulp and paper industry. This will be verified by hydrolyzing the solids to sugar. The next process optimization steps will include decreasing the chemical charge, and altering the time/temperature of the pretreatment.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Prepared independently of NARA funding, but provides background for the starting point of optimization funded by NARA: http://www.biotechnologyforbiofuels.com/content/6/1/10 Gao, Johnway; Anderson, Dwight; Levie, Benjamin; “Saccharification of Recalcitrant Biomass and Integration Options for Lignocellulosic Sugars from Catchlight Energy’s Sugar Process (CLE Sugar),” Biotechnology for Biofuels, **6**:10, Jan. 28, 2013.

### Research Presentations

Anderson, D., J. Gao, and B. Levie. 2012. Mild bisulfite pretreatment. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Aviation Team

## C-AF-1: Production of Lignocellulosic Isobutanol by Fermentation and Conversion to Biojet

| Key Personnel | Affiliation |
|---|---|
| Andrew Hawkins | Gevo, Inc |
| Glenn Johnson | Gevo, Inc |
| Chris Ryan | Gevo, Inc |
| Bob Wooley | Gevo, Inc |

### Task Description

Gevo has developed fermentation and process technology to convert biomass sugars to isobutanol and further into renewable jet fuel through chemical processing. Gevo will concurrently develop GIFT®, Gevo Integrated Fermentation Technology, to produce isobutanol at high productivity, titer, and yield using a yeast biocatalyst adapted to hydrolyzate. The goal of this project will be to produce isobutanol according to a specification developed by Gevo that ensures the isobutanol will be converted into renewable biojet using existing Gevo technology. Quantities of about 1000 gallons (approx. 20 tons feedstock) of biojet will be prepared and validated as suitable jet fuel blend stock using ASTM's fit for purpose testing protocol and input from stakeholders. The specific tasks of this project are: (1) Characterize toxicity of a representative sample of pre-treated woody biomass (Douglas Fir) for fermentation; (2) Adapt yeast biocatalyst to pretreated biomass hydrolyzate; (3) Produce isobutanol in a 1L batch fermentation from pretreated biomass sugars using the adapted yeast biocatalyst; (4) Economic assessment of wood to isobutanol, jet; (5) Produce isobutanol in a 1L GIFT® fermentation from pretreated biomass sugars using the adapted yeast biocatalyst; (6) Analysis of isobutanol to close the mass balance and determine potential low-level impurities; (7) . Produce isobutanol in a 20L GIFT® SSF fermentation from pretreated biomass; (8) Produce ≥1000 gallons isobutanol from GIFT® SSF fermentations at 40,000 L demonstration scale. Convert lignocellulosic isobutanol to ≥ 1000 gallons biojet for further testing.

### Activities and Results

To address Task C-AF-1.1, analytical data for sugar concentrations and inhibitor concentrations are determined by high pressure liquid chromatography (HPLC) analysis for each feedstock and pretreatment method received. To date, Gevo has received and characterized pretreated materials from NARA feedstock FS-01 and FS-03. SPORL-treated material from Dr. JY Zhu at the USDA Forest Products Laboratory (Madison, WI) and wet oxidation treated material from Dr. Birgitte Ahring at Washington State University – Tricities (Richland, WA) were analyzed from each feedstock. In addition, two hydrolyzates types of pretreated FS-03 material were received from Catchlight Energy and are currently being characterized at Gevo. Concentrations of sugars and inhibitors have been determined for all materials received (Table 1).

Characterization of new hydrolyzates is ongoing and occurs through benchmarking growth and fermentation. Growth performance of a benchmark wild-type ethanol producing strain was compared to an isobutanol producing biocatalyst in different pretreated hydrolyzates using the current NARA feedstock FS-03 in a high-throughput microfermentation system (BioLector, m2p-labs) (Figure 1). Growth and fermentation performance were compared using a wild type ethanol producing strain and the current best isobutanol producing biocatalyst in different hydrolyzates of the current NARA feedstock FS-03. As an example, growth and isobutanol production data from shake flask fermentations using the wet oxidation (WO) adapted strain LB4 is presented in Figure 2.

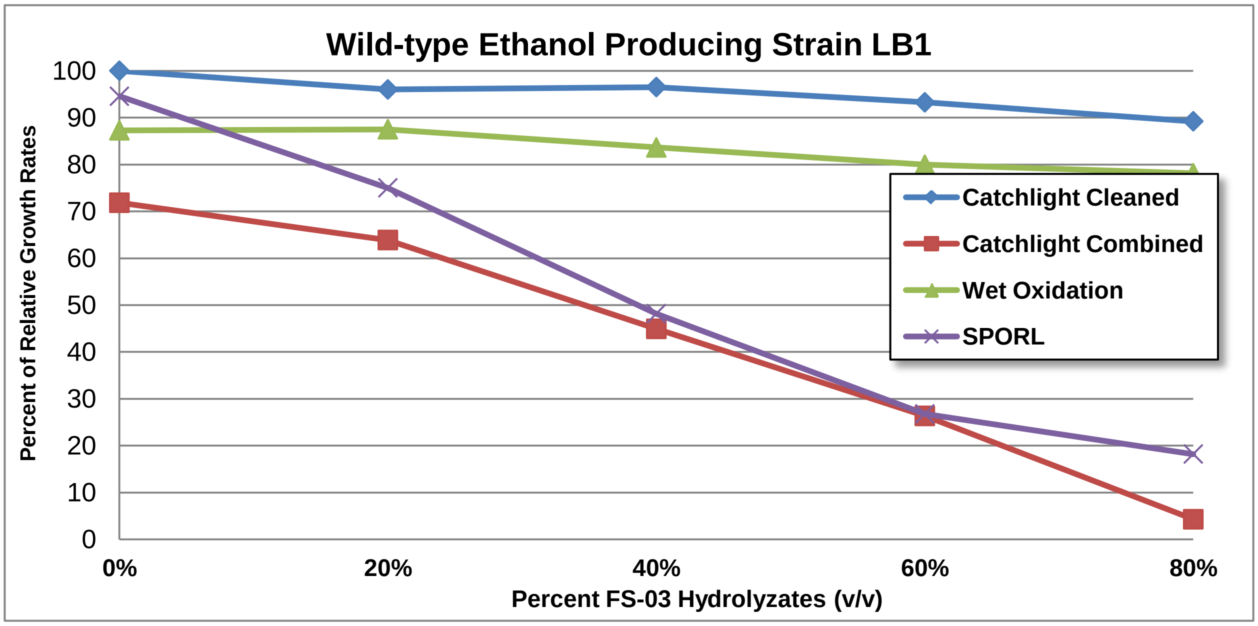
To address task C-AF-1.2, inhibitor concentrations in biomass pretreatments can vary widely depending on the pretreatment method. To generate robust biocatalysts adaptation to a specific pretreated hydrolyzate is needed. A strain adaptation program to generate higher performing isobutanol producing biocatalysts to different hydrolyzates is ongoing. The isobutanol producing biocatalyst LB3 was used as a starting strain for evolutionary engineering using wet oxidation (WO) hydrolyzate. Several improved isolates were identified in a screen for improved growth in WO pretreated biomass derived from FS-01. Comparative growth of one of these adapted strains is presented in Figure 3. The growth of the WO adapted strain was improved over the parental strain for all percentages of WO hydrolyzate. However, the WO adapted strain did not have improved performance in SPORL hydrolyzates above 40% (v/v). Therefore, a similar adaptation program was carried out with the SPORL hydrolyzate using the WO adapted strain LB4 and strains with improved growth in SPORL hydrolyzate were identified and characterized. Figure 4 shows the percent of relative biomass and isobutanol titers for the LB4 parental strain and the SPORL adapted LB17 strain in 50% v/v SPORL black liquor medium. Relative biomass and isobutanol titers were improved for the LB17 strain over the parent LB4. The increased performance of strains adapted to specific hydrolyzates exemplifies the differences in pretreatments and the power of evolutionary engineering. It also indicates the need to focus on a particular pretreatment hydrolysis method, so that a biocatalyst adaptation program may be focused to generate improved performance.

To address Task C-AF-1.3, work began to optimize fermentation conditions for the isobutanol producing biocatalyst strain LB3. This strain is the parent strain of adapted biocatalyst strains such as LB4 and LB17 and serves as a benchmark strain for establishing conditions that can be applied to adapted strains.

To address Task C-AF-1.4, Gevo Process Engineering team members have held several teleconferences and multiple information exchanges with Gevan Marrs (Catchlight Energy) and Tom Spink (TSI, Inc.) to provide information for the NARA techno-economic analysis. Gevo has provided information on its production process unit operations to convert isobutanol to biojet (IPK, isoparafinic kerosene). Gevo has also provided information and direction on how to model the lignocellulosic capital costs using analysis completed by NREL for the production of ethanol and insight on how to adapt this to the production of isobutanol.

**Table 1.** Sugar and inhibitor concentrations in FS-01 and FS-03 feedstocks from different pretreatments. Compositional analysis was determined using high performance liquid chromatography (HPLC) at Gevo. (n.d. = not detected)

| | **Glucose (g/L)** | **Xylose (g/L)** | **Galactose (g/L)** | **Arabinose (g/L)** | **Mannose (g/L)** | **Acetate (g/L)** | **HMF (g/L)** | **Furfural (g/L)** |
|---|---|---|---|---|---|---|---|---|
| **FS-01 Wet Oxidation Hydrolyzate** | 57.20 | 6.67 | 5.12 | 1.58 | 20.87 | 7.27 | 3.90 | 0.99 |
| **FS-03 Wet Oxidation Hydrolyzate** | 89.58 | 5.25 | 3.00 | n.d. | 7.66 | 7.00 | n.d. | n.d. |
| **FS-01 SPORL Hydrolyzate** | 93.65 | 6.89 | 4.94 | 1.24 | 23.01 | 4.56 | 0.73 | 0.07 |
| **FS-03 SPORL Hydrolyzate** | 81.81 | 5.79 | 3.82 | 0.40 | 7.02 | 5.78 | 1.76 | 0.61 |
| **FS-03 Catchlight Combined Hydrolyzate** | 164.12 | 8.56 | 5.24 | 0.94 | 13.34 | 3.45 | 0.16 | 0.13 |
| **FS-03 Catchlight Cleaned Hydrolyzate** | 130.89 | 1.84 | 0.49 | n.d. | 1.34 | 0.26 | 0.14 | 0.01 |



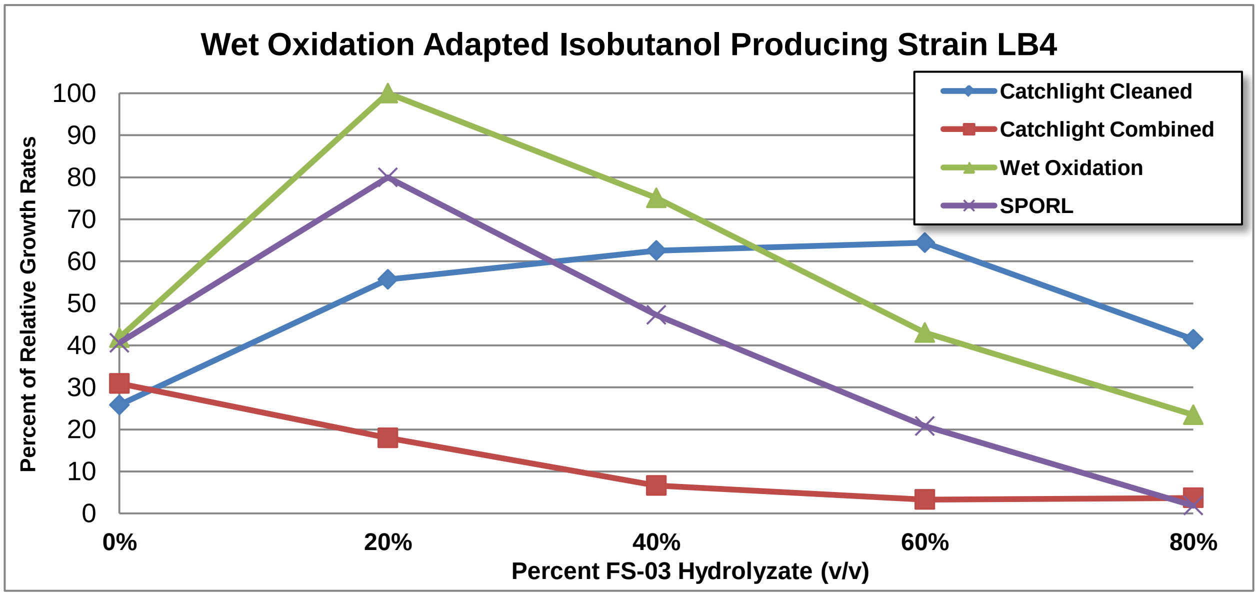


**Figure 1.** Graphs showing the percent of relative growth rates of the benchmark ethanol producing strain LB1 (Top) and the wet oxidation adapted strain LB4 (Bottom). Data for µMAX values were obtained using a high-throughput microfermentation system (BioLector, m2p-labs). The clarified hydrolyzates preteated using wet oxidation, SPORL, and the process used by Catchlight from NARA feedstock FS-03 were all supplemented with a nutrient package, salts, and a buffering agent. Different percentages of hydrolyzate media contained equal amounts of corresponding sugars and supplements. 100% (v/v) hydrolyzate is equal to approximately 20-30% equivalent solids for all materials.

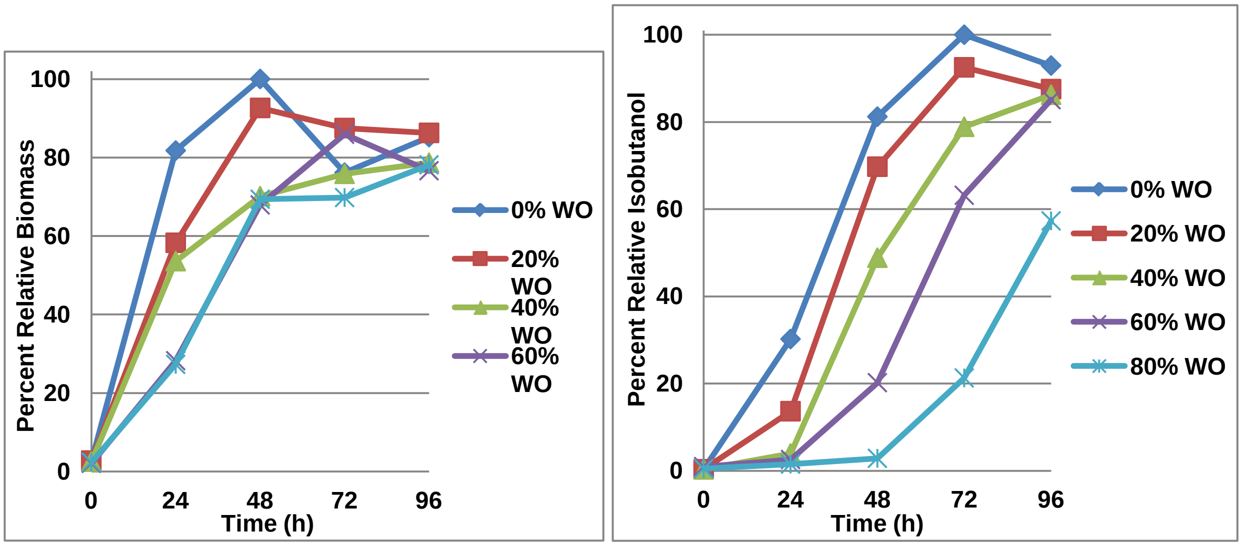


**Figure 2.** Shake flask fermentations showing the percent relative growth (Left) and relative isobutanol titer (Right) of the wet oxidation adapted parent LB4 in different percentages of FS-03 WO hydrolyzate. The clarified FS-03 wet oxidation pretreated hydrolyzate was supplemented with a nutrient package, salts, and a buffering agent. Different percentages of hydrolyzate media contained equal amounts of corresponding sugars and supplements. At 100% (v/v), not shown, wet oxidation pretreated hydrolyzate was equal to approximately 20-30% equivalent solids. Fermentation was carried out at 33°C for 96 hours in shake flasks. Isobutanol levels were determined by GC analysis.

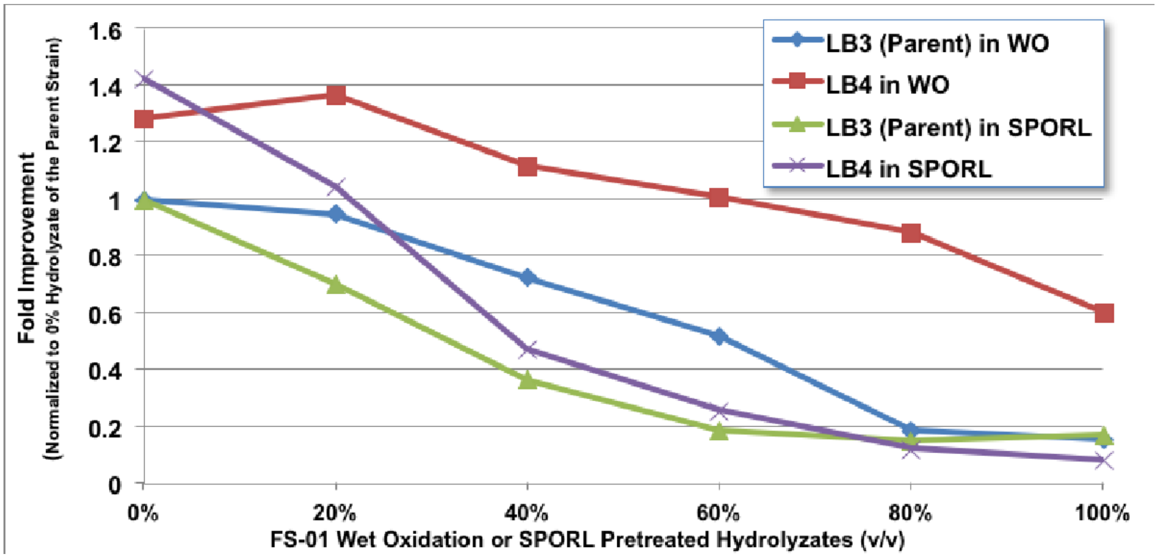


**Figure 3.** Graph showing the fold improvement in growth rates of the wet oxidation (WO) adapted strain (LB4). Values were normalized to the parental control (LB3) grown in 0% hydrolyzate. Data was obtained using a high-throughput microfermentation system (BioLector, m2p-labs). The clarified FS-01 wet oxidation and SPORL pretreated hydrolyzates were supplemented with a nutrient package, salts, and a buffering agent. Different percentages of hydrolyzate media contained equal amounts of corresponding sugars and supplements. 100% (v/v) SPORL and wet oxidation pretreated hydrolyzate were equal to approximately 20-25% equivalent solids.

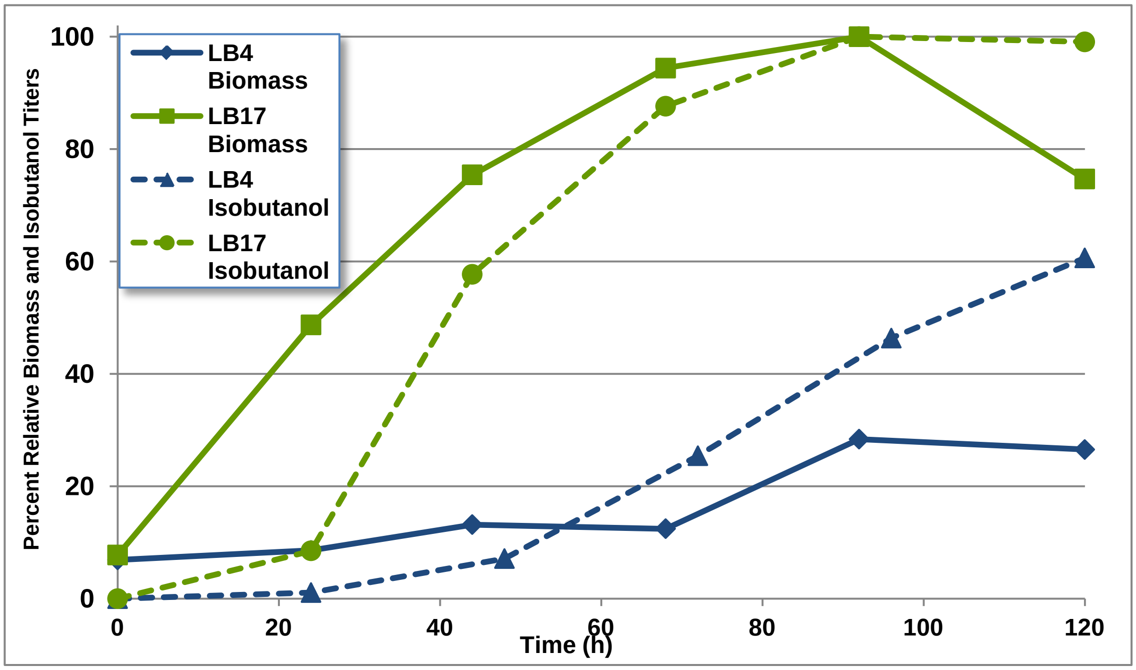


**Figure 4.** Percent relative growth and isobutanol titers of the wet oxidation adapted parent LB4 compared to a SPORL adapted isolate LB17 both grown in SPORL black liquor (50% v/v) medium derived from SPORL pretreated biomass (FS-01). The liquid black liquor stream was supplemented with a nutrient package, salts, and a buffering agent. Fermentation was carried out at 33°C for 120 hours in shake flasks. Isobutanol levels were determined by GC analysis.

## Recommendations/Conclusions

The overall summary to date is that methods for characterizing new hydrolyzate materials have been established. A strain adaptation program to generate higher performing isobutanol producing biocatalysts in different hydrolyzates is currently ongoing. Strains from adaptation programs perform better in the specific hydrolyzate to which they were adapted. In order to obtain the best biocatalyst possible and identify the best conditions for fermentations, narrowing down the types of pretreatments examined will a strain adaptation program to focus on producing improved strains and subsequently determine the optimum parameters for fermentations and scale-up.

## Physical and Intellectual Outputs

### Physical

None. To date we have not produced physical samples or outputs for transfer to other project components.

# C-AF-2: Production of Jet Fuel using BioChemCat

| Key personnel | Affiliation |
|---|---|
| Birgitte Ahring | Washington State University |

## Task Description

Using the proprietary BioChemCat Process, WSU BSEL will in parallel with Gevo investigate the production of jet fuel from woody residues. All results are from pretreated materials that have not been further treated with enzymes. In the project we will concentrate our effort on the following two areas: 1) Co-culture optimization for high production yield and productivity of platform molecules (VFA) from pretreated biomass hydrolysate, and 2) Catalysis of platform molecules into jet fuel. WSU BSEL will work with PNNL (Pacific Northwest National Laboratory) using the PNNL combinatorial catalysis computational laboratory platform.

## Activities and Results

Task C-AF-2.1 is to optimize fermentation for making platform molecules. A 40 liter (L) fermentor was setup in the previous quarter and operated on continuous mode. The fermentor is currently producing higher quantities of 2-carbon (C2) and 3-carbon (C3) acids compared to 4-carbon (C4) acids or higher volatile fatty acids (VFA) in the first quarter (total of 32 g/l compared to 22 g/l). The system is fed 10% TS pretreated FS-01. A 5 L lab reactor has been setup to operate in fed-batch mode to form a stable cultured from the 40 L reactor. The sugar and VFA analysis from the first 30-day fed batch reactor run is shown in Figure 1. There is a substantial increase in the production of C3 acid when compared to the continuous fermentor. The system is fed 10% TS pretreated biomass materials and the mass balance shows a very high conversion degree of carbohydrates in the culture (ca. 80%).

In the first quarter of 2013 we concentrated our efforts to produce platform molecules from FS-03. As this material needs a more severe pretreatment compared to FS-01, the amounts of inhibitors are significant higher. The result shown in Fig. 2 clearly demonstrate that the culture is fully capable of handling the new substrate and that stable high yields of especially C2 acid is produced consistently with variable yields of higher acids all the way to C6 acid. The overall yield of acids produced expressed as acetic acid equivalents per gram of total solids or per gram of carbohydrate is shown in Figure 3.

To extract the platform molecules, a pressurized carbon dioxide extraction system has been implemented in our laboratory aimed at the extraction of platform molecules (VFAs) from the fermentation broth(s) (Figure 4). The extraction of acetic acid from water using pressurized carbon dioxide was tested between 25 and 50° C at pressures between 1500 and 2500 psi. A response surface design was set up with concentrations of acetic acid in water varying between 5 g/L and 100 g/L, run time of 1 hour to 5 hours and the carbon dioxide flow rate as measured at the outlet varying between 500 and 1500 mL/min air equivalent (or 350 and 1050 mL/min $CO_2$ respectively). 32 experiments were run and the experiments were optimized based on both % acetic acid recovery and acetic acid yield (mg acid/g $CO_2$). It was found that we could extract about 85% of acetic acid from water using carbon dioxide at 50° C, 1500 psi, 1050 mL/min for 5 hours. Statistical analysis of the data indicated that it is possible to get about 98% of the acetic acid extracted from water using carbon dioxide at 2500 psi with all the other experimental conditions remaining the same as described above (Figures 5 and 6).

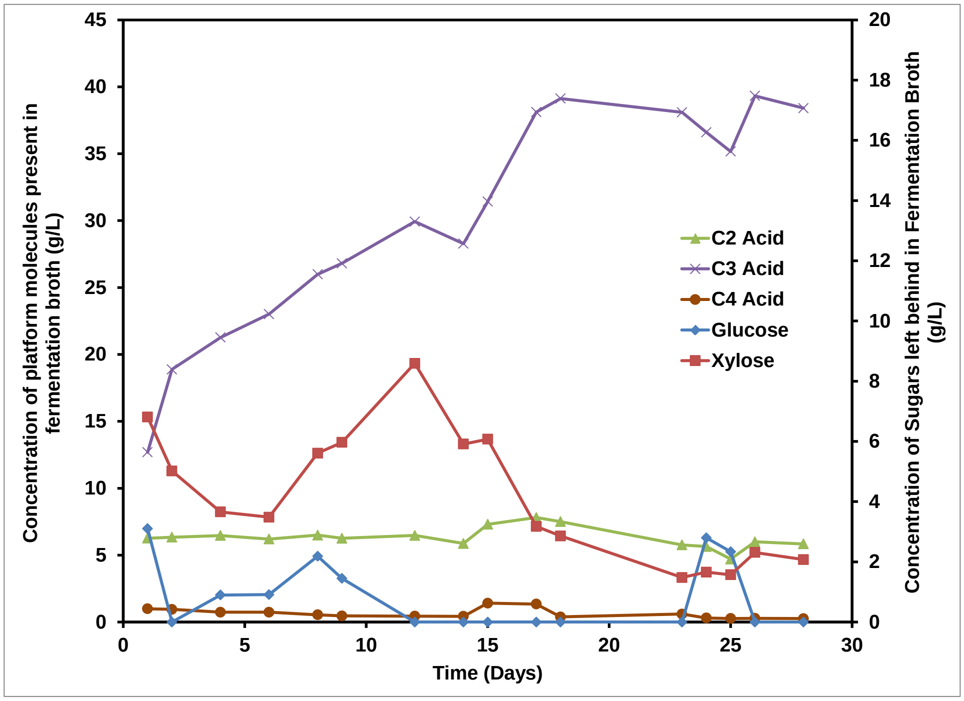
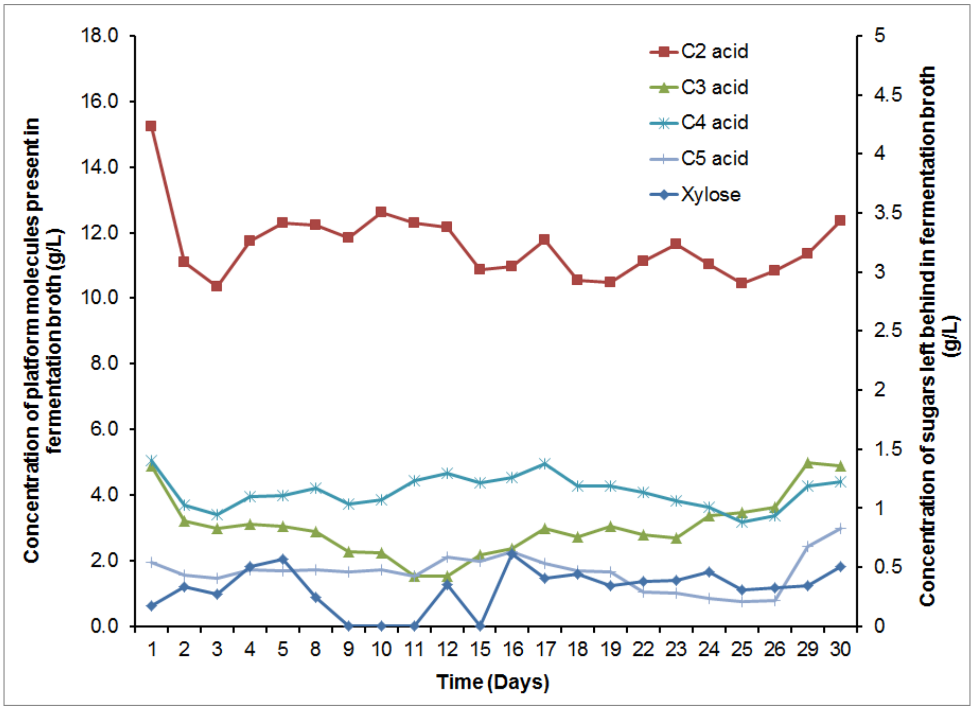


Figure 1: Analysis of Sugars and VFAs in 5L Fermentation Broth Operated in Fed-Batch Mode using pretreated FS01 substrate



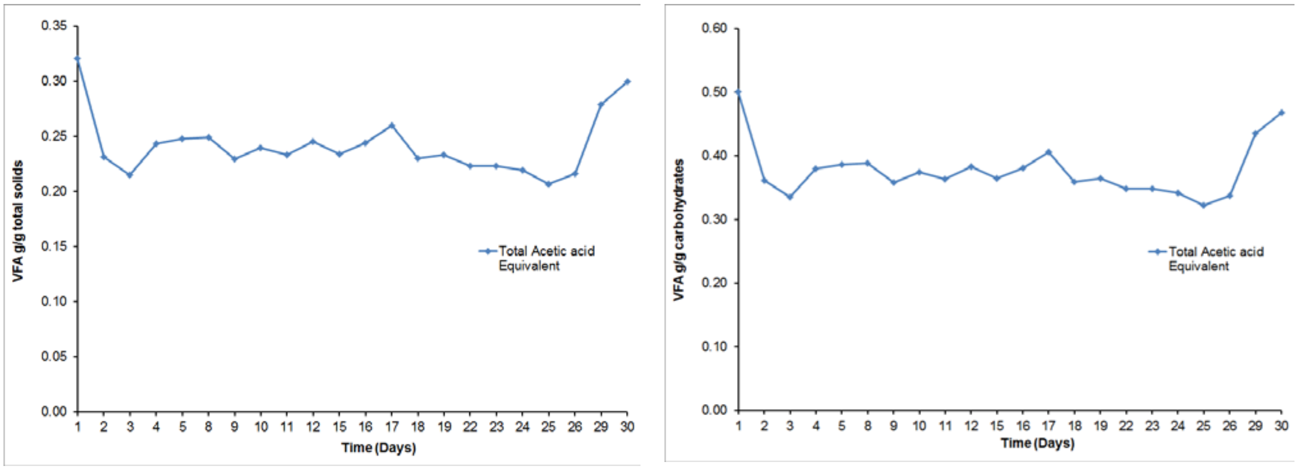


Figure 2: Analysis of Sugars and VFAs in 5L Fermentation Broth Operated in Fed-Batch Mode using pretreated FS03 substrate

Figure 3: Analysis of VFAs as a function of (a) total solids; and (b) sugars in 5 L Fermentation Broth Operated in Continuous Mode with pretreated FS-03 biomass substrate

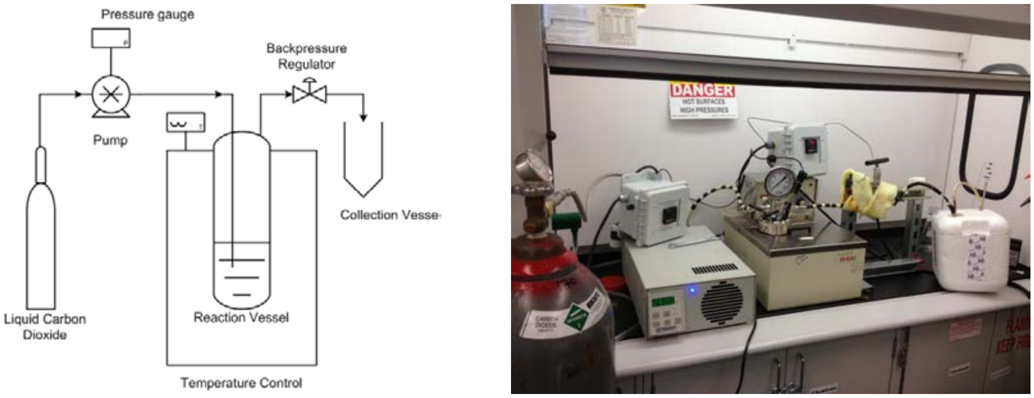


Figure 4: Supercritical carbon dioxide apparatus for extraction of platform molecules

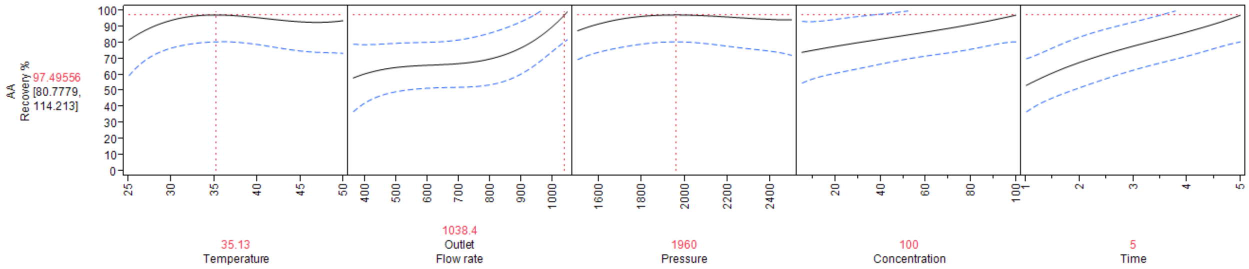


Figure 5: Optimized conditions and maximum acetic acid yield from water using pressurized carbon dioxide – statistical data from response surface experimental design

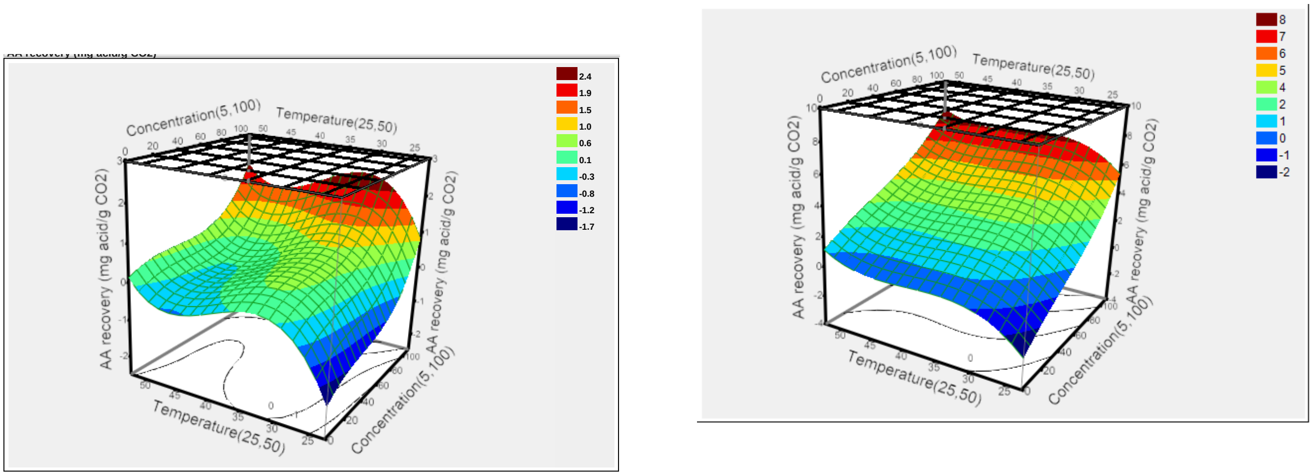


Figure 6: Variation of acetic acid yield (mg acid/g $CO_2$) as a function of concentration and temperature at 2500 psi and run time of (a) 5 hours; and (b) 1 hour

## Recommendations/Conclusions

Stabilization of the culture and increasing the overall productivity has been achieved in the first quarter of 2013. Through optimization of experimental conditions mainly the residence time, the overall yield of C3 acid was found to have increased to as high as 65-70 g/L. Further stabilization is being done of the reactor followed by scale-up to be tested in the second quarter of 2013.

The studies during the period have clearly shown that a fed-batch fermentation of the pretreated woody biomass can provide a stable yield of C2 to C6 acids. Further experiments are being designed to improve the yield from the 5L fed-batch fermenter followed by scale-up under these conditions to a 100L fermenter. Operation of the feed batch reactor with in-situ removal of acids during the fermentation is expected to further improve the fermentation process.

It can be seen from the statistical analysis of the experimental design that the optimized conditions for the extraction of acetic acid from water is 50° C, 2500 psi, outlet $CO_2$ flow rate of 1050 mL/min and run time of 5 hours. While 5 hours run time was very effective to remove greater amount of acetic acid from water, it was found that greater extraction rate of acetic acid happened in shorter run times (1 hr or less). For example, it was found that under the afore-mentioned conditions, the total acetic acid extracted at the end of 5 hours at 1500 psi was found to be around 3 mg acid/g $CO_2$ (Figure 6a) while the amount extracted at the end of the first hour was found to be around 7 mg acid/g $CO_2$ (Figure 6b). The reason for this difference is because at higher flow rates as a function of pressure, greater extraction happens in the first hour or so followed by continuous extraction at a slower rate as run time is increased. Further experiments are currently being done to study the kinetics of pressurized carbon dioxide extraction of acetic acid from water and fermentation broth.

It can be seen from Figure 5 that temperature does not have too significant an effect on the extraction efficiency between 35° and 50° C. It can also be seen from Figure 5 that the percent recovery of acetic acid using pressurized carbon dioxide varied linearly with the concentration of acetic acid in the feed. This indicates that the higher the amount of acetic acid in the feed, the higher the extraction efficiency of carbon dioxide will be. This can be attributed to the non-polar nature of acetic acid that makes it more attractive to pressurized carbon dioxide when compared to water. This behavior of the volatile fatty acids and the non-polarity of pressurized carbon dioxide as a solvent make this separation process more attractive to extract these platform molecules directly from the fermentation broth. It is also evident from the experiments that the headspace has a significant effect on the extraction rate as it would increase the residence time and hence, decrease the total run time to get the same acid yield. Further experiments will be designed to increase the headspace in the reactor through recirculation of the pressurized carbon dioxide to increase both the percent recovery of acetic acid as well as the extraction rate, thereby significantly reducing the total run time of the extraction.

## Physical and Intellectual Outputs

None. The process is still being optimized and hence, no physical outputs have been obtained yet.

### Refereed Publications (accepted or completed)

None. However, two manuscripts are under preparation and are planned to be submitted to journals in the start of the next quarter.

## Conference Proceedings and Abstracts from Professional Meetings

### Research Presentations

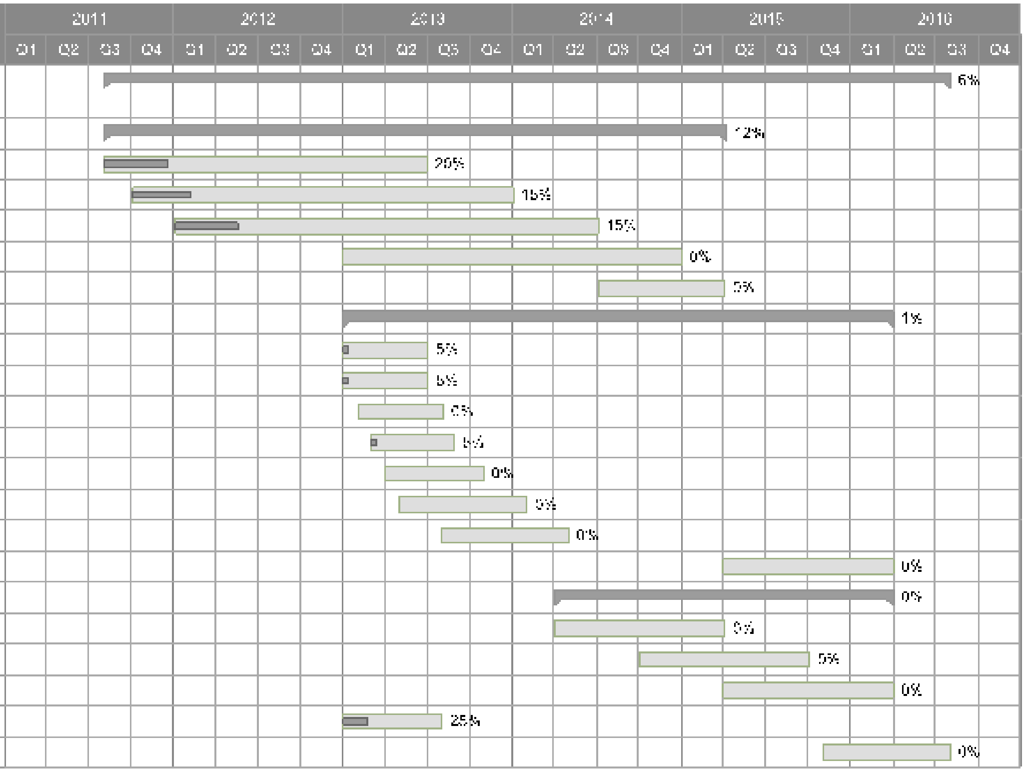
Ahring, B.K., D. Rana, V. Rana, and P. Teller. 2012. Producing high sugar yields from softwood using wet explosion pretreatment. 34th SBFC Meeting, New Orleans, LA. Apr 30-May 2, 2012.

Ahring, B.K., D. Rana, P.Teller. 2012. Wet explosion pretreatment of different feedstocks and its potential for producing biofuels. Pacific Rim Summit on Industrial Biotechnology and Bioenergy, Vancouver. Oct 10-12.

Ahring, B.K. 2012. New development for production of hydrocarbon biofuels. Frontier in Biorefining. St. Simon Island, Georgia. Oct 30-Nov 2.

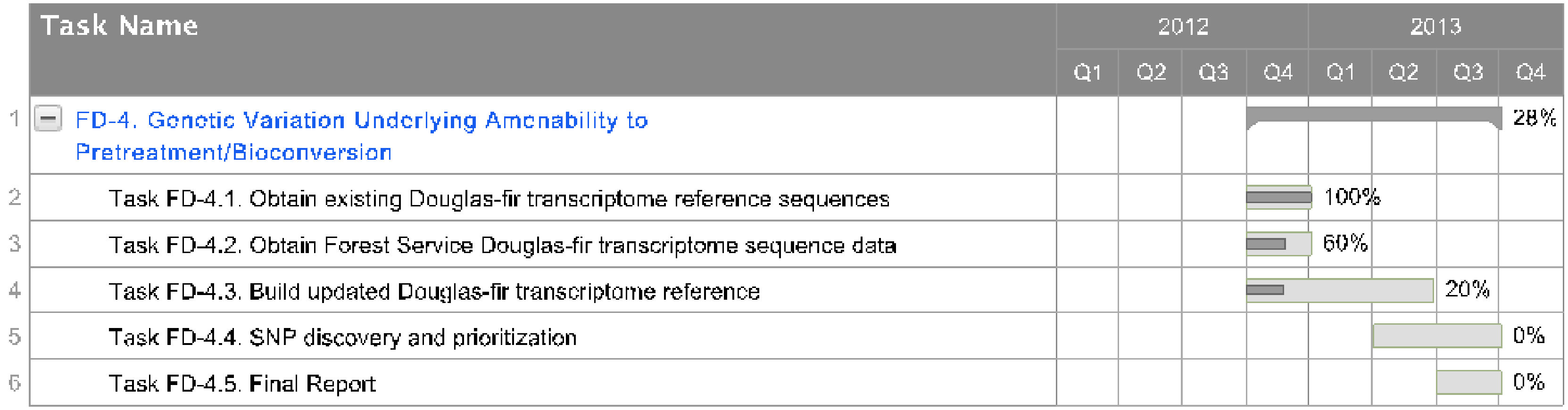
Ahring, B.K. 2012. Panel Meeting and Presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# FeedstockDevelopment_Jayawickrama



| | Task Name | |
|---|---|---|
| 1 | FD-3.Combining Genomic and Field-based Breeding and Testing Methods to Improve Woody Feedstock Production | 6% |
| 2 | Task FD-3.1. Collect wood samples and combine with phenotypic data | 12% |
| 3 | Select optimal populations of trees to obtain samples of woody tissue | 20% |
| 4 | Obtain wood samples | 15% |
| 5 | Measure variation in chemical properties | 15% |
| 6 | Combine with existing growth rate data to estimate variation in biofuel potential | 0% |
| 7 | Report | 5% |
| 8 | Task FD-3.2. Collect tree tissue samples and obtain marker data | 1% |
| 9 | Write a plant breeding plan | 5% |
| 10 | Write a marker data plan | 5% |
| 11 | Summarize available NWTC materials | 0% |
| 12 | Select optimal populations of trees to obtain needle samples | 5% |
| 13 | Collect, store and manage tree tissue samples | 0% |
| 14 | Extract DNA | 0% |
| 15 | Initiate and manage contract for building genotyping array | 0% |
| 16 | Report | 0% |
| 17 | Task FD-3.3. Develop relationships between multiple data sources | 0% |
| 18 | Develop relationships between phenotypic and marker data | 0% |
| 19 | Develop improved methods for detecting marker-trait associations | 5% |
| 20 | Make selections for increased biofuel production using phenotypic and marker data | 0% |
| 21 | Task FD-3.4. Provide Douglas-fir seedlings for phenomics study | 25% |
| 22 | Task FD-3.5. Final Report | 0% |

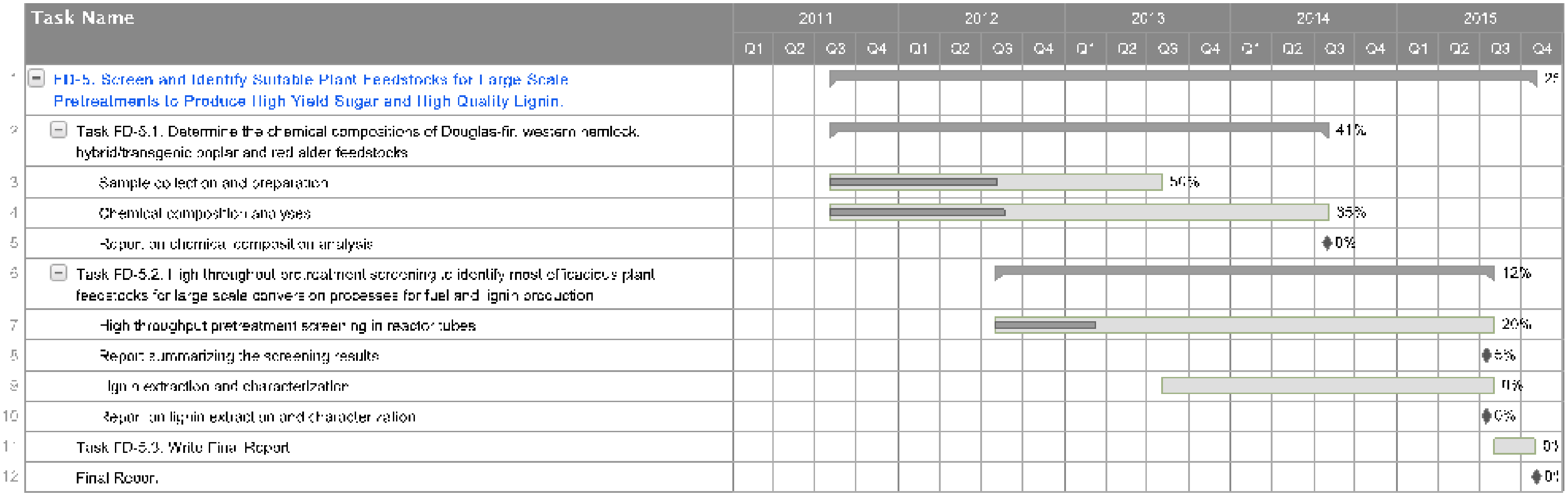
# FeedstockDevelopment_NCGR



|  | Task Name |
|---|---|
| 1 | FD-4. Genetic Variation Underlying Amenability to Pretreatment/Bioconversion |
| 2 | Task FD-4.1. Obtain existing Douglas-fir transcriptome reference sequences |
| 3 | Task FD-4.2. Obtain Forest Service Douglas-fir transcriptome sequence data |
| 4 | Task FD-4.3. Build updated Douglas-fir transcriptome reference |
| 5 | Task FD-4.4. SNP discovery and prioritization |
| 6 | Task FD-4.5. Final Report |

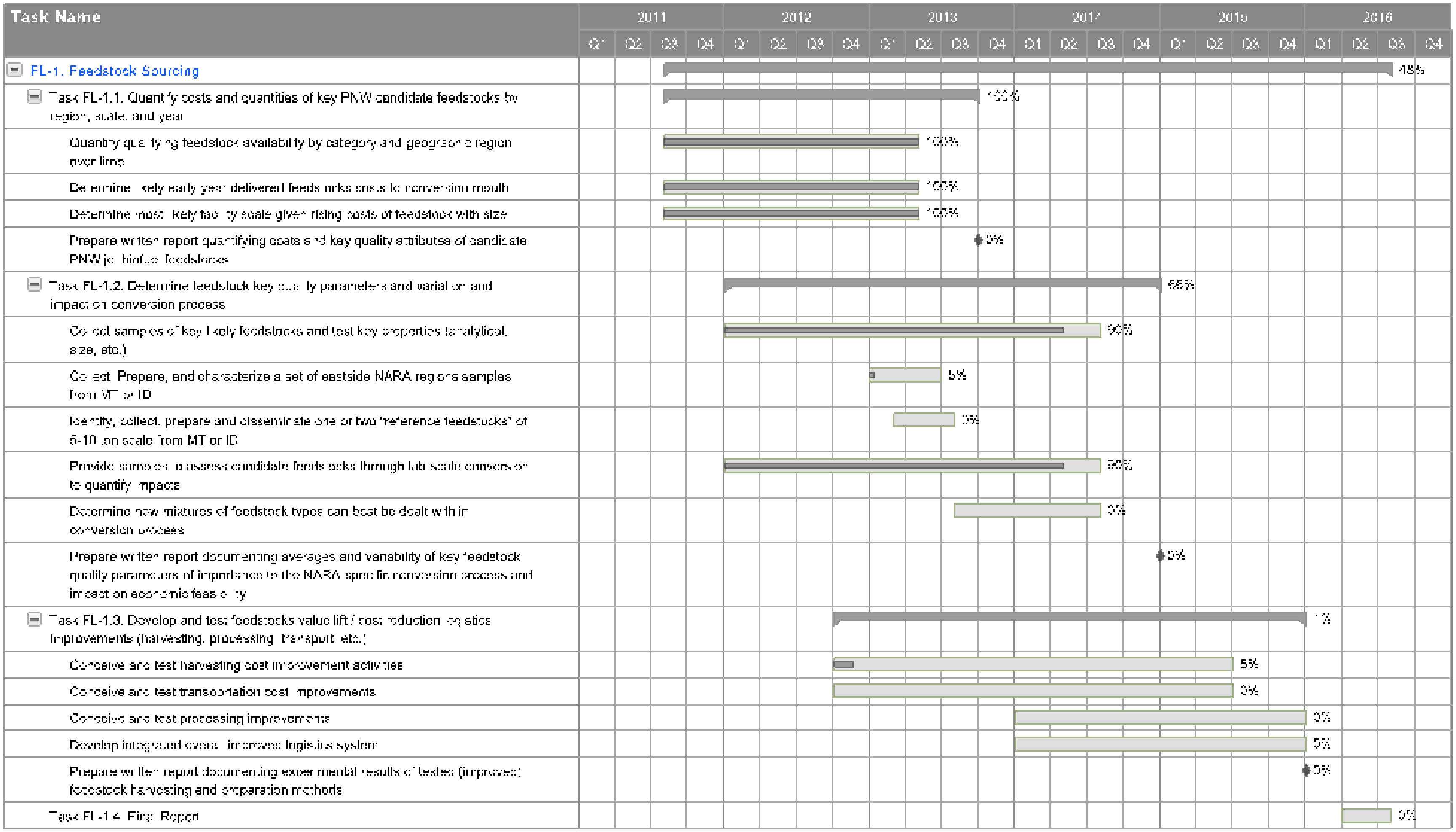
# FeedstockDevelopment_XZhang

NARA



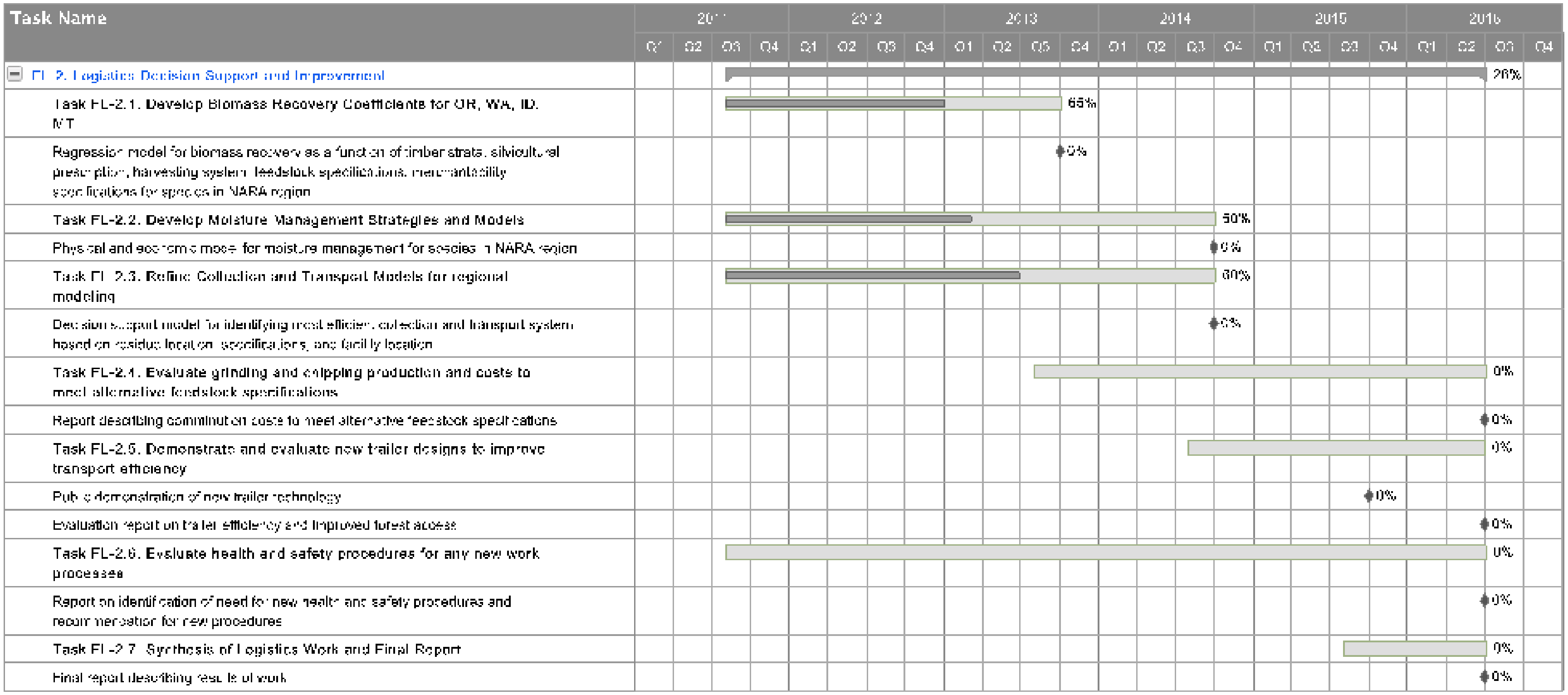
| | Task Name |
|---|---|
| 1 | FD-5. Screen and Identify Suitable Plant Feedstocks for Large Scale Pretreatments to Produce High Yield Sugar and High Quality Lignin. |
| 2 | Task FD-5.1. Determine the chemical compositions of Douglas-fir, western hemlock, hybrid/transgenic poplar and red alder feedstocks |
| 3 | Sample collection and preparation |
| 4 | Chemical composition analyses |
| 5 | Report on chemical composition analysis |
| 6 | Task FD-5.2. High throughput pretreatment screening to identify most efficacious plant feedstocks for large scale conversion processes for fuel and lignin production |
| 7 | High throughput pretreatment screening in reactor tubes |
| 8 | Report summarizing the screening results |
| 9 | Lignin extraction and characterization |
| 10 | Report on lignin extraction and characterization |
| 11 | Task FD-5.3. Write Final Report |
| 12 | Final Report |

# FeedstockLogistics_Marrs



| | Task Name | |
|---|---|---|
| 1 | FL-1. Feedstock Sourcing | 48% |
| 2 | Task FL-1.1. Quantify costs and quantities of key PNW candidate feedstocks by region, scale, and year | 100% |
| 3 | Quantify qualifying feedstock availability by category and geographic region over time | 100% |
| 4 | Determine likely early year delivered feedstocks costs to conversion mouth | 100% |
| 5 | Determine most likely facility scale given rising costs of feedstock with size | 100% |
| 6 | Prepare written report quantifying costs and key quality attributes of candidate PNW jet biofuel feedstocks | 0% |
| 7 | Task FL-1.2. Determine feedstock key quality parameters and variation and impact on conversion process | 66% |
| 8 | Collect samples of key likely feedstocks and test key properties (analytical, size, etc.) | 90% |
| 9 | Collect, Prepare, and characterize a set of eastside NARA regions samples from MT or ID | 5% |
| 10 | Identify, collect, prepare and disseminate one or two "reference feedstocks" of 5-10 ton scale from MT or ID | 0% |
| 11 | Provide samples to assess candidate feedstocks through lab scale conversion to quantify impacts | 90% |
| 12 | Determine how mixtures of feedstock types can best be dealt with in conversion process | 0% |
| 13 | Prepare written report documenting averages and variability of key feedstock quality parameters of importance to the NARA specific conversion process and impact on economic feasibility | 0% |
| 14 | Task FL-1.3. Develop and test feedstocks value lift / cost reduction logistics improvements (harvesting, processing, transport, etc.) | 1% |
| 15 | Conceive and test harvesting cost improvement activities | 5% |
| 16 | Conceive and test transportation cost improvements | 0% |
| 17 | Conceive and test processing improvements | 0% |
| 18 | Develop integrated overall improved logistics system | 5% |
| 19 | Prepare written report documenting experimental results of tested (improved) feedstock harvesting and preparation methods | 5% |
| 20 | Task FL-1.4. Final Report | 0% |

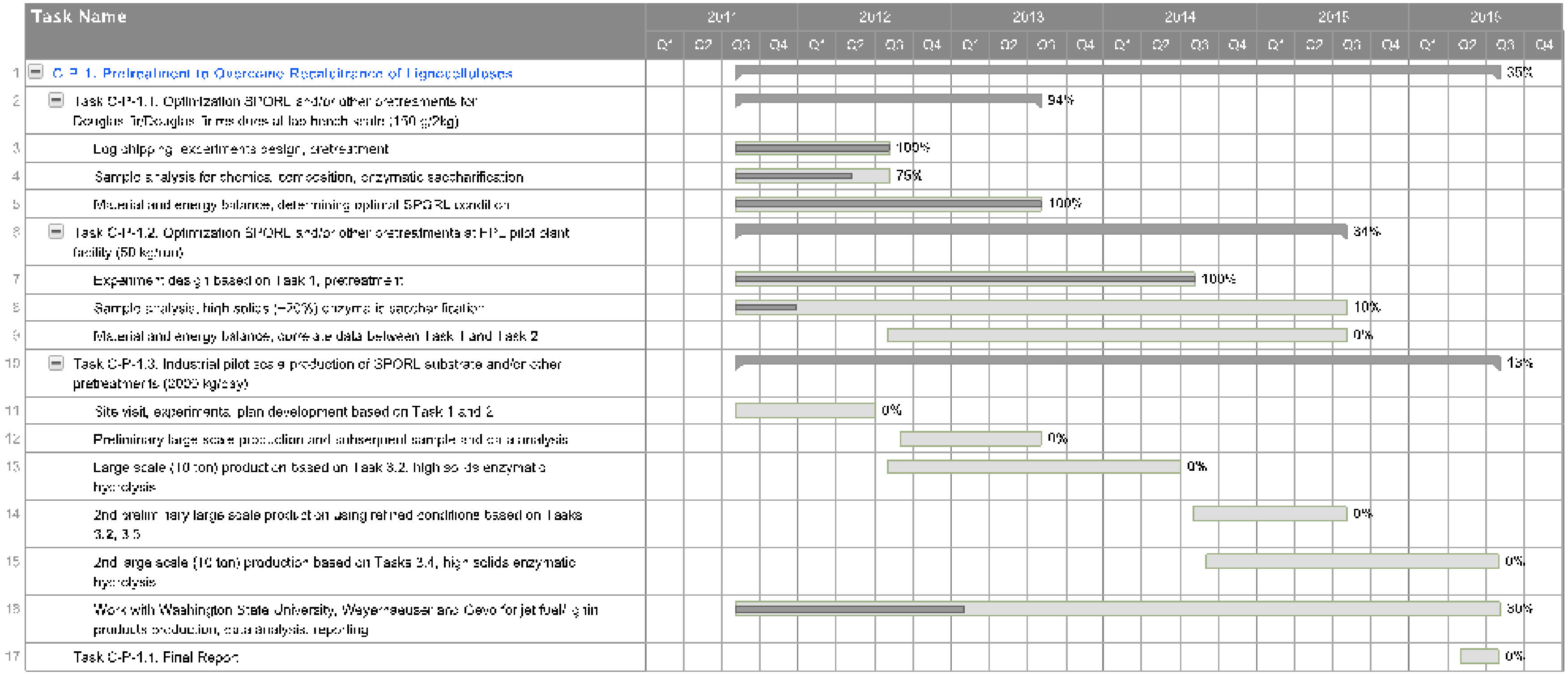
# FeedstockLogistics_Sessions



| | Task Name | |
|---|---|---|
| 1 | FL-2. Logistics Decision Support and Improvement | 26% |
| 2 | Task FL-2.1. Develop Biomass Recovery Coefficients for OR, WA, ID, MT | 65% |
| 3 | Regression model for biomass recovery as a function of timber strata, silvicultural prescription, harvesting system, feedstock specifications, merchantability specifications for species in NARA region | 0% |
| 4 | Task FL-2.2. Develop Moisture Management Strategies and Models | 50% |
| 5 | Physical and economic model for moisture management for species in NARA region | 0% |
| 6 | Task FL-2.3. Refine Collection and Transport Models for regional modeling | 60% |
| 7 | Decision support model for identifying most efficient collection and transport system based on residue location, specifications, and facility location | 0% |
| 8 | Task FL-2.4. Evaluate grinding and chipping production and costs to meet alternative feedstock specifications | 0% |
| 9 | Report describing comminution costs to meet alternative feedstock specifications | 0% |
| 10 | Task FL-2.5. Demonstrate and evaluate new trailer designs to improve transport efficiency | 0% |
| 11 | Public demonstration of new trailer technology | 0% |
| 12 | Evaluation report on trailer efficiency and improved forest access | 0% |
| 13 | Task FL-2.6. Evaluate health and safety procedures for any new work processes | 0% |
| 14 | Report on identification of need for new health and safety procedures and recommendation for new procedures | 0% |
| 15 | Task FL-2.7. Synthesis of Logistics Work and Final Report | 0% |
| 16 | Final report describing results of work | 0% |

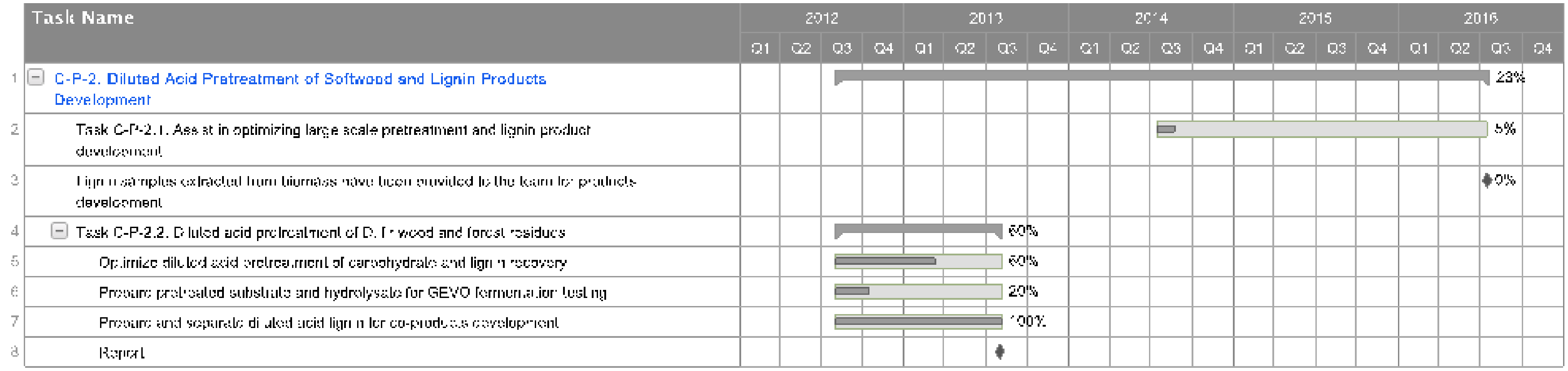
# Pretreatment_Zhu

NARA



|  | Task Name |  |
|---|---|---|
| 1 | C-P-1. Pretreatment to Overcome Recalcitrance of Lignocelluloses | 35% |
| 2 | Task C-P-1.1. Optimization SPORL and/or other pretreatments for Douglas fir/Douglas fir residues at lab bench scale (150 g/2kg) | 94% |
| 3 | Log shipping, experiments design, pretreatment | 100% |
| 4 | Sample analysis for chemical composition, enzymatic saccharification | 75% |
| 5 | Material and energy balance, determining optimal SPORL condition | 100% |
| 6 | Task C-P-1.2. Optimization SPORL and/or other pretreatments at FPL pilot plant facility (50 kg/run) | 31% |
| 7 | Experiment design based on Task 1, pretreatment | 100% |
| 8 | Sample analysis, high solids (~20%) enzymatic saccharification | 10% |
| 9 | Material and energy balance, correlate data between Task 1 and Task 2 | 0% |
| 10 | Task C-P-1.3. Industrial pilot scale production of SPORL substrate and/or other pretreatments (2000 kg/day) | 13% |
| 11 | Site visit, experiments, plan development based on Task 1 and 2 | 0% |
| 12 | Preliminary large scale production and subsequent sample and data analysis | 0% |
| 13 | Large scale (10 ton) production based on Task 3.2, high solids enzymatic hydrolysis | 0% |
| 14 | 2nd preliminary large scale production using refined conditions based on Tasks 3.2, 3.5 | 0% |
| 15 | 2nd large scale (10 ton) production based on Tasks 3.4, high solids enzymatic hydrolysis | 0% |
| 16 | Work with Washington State University, Weyerhaeuser and Gevo for jet fuel/lignin products production, data analysis, reporting | 30% |
| 17 | Task C-P-1.1. Final Report | 0% |

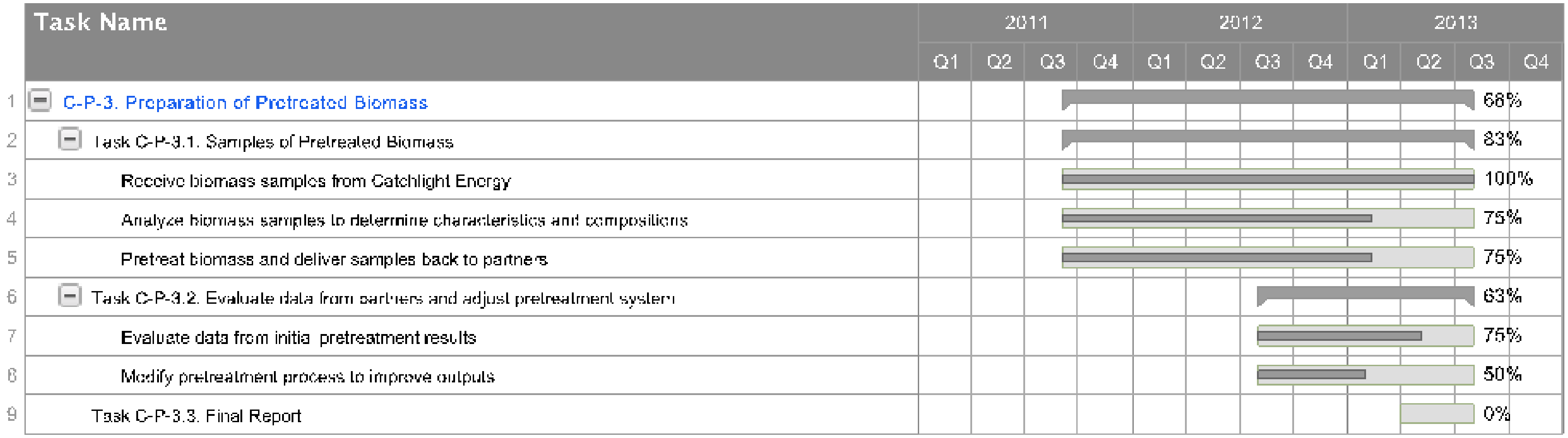
# Pretreatment_XZhang



|  | Task Name |
|---|---|
| 1 | ⊟ C-P-2. Diluted Acid Pretreatment of Softwood and Lignin Products Development |
| 2 | Task C-P-2.1. Assist in optimizing large scale pretreatment and lignin product development |
| 3 | Lignin samples extracted from biomass have been provided to the team for products development |
| 4 | ⊟ Task C-P-2.2. Diluted acid pretreatment of D. Fir wood and forest residues |
| 5 | Optimize diluted acid pretreatment of carbohydrate and lignin recovery |
| 6 | Prepare pretreated substrate and hydrolysate for GEVO fermentation testing |
| 7 | Prepare and separate diluted acid lignin for co-products development |
| 8 | Report |

# Pretreatment_Ahring

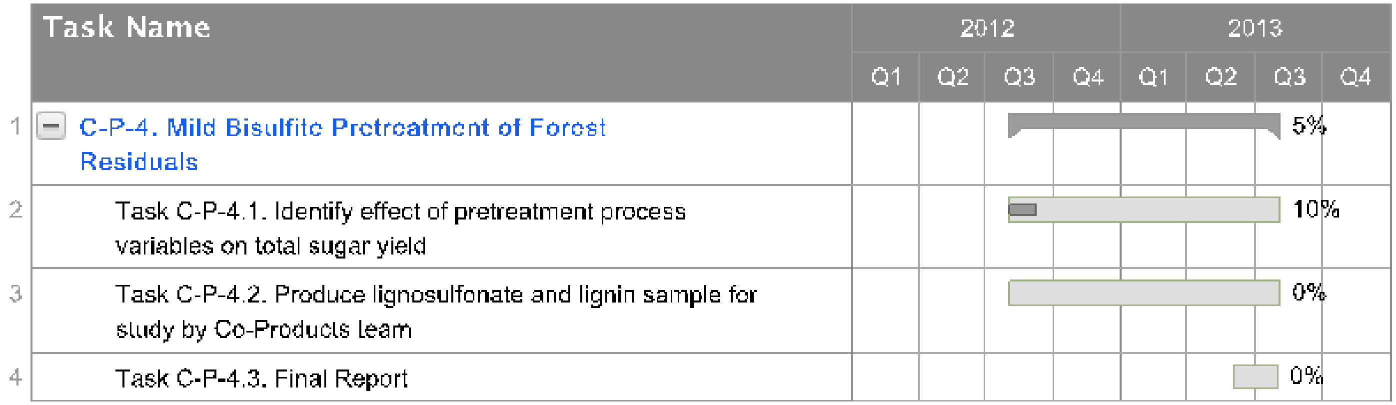
NARA



| | Task Name | |
|---|---|---|
| 1 | C-P-3. Preparation of Pretreated Biomass | 68% |
| 2 | Task C-P-3.1. Samples of Pretreated Biomass | 83% |
| 3 | Receive biomass samples from Catchlight Energy | 100% |
| 4 | Analyze biomass samples to determine characteristics and compositions | 75% |
| 5 | Pretreat biomass and deliver samples back to partners | 75% |
| 6 | Task C-P-3.2. Evaluate data from partners and adjust pretreatment system | 63% |
| 7 | Evaluate data from initia pretreatment results | 75% |
| 8 | Modify pretreatment process to improve outputs | 50% |
| 9 | Task C-P-3.3. Final Report | 0% |

# Pretreatment_Catchlight

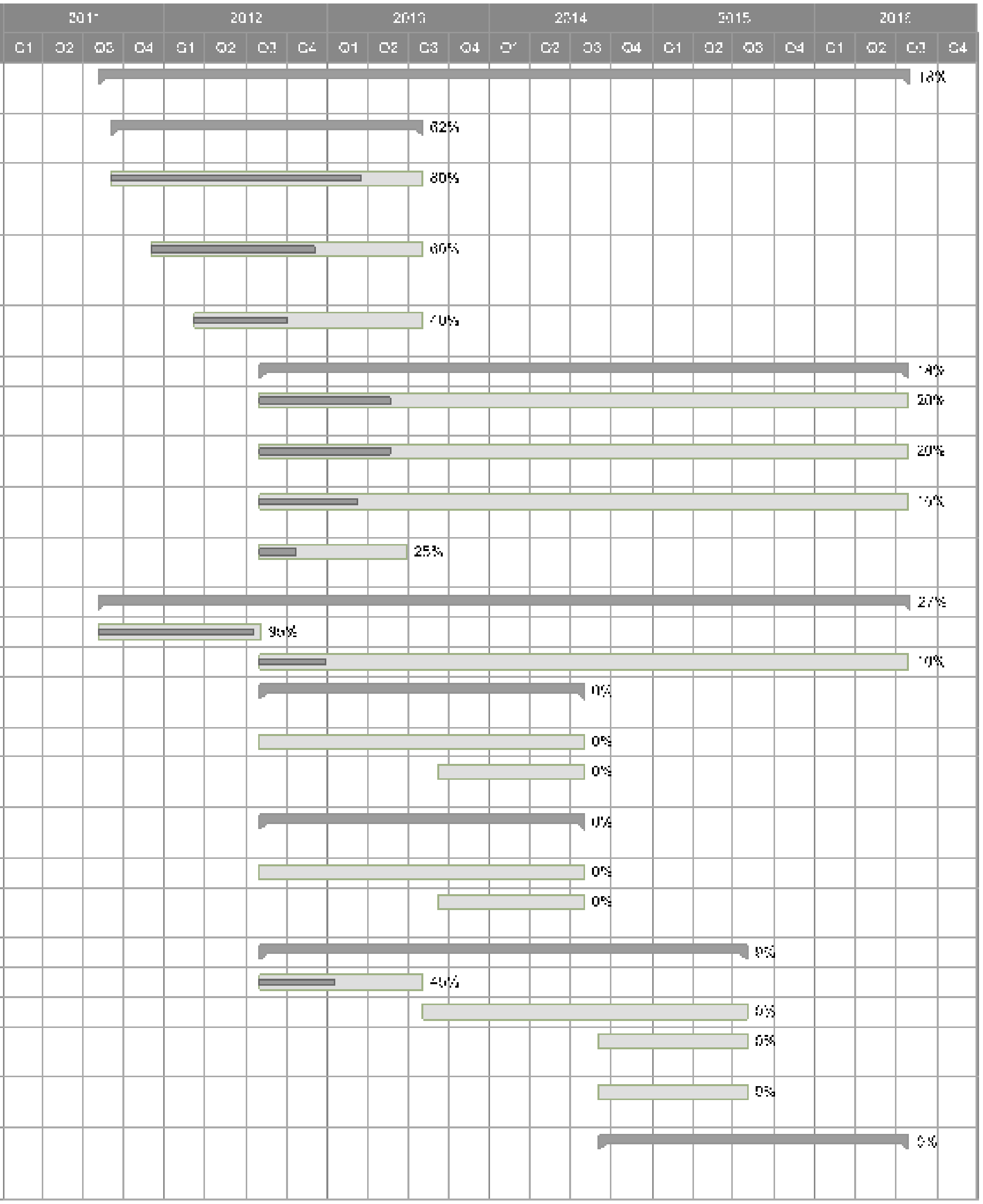
NARA

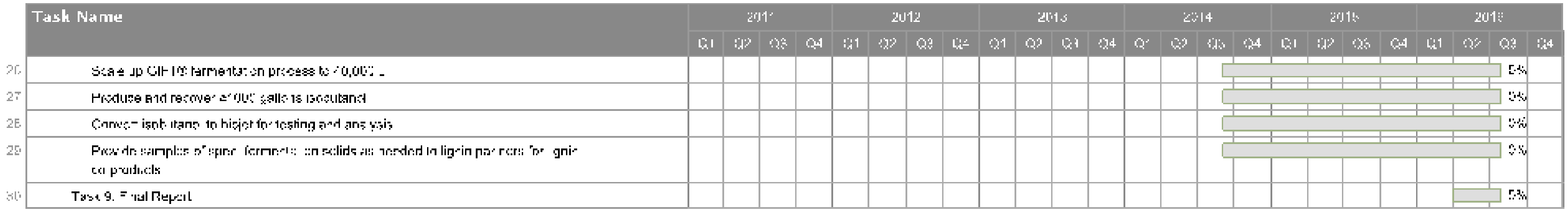


|  | Task Name | 2012 |  |  |  | 2013 |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |  |
| 1 | C-P-4. Mild Bisulfite Pretreatment of Forest Residuals |  |  | ▨ | ▨ | ▨ | ▨ | ▨ |  | 5% |
| 2 | Task C-P-4.1. Identify effect of pretreatment process variables on total sugar yield |  |  | ▨ | ▨ | ▨ | ▨ | ▨ |  | 10% |
| 3 | Task C-P-4.2. Produce lignosulfonate and lignin sample for study by Co-Products team |  |  | ▨ | ▨ | ▨ | ▨ | ▨ |  | 0% |
| 4 | Task C-P-4.3. Final Report |  |  |  |  |  | ▨ | ▨ |  | 0% |

# Conversion-AF_Gevo

| | Task Name |
|---|---|
| 1 | C-AF-1 Production of Lignocellulosic Isobutanol by Fermentation and Conversion to Biojet |
| 2 | Task C-AF-1.1 Characterize toxicity of a representative sample of pretreated woody biomass (Douglas Fir) for fermentation |
| 3 | Benchmark "fermentability index" assay which includes yeast growth and fermentation performance with pretreated/enzymatic digested woody biomass, in a combined sugar stream containing C5 and C6 sugars |
| 4 | Characterize samples from a single pre-treatment/enzymatic digestion condition from Task 1.1 in high resolution "fermentability index" (samples will meet criteria established for sugar yields and enzymatic digestibility) |
| 5 | Batch characterization for fermentation performance based on conditions established in Task 1.2 |
| 6 | Task C-AF-1.2 Adapt yeast biocatalyst to pretreated biomass hydrolysate |
| 7 | Batch characterization for fermentation performance fully hydrolyzed, pretreated feedstock based on conditions established in Task 1.3 |
| 8 | Evolutionary engineering to improve tolerance of biocatalyst to inhibitors present in pretreated biomass |
| 9 | Batch characterization for fermentation performance based on adapted yeast generated in Task 2.2 |
| 10 | Task C-AF-1.3 Produce isobutanol in a 1L batch fermentation from pretreated biomass sugars using the adapted yeast biocatalyst |
| 11 | Task C-AF-1.4 Economic assessment of wood to isobutanol / jet |
| 12 | Develop process economic model |
| 13 | Economic analysis of project data and results |
| 14 | Task C-AF-1.5 Produce isobutanol in 1L GIFT® fermentation from pretreated biomass sugars using the adapted yeast biocatalyst |
| 15 | Develop fermentation process parameters |
| 16 | Produce isobutanol at rate of 0.3 g/L/h, titer of 10 g/L, and yield of 40% of theoretical based on total fermentable sugars (glucose, xylose, mannose) |
| 17 | Task C-AF-1.6 Analysis of isobutanol produced to close mass balance and determine potential low level impurities |
| 18 | Analyze isobutanol for impurities |
| 19 | If needed, develop distillation/separation modifications to meet isobutanol specification before conversion to biojet |
| 20 | Task C-AF-1.7 Produce isobutanol in 20L GIFT® SSF fermentation from pretreated biomass |
| 21 | Design and build 20L GIFT Pilot Scale System |
| 22 | Develop fermentation process parameters |
| 23 | Produce isobutanol at rate of 0.5 g/L/h, titer of 70 g/L, and yield of >75% of theoretical based on total fermentable sugars (glucose, xylose, mannose) |
| 24 | Provide samples of spent fermentation solids at relevant scale to lignin partners for lignin co-products |
| 25 | Task C-AF-1.8 Produce ≥1000 gallons isobutanol from GIFT®-SSF fermentations at 40,000 L demonstration scale. Convert lignocellulosic isobutanol to ≥ 1000 gallons biojet for further testing |

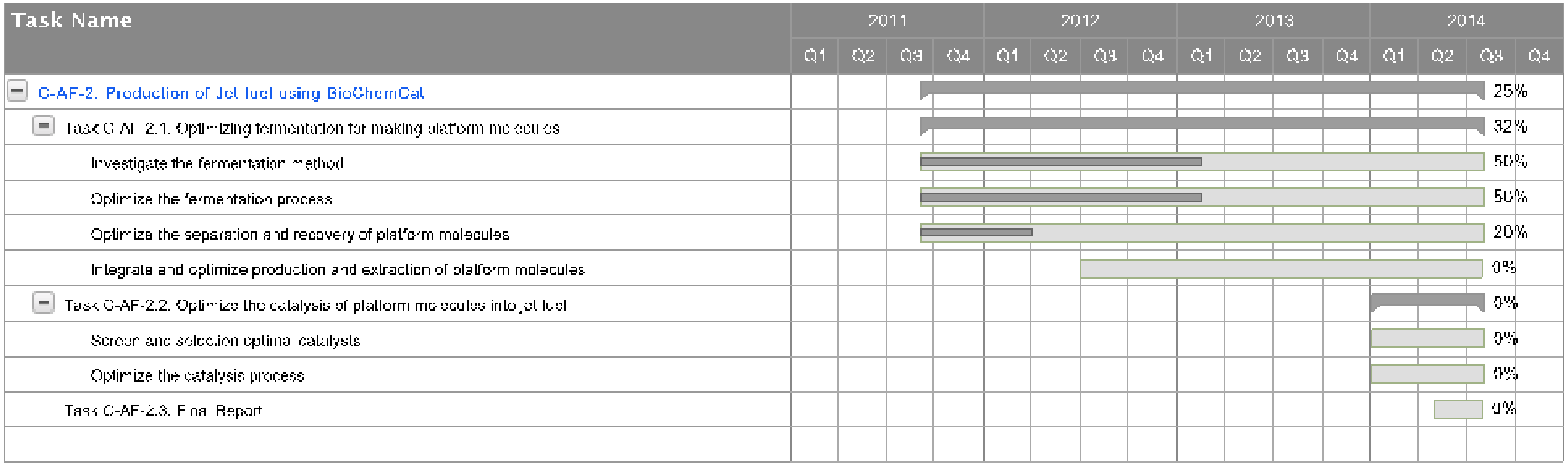




|  | Task Name |  |
|---|---|---|
| 26 | Scale up GIFT® fermentation process to 20,000 L | 0% |
| 27 | Produce and recover ≥1000 gallons isobutanol | 0% |
| 28 | Convert isobutanol to biojet for testing and analysis | 0% |
| 29 | Provide samples of spent fermentation solids as needed to lignin partners for lignin co-products | 0% |
| 30 | Task 9. Final Report | 0% |

# Conversion-AF_Ahring

NARA



| | Task Name | |
|---|---|---|
| 1 | C-AF-2. Production of Jet fuel using BioChemCat | 25% |
| 2 | Task C-AF-2.1. Optimizing fermentation for making platform molecules | 32% |
| 3 | Investigate the fermentation method | 50% |
| 4 | Optimize the fermentation process | 50% |
| 5 | Optimize the separation and recovery of platform molecules | 20% |
| 6 | Integrate and optimize production and extraction of platform molecules | 0% |
| 7 | Task C-AF-2.2. Optimize the catalysis of platform molecules into jet fuel | 0% |
| 8 | Screen and selection optimal catalysts | 0% |
| 9 | Optimize the catalysis process | 0% |
| 10 | Task C-AF-2.3. Final Report | 0% |
| 11 | | |

# NARA | GOAL TWO

August 2011 - March 2013 Cumulative Report

## VALUE-ADDED POLYMER AND CARBON PRODUCTS FROM LIGNIN

Northwest Advance Renewables Alliance

# Goal Two: 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, 1450 dry pounds of co-product residuals are produced (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 (Table 1; Task C-CP-2 each task progress is detailed in progress reports following this summary). The most common strategy for dealing with these residual solids is to recover their fuel value to assist in powering the plant. While this strategy remains as a potential, NARA researchers are developing new lignin-based products that provide a higher value than current commercial lignin use. Creating high-value products from the lignin-rich byproduct is essential to establishing a value-chain to improve profitability of the bio-refinery.

To meet this challenge, NARA's co-product residual research has progressed on multiple fronts. First, hydrolysis residuals were collected from the four pretreatment processes (SPORL, mild bisulfite (CLE), wet oxidation, and dilute acid), and evaluated for the lignin, carbohydrate and ash contents (Table 1; Task C-CP-2). Three methods were developed to isolate the lignin from spent sulfite liquors (SSL) — amine extraction, ultra-filtration, and calcium precipitation — and the lignin molecular weight was determined. (Table 2; Task C-CP-2)

Two promising applications are currently targeted for near-term use of the hydrolysis residuals. First, we are developing lignin-based activated carbon with a very high surface area. Laboratory procedures were developed to produce activated carbons (AC) with different surface areas and different types of porosity from hydrolysis residuals. The second application is for use as a viscosity modifier for concrete. Initial analyses have been completed for other applications include modifying the hydrolysis residuals to serve as a replacement for carbon black and use as an anti-oxidant for asphalt binder for roads. (Task C-CP-2)

A more long-term directive is to evaluate the use of co-product residuals as a component in bioplastics. The domestic U.S. market for foamed commodity thermoplastics is projected to reach 4 billion kg in 2013. Unfortunately, our initial attempts to form bioplastics using the lignin-rich solids generated from pretreated material were unsuccessful. An alternative approach is to use ball milled softwood lignin, which is a relatively purified lignin source. Using this feedstock, which is not produced in our process, miscible polymer blends were produced of methylated ball-milled softwood lignins (MBMLs) at 85% (w/w) levels with low-$T_g$ polymers. This approach has led to formulations for materials that approach 70 MPa in tensile strength. Ongoing work has introduced a wide range of *block*-copolymers with lignins of varied molecular weights to explore blends that lead to commercially valuable bioplastics. Successful approaches here will be transferred later to NARA lignin samples. (C-CP-1)

Our final lignin effort is aimed at partially depolymerizing the high molecular weight and recalcitrant form of lignin that results from the enzymatic hydrolysis process. The goal of producing partially depolymerized lignin (DPL) is to create building blocks for engineering high value polymers. In route to this approach, naturally occurring lignomers were evaluated for their use in epoxy. Eugenol was converted to an epoxy depolymerization. The partially depolymerized lignin was evaluated as a curing agent for epoxies. A third protocol, phenolation liquefaction, has been applied to hydrolysis lignin with the intent to generate lignin-based polyurethanes and phenolics. (C-CP-3)

Significant internal outputs to date for this team are listed below. Additional outputs are listed at the end of each progress report.

- Analysis shows that the lignin produced from the various pretreatments and post hydrolysis is significantly different from the traditional Kraft and sulfite lignin currently in the marketplace. The NARA lignins derived from various pretreatment protocols exhibit unique characteristics. Although analysis is ongoing, these unique lignin types present an exciting opportunity for use as feedstocks to generate novel lignin-based products with high potential economic return (Table 1; Task C-CP-2).

- A high porosity activated carbon can be made from NARA fermentation residual lignin. The techno-economic analysis of NARA activated carbon (AC) indicates a positive potential for this material. Using a conventional steam activation method, it predicts that the cost of producing AC will be $0.57/lb, including a transfer price of $0.145/lb to the iso-paraffinic kerosene (IPK) plant. Given an activated carbon selling price of $0.75/lb for mercury-emissions-control-grade and given a total capital cost estimated at $168,000,000, the internal rate of return (IRR) is calculated to be 22.5%. Furthermore, the market for such a grade is growing rapidly and would consume a major portion of the output of hydrolyzed residues from the IPK plant. CLE-HydR-derived carbon samples had significant elemental mercury adsorption capacities as shown in the Table 3. Task C-CP-3). The mercury adsorption capacity values were 95 and 88% of the adsorption capacity measured for a commercial standard carbon used for mercury adsorption, Norit Darco-Hg. The most significant result was that the carbonized/washed CLE-HydR materials were capable of performing nearly as well as the commercial carbon and the KOH-activated carbon without any physical or chemical activation, which may significantly reduce the cost of activated carbon production compared to competing products (Task C-CP-2).

- Lignin separated from the spent sulfite liquor of the SPORL and CLE (Mild Bisulfite) pretreatment methods display excellent concrete dispersion properties. Initial results show a two-fold increase in effectiveness over commercially available dispersants (Table 3; Task C-CP-2).

- Formulations for lignin-based thermoplastics have been achieved with suitable block copolymers when using model lignin compounds (Figures 1-3, Task C-CP-1).

- Experimental results validated our hypothesis that partially depolymerized lignin (PDL) with good solubility and dispersion characteristics can be converted into effective building blocks for engineering polymers (Task C-CP-3).

# Outcomes/Impacts

Events that cause a change of knowledge, actions or conditions for stakeholders and society.

- None to report

# Training

| **Name** | **Affiliation** | **Role** | **Contribution** |
|---|---|---|---|
| Yi-ru Chen | Univ of Minnesota | Res. Assoc. | Lignin isolation and characterization |
| Yun-Yan Wang | Univ of Minnesota | Grad. Stud. | Lignin-based plastic formulations |
| Jianglei Qin | WSU, CMEC | Post-doc | Eugenol –derived epoxies, developing BCD methods, developing lignin epoxies and curing agent |
| Junna Xin | WSU, CMEC | Post-doc | Developing hydrogenolysis method |
| Kun Huang | WSU, CMEC | Visiting Student | developing lignin epoxies and curing agent |
| Jinwu Wang | WSU, CMEC | Research Asst Professor | Investigating potential resin applications |

# Resource Leveraging

None to report

# CONVERSION

## Co-products Team

### Task C-CP-1: Formulations for Co-product Lignin-based Plastics

| Key personnel | Affiliation |
|---|---|
| Simo Sarkanen | University of Minnesota |

### Task Description

The scale of biofuels production from lignocellulosic biomass to be implemented by 2030 will give rise annually to more than 200 million tons of lignin derivatives. Here, systematically reliable means are being developed for converting such co-product lignins into thermoplastics that are much like polystyrene mechanically; the most suitable of these are to be transformed into foams for the thermal insulation of residential buildings. Sources of co-product lignins will ultimately be from our NARA partners at the scales needed. Apart from reducing the heating/cooling costs for buildings, the value added to the co-product lignins will improve the economic viability of biorefining processes. The advantage of designating thermally insulating foams as early applications of lignin-based plastics is that the mechanical properties of such materials will not have to meet demands as stringent as, for example, engineering plastics. The domestic U.S. market for foamed plastic is projected to reach 4 billion kg in 2013.

It is certainly possible to plasticize simple lignin derivatives by, for example, blending them with miscible low-$T_g$ polymers. It has been demonstrated at the University of Minnesota that methylated and ethylated softwood kraft lignins (which themselves can be similar to polystyrene in tensile behavior) are readily plasticized when blended at 25–35% levels with poly(ethylene glycol) or certain main-chain aliphatic polyesters. In a preliminary demonstration, it has proven possible to convert homogeneous blends of methylated softwood kraft lignins with 20% (w/w) low-$T_g$ aliphatic polyesters into uniform 0.10 g cm$^{-3}$ foams using chemical blowing agents at temperatures approaching 160 °C.

The ultimate goal of the present project is the conversion of co-product lignosulfonates and dilute-acid lignins from softwood pretreatment processes into useful thermoplastic polymer blends with high (75 – 85% w/w) lignin contents. The lignosulfonates have to be methylated prior to incorporation into suitable blend formulations, while the dilute-acid lignins will be analogously employed with and without derivatization. It is anticipated that the latter will lead to the creation of the first generation of 85% w/w dilute-acid lignin-based plastics.

At the time of writing, attempts to convert co-product dilute-acid lignins and ligninsulfonates to thermoplastics have not succeeded. The dilute-acid lignins provided have either been of too low molecular weight or possessed too high carbohydrate content. The methylated ligninsulfonates, on the other hand, readily form cohesive materials, but the casting conditions employed have generated voids within the materials produced for reasons that remain to be elucidated. Thus, attention has been preliminarily focused upon blends of methylated native ball-milled softwood lignins for the purposes of establishing realistic expectations for the mechanical properties of plastics based on such starting materials. These experiments have shown considerable promise, and the new blend formulations will be translated to co-product dilute-acid lignins and ligninsulfonates once the boundaries of these next-generation native lignin-based plastics have been delineated.

### Task C-CP-1.1 Biorefinery coproduct lignins

This project is dedicated to developing reliable means for converting biorefinery lignins into homogeneous thermoplastic polymer blends with mechanical properties similar to those of polystyrene. The co-product lignins isolated as a result of pretreating softwoods for saccharification purposes need to be purified, fractionated and derivatized prior to blending with low-$T_g$ polymers to produce plastics. The most appropriate candidates in the present context are those formed as a result of bisulfite or dilute-acid pretreatment. It is essential that any samples to be investigated for thermoplastic formulation development be polymeric rather than oligomeric. A reference point has been created for comparing the raw materials from any particular lignocellulosic source upon which different lignin-based plastics are to be based. Accordingly, three contrasting lignin preparations have been methylated to develop blend formulations for next-generation lignin-based plastics. The lignin derivatives included a Jack-pine native ball-milled lignin, a high (>10 k) molecular weight fraction from a commercially available ligninsulfonate, and a Douglas fir lignin sample alkali-extracted after dilute-acid pretreatment and cellulase-catalyzed saccharification of steam-exploded wood.

### Task C-CP-1.2 Plasticizers for lignin-based polymeric materials

In this study, the most promising formulations will be converted into foams capable of acting as efficient insulation materials. The advantage of designating thermally insulating foams as early applications of lignin-based plastics is that the mechanical properties of such materials will not have to meet demands as stringent as, for example, engineering plastics. For this purpose, all three kinds of methylated lignin derivatives will be plasticized with miscible low-$T_g$ polymers analogous to those previously employed.

This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.

### Task C-CP-1.3 Processability of lignin-based plastics

We have carried out mechanical testing and thermal analysis of several lignin-based thermoplastic blends. As described in Task Progress, the mechanical properties of the thermoplastics that have been produced are extremely promising. As far as thermoplastic processability is concerned, strain-hardening is considered to be an important feature, especially in regard to reducing foam density. The extensional viscosimetric behavior of each series of methylated lignin-based blends will be examined as a function of low-$T_g$ plasticizing polymer content between 0 and 35% (w/w). These studies will be focused on how strain-hardening varies with the relative strengths of the intermolecular interactions between the blend components. It is anticipated that strain-hardening will be enhanced when these interactions are stronger: the associated lignin complexes are partially dismantled under such circumstances so that there should be a greater incidence of chain entanglement between the peripheral components in the huge supramacromolecular assemblies that make up these materials. To the best of our knowledge, this would be the first time that any extensional viscosimetric studies are carried out with lignin-based polymer melts.

Most commercial foams are produced through continuous extrusion processes. Nevertheless, batch processing offers several advantages. It requires only small quantities of material and allows operating conditions such as temperature and pressure to be more flexibly controlled. For example, the saturation pressure and temperature affect the amount of blowing agent dissolved in the polymer matrix and hence these parameters influence the nucleation rate. The growth of nucleated cells is affected by the viscosimetric behavior of the polymer matrix, which in turn can be modulated by the temperature of the foaming medium. In this connection, specimens of precise composition and processing history can be prepared and tested with high reproducibility.

## Task Progress

### Activities and Results

In its first chapter, the present research project has sought to determine what goals should be set for improvements in the mechanical properties of next-generation lignin-based plastics. In this context, miscible blends of methylated ball-milled softwood lignins (MBMLs) at 85% (w/w) levels with low-$T_g$ polymers have led to formulations for materials that approach 70 MPa in tensile strength. Few polymeric materials in common use can exceed such lignin-based plastics in engineering stress, and thus the frontier of next-generation applications for co-product lignins has been reached.

This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.

The impact of the lower molecular weight methylated components in these materials can be seen through comparisons between the blends of the parent MBML and higher molecular weight lignin fraction that contain 15 – 20% EBE. Absence of the lower molecular weight lignin components in these blends clearly results in lower tensile strength and greater brittleness. Yet, the respective blends of the parent MBML and higher molecular weight fraction with 25 – 30% (w/w) EBE exhibit very similar tensile behavior (Figure 1) because the predominant lignin species in these materials are associated complexes rather than individual molecular components.

This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.

For comparative purposes, the effects of low-$T_g$ polyesters as blend components in MBML-based plastics were also investigated. Thus, in Figure 3 the consequences of 15% (w/w) levels of poly(ε-caprolactone) (PCL) are compared with those of somewhat higher (25 – 30% (w/w)) proportions of poly(butylene adipate) (PBA), poly(ethylene succinate) (PES) and poly(trimethylene succinate) (PTMS). Remarkably, 15% PCL contents in these materials result in tensile behavior not far removed from that observed with MBML-based blends containing 15% EBE (Figure 1). This is noteworthy because PCL at these levels is not fully miscible with MBML. On the other hand, 30% (w/w) PBA is similar to 25% EBE in its impact on MBML blends. In contrast, 30% (w/w) PES and PTMS produce MBML-based plastics with lower ductility and tensile strength than observed with the corresponding amount of PBA.

This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information. Concomitantly, it should be possible to approach these goals fairly closely through appropriate formulations with homopolymers in binary or ternary blends.

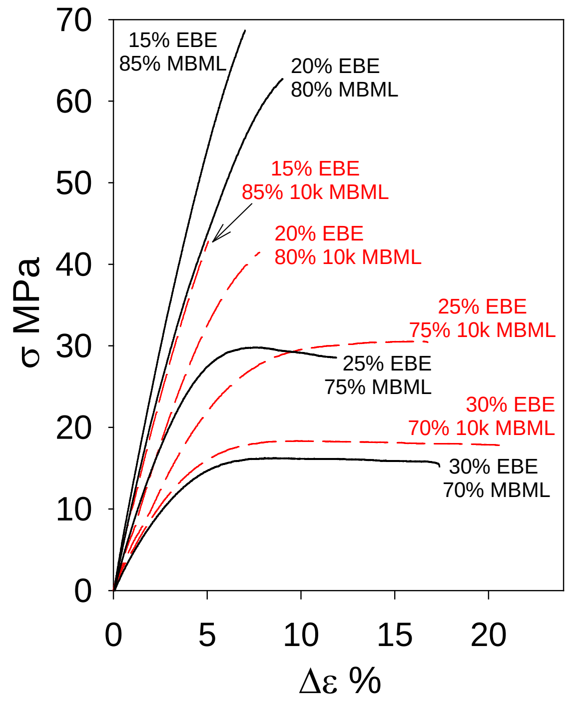


**Figure 1.** This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information. The 10k MBML in the higher molecular weight lignin-based blends was prepared by extensive ultrafiltration prior to methylation through a 10,000 nominal molecular weight cutoff membrane in aqueous 0.1 M NaOH. (Stress-strain curves were determined with an

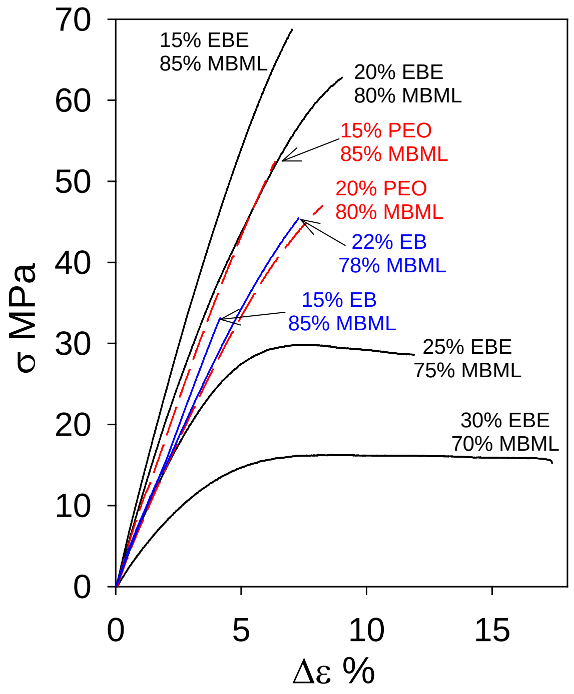


**Figure 2.** Tensile behavior of parent methylated ball-milled softwood lignin (MBML) in blends with poly(ethylene oxide) (PEO), This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.

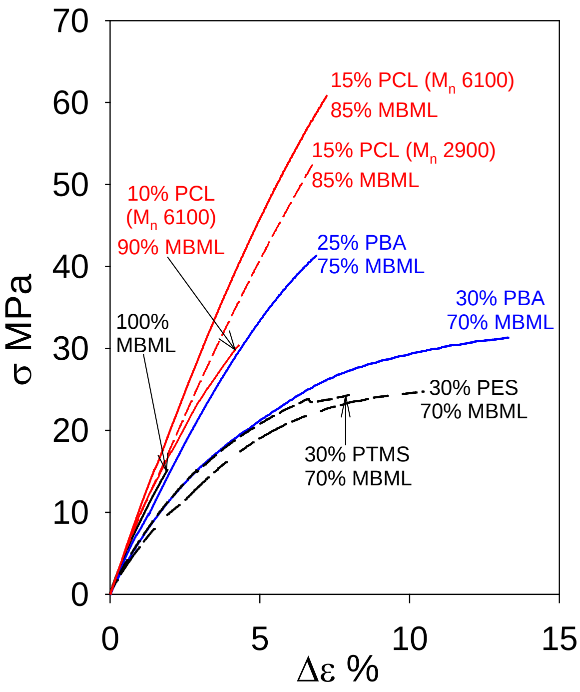


**Figure 3.** Tensile behavior of parent methylated ball-milled softwood lignin (MBML) in blends with poly(ε-caprolactone) (PCL), poly(butylene adipate) (PBA), poly(ethylene succinate) (PES) and poly(trimethylene succinate) (PTMS).

## Recommendations/Conclusions

The methylated ball-milled softwood lignin-based polymeric materials created for reference purposes have confirmed that the kinds of lignin derivatives produced from future biorefineries should be amenable to the development of useful next-generation lignin-based plastics. The tensile properties of the methylated native lignin-based blends with the [This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.], the PEO homopolymer and the PCL homopolyester are striking in their similarity. Accordingly, there is little doubt that simple softwood lignin derivatives are valuable starting materials for producing renewable biodegradable plastics. A search for new miscible blend components has been initiated to develop native-lignin-based material formulations that are more ductile without incurring reduced strength properties. Routes to the best possible binary and ternary homopolymer formulations will be investigated in attempts to replicate the properties of the most promising MBML-based blends with [This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.]. Such new plastics will serve as a foundation for developing analogous formulations for NARA co-product dilute-acid lignins and ligninsulfonates.

## Physical and Intellectual Outputs

### Research Presentations

S.Sarkanen, Y.-r. Chen, Y.-Y. Wang. Formulations for Coproduct Lignin-based Plastics. Oral presentation at NARA Coproducts Team Meeting, Spokane, WA, August 22, 2012.

Y.-Y. Wang, S.Sarkanen, Y.-r. Chen. Formulations for Coproduct Lignin-based Plastics. Oral presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Y.-Y. Wang, S.Sarkanen, Y.-r. Chen. Formulations for Coproduct Lignin-based Plastics. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

S.Sarkanen, Y.-r. Chen, Y.-Y. Wang. Formulations for Coproduct Lignin-based Plastics. Oral presentation at NARA Coproducts Team February 2013 Quarterly Meeting, Spokane, WA, February 27, 2013.

## C-CP-2: Conversion of Lignin to High Value, Large Market Products

| Key personnel | Affiliation |
|---|---|
| John Westland* | Weyerhaeuser |
| Davis Fish | Weyerhaeuser |
| Carter Fox | Weyerhaeuser |
| Ian Dallmeyer | Weyerhaeuser |

*retired from Weyerhaeuser

### Task Description

In this project, the sources of lignin will be from one or more processes identified in the NARA project and from one or more steps in the process. These processes are being used to supply the carbohydrates for the fermentation to isobutanol for fuel production. A key component of the project is to create high value products from the residual lignin. The lignin produced from the various pretreatment processes is significantly different from traditional Kraft lignins. The first part of the work was to characterize the lignin with respect to molecular weight, G/S ratio, hydroxyl content, thermal properties, and other properties thought important by the Co-Products Team. This information is essential to developing suitable end-uses for the various lignins.

Originally there were only two product areas that were targeted. The first was the conversion of the lignin to a high value activated carbon (AC), with a very high surface area. It was found that with recent EPA requirements that coal burning facilities must reduce their mercury pollution, the market for AC designed to clean up flue gas emission has exploded. Our primary goal has become to develop an AC that will be effective in mercury clean-up. The market size for this application is so large that it should consume a significant amount of the lignin produced. Furthermore the value generated should be significant. Additional applications might include some very high-end AC's for uses such as in supercapacitors and batteries. This is a new and emerging market where there is a need for a sustainable alternative to current materials and would be used in industries where the generation of electricity is variable (wind generators, electric vehicles).

The second initially-targeted area was the non-traditional use to convert the lignin to a nano-lignin where it would be substituted for carbon black. However, we have decided to first look at the possibility of replacement or partial substitution of carbon black with conventional lignin in the areas of automotive tires, hoses and belts. Another possibility is the conversion of lignin directly to carbon black.

We are now proposing to also evaluate lignin as an anti-oxidant for asphalt binder for roads and evaluate the effectiveness of the lignin in the traditional area of cement additives.

### Activities and Results

The evaluation of hydrolysis residual (HydR) lignins from the pre-treatment processes – Catchlight Energy (CLE), SPORL, wet oxidation (WetOx) and dilute acid (DA) – was completed. Three methods were developed to isolate the lignin from spent sulfite liquors (SSL) – amine extraction, ultra-filtration, and a novel calcium precipitation method. CLE and SPORL SSL's and HydR's had moderate levels of sulfur arising from the pulping chemicals while the WetOx and DA HydR's exhibited background levels of sulfur since there were no sulfur-containing pulping chemicals used.

Table **1** summarizes the HydR results. CLE and SPORL have high ash levels from the residual salts from the pulping chemicals compared to WetOx and DA HydR's levels. The carbohydrate to lignin ratio, which eliminates the dilution effect of the ash for the WetOx and DA residuals is almost double that of the CLE and SPORL. Additional washing of the WetOx residuals had little effect indicating the absence of soluble sugars. Table **2** shows that the molecular weight (MW) for the SPORL HydR is significantly lower than the CLE. Slight differences in the CLE process conditions appear to impact the MW's.

Laboratory procedures were developed to produce activated carbons (AC) from hydrolysis residuals with different surface areas and different types of porosity. The CLE HydR's (as is) were heated to 800 °C under a nitrogen atmosphere. The surface area was 250 $m^2/g$ with a microporous structure. The same material was also acid-washed and the surface area was 450 $m^2/g$ and showed mesoporosity. Adding between 1 and 3 parts potassium hydroxide to 1 part HydR, the surface area generated varied from 1330 to 2200 $m^2/g$ with a highly microporous structure. CLE-HydR-derived carbon samples had significant elemental mercury adsorption capacities as shown in the Table 3. The mercury adsorption capacity values were 95 and 88% of the adsorption capacity measured for a commercial standard carbon used for mercury adsorption, Norit Darco-Hg. The most significant result was that the carbonized/washed CLE-HydR materials were capable of performing nearly as well as the commercial carbon and the KOH-activated carbon ***without any physical or chemical activation***, which may significantly reduce the cost of activated carbon production compared to competing products. A TEA was developed for production of AC from HydR. Using a conventional steam activation method, it predicts that the cost of producing AC will be $0.57/lb, including a transfer price of $0.145/lb to the iso-paraffinic kerosene (IPK) plant. Given an activated carbon selling price of $0.75/lb for mercury emissions control grade and given a total capital cost estimated at $168,000,000, the internal rate of return (IRR) is calculated to be 22.5%. Furthermore, the market for such a grade is growing rapidly and would consume a major portion of the output of HydR from the IPK plant.

Using commercially available lignosulfate salts and Kraft lignin, we evaluated partial substitution of these salts for carbon black in rubber. Total replacement of all the carbon black gave very poor results while partial substitution did have some positive effects – especially the rubber modulus with the sodium salt. The cure times increased with the addition of the Kraft lignin and the calcium salt. However, the addition of sodium salt seemed to have little effect on the cure time or may have actually reduced it slightly.

A positive effect was seen from the addition of 3% CLE-HydR to asphalt with regards to offering protection against oxidation. (See Figure 1.) Also, the CLE-SSL lignin was shown to be superior to other commercially available lignosulfonate salts as a viscosity modifier for cement (See Table 4).

Table 1: Summary of Results for Hydrolysis Residual Lignins

| | Total Carbohydrate wt. % | Total Klason Lignin wt. % | Ash wt. % | Total wt. % | Carb: Lignin Ratio |
|---|---|---|---|---|---|
| CLE-A | 20.6 | 69.8 | 7.80 | 98.2 | 0.295 |
| CLE-B | 19.4 | 70.1 | 7.35 | 96.8 | 0.277 |
| SPORL | 22.5 | 70.6 | 5.73 | 98.9 | 0.319 |
| SPORL- Washed | 19.6 | 70.2 | 5.89 | 95.7 | 0.279 |
| Wet Ox | 39.0 | 56.8 | 2.02 | 97.8 | 0.687 |
| Wet Ox - Washed | 38.1 | 58.3 | 1.93 | 98.3 | 0.653 |
| Dilute Acid | 33.4 | 66.2 | 1.99 | 101.6 | 0.505 |

Table 2 Molecular Weights of SSL Lignins as Measured by SEC-MALS

| Sample | $M_n$ (kDa) | $M_w$ (kDa) | PDI ($M_w/M_n$) |
|---|---|---|---|
| CLE A | 16.6 ± 0.3 | 24.1 ± 0.4 | 1.4 ± 0.1 |
| CLE B | 29.7 ± 0.7 | 43.0 ± 1.0 | 1.5 ± 0.1 |
| SPORL | 3.0 ± 0.2 | 4.2 ± 0.3 | 1.4 ± 0.2 |

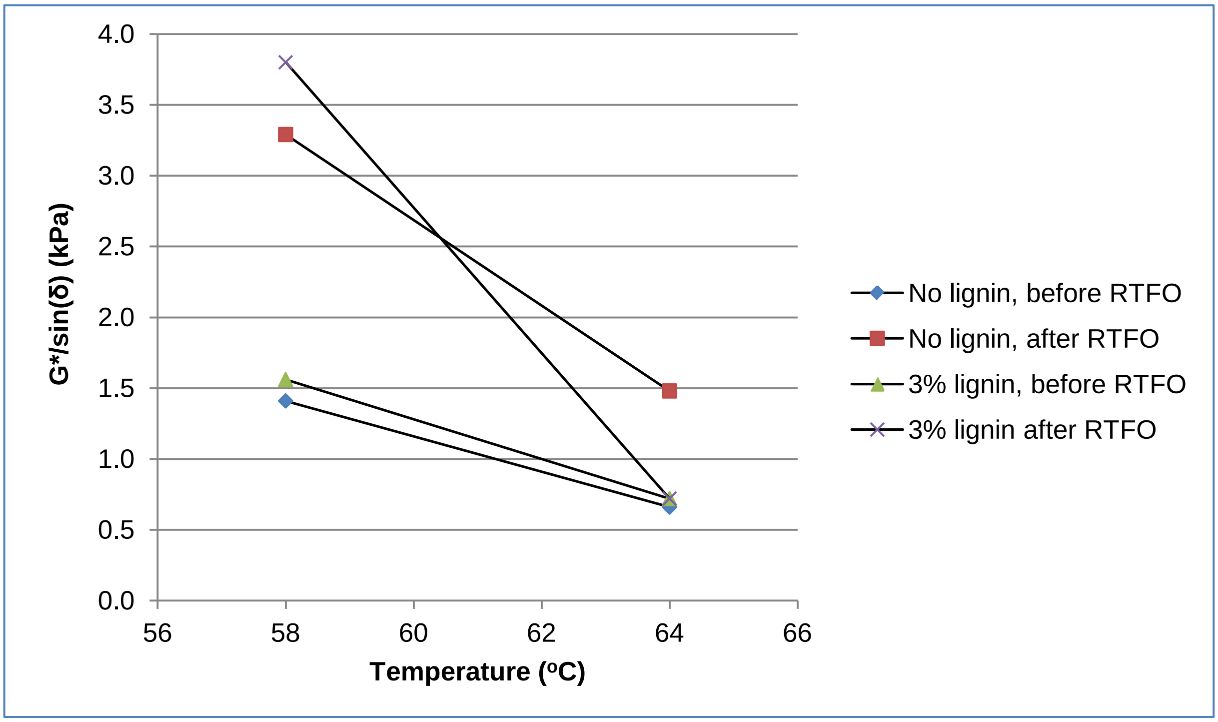


Figure 1: Mechanical Properties of Asphalt Containing 3% Lignin as a Function of Temperature (G* is the complex dynamic shear and δ is the phase lag between stress and strain.)

Table 3: Equilibrium vapor phase elemental mercury adsorption capacities of CLE-HydR-derived carbons prepared at 800°C, with (KOH:CLE-HydR, 1:1) and without KOH activation (CLE-HydR).

| Sample | Equilibrium adsorption capacity $\mu$g Hg/g carbon (@ 50 $\mu$g/Nm$^3$) |
|---|---|
| CLE-HydR, 800°C | 1415 |
| KOH:CLE-HydR, 1:1, 800°C | 1605 |
| Darco-Hg | 1680 |

Table 4: Effect of Various Lignosulfonates on Freshly Mixed Cement Viscosity as Measured by ASTM C 1437-07," *Standard Test Method for Flow of Hydraulic Cement Mortar".*

| Lignosulfonate Sample | Measured Flow (%) |
|---|---|
| Control | 68.1 |
| Control | 65.2 |
| CLE A | 123.3 |
| CLE B | 125.6 |
| Ultrafiltered CLE A | 120.7 |
| Ultrafiltered CLE B | 120.6 |
| SPORL SSL | 120.9 |
| Control | 69.0 |
| Georgia Pacific L - CN | 84.4 |
| Georgia Pacific L - 100 | 78.3 |
| Georgia Pacific L - 458 | 88.0 |

## Recommendations/Conclusions

### I. Evaluation of Lignins from the Pre-Treatment Processes

All the analyses show there are significant differences among lignins from different pretreatment processes – some expected, some unexpected. Sulfur may have a beneficial effect on mercury adsorption from flue gas and this hypothesis will have to be studied more. When taking into account the level of sulfur on the total analysis, nothing remarkable is seen regarding the carbon, hydrogen, and nitrogen levels.

From an end-use perspective, we don't have sufficient data to say whether these high levels of carbohydrates will have a negative impact on the end-uses being investigated by Weyerhaeuser. This point needs to be evaluated next. However, it is clear that high carbohydrate levels remaining after pretreatment will have a significant impact on the economics of the biofuel production. The differences in molecular weights among CLE and SPORL SSL lignins show that choice of pretreatment affects lignin molecular weight. Interestingly, even subtle differences between batches using CLE pretreatment produced lignosulfonates with different molecular weights. More research on the relationship between pretreatment conditions and lignin molecular weight is needed. Furthermore, NMR analyses showed major differences between the SSL's. More analysis will have to be done to verify these findings.

### II. Evaluation of End-Uses for Lignins

Production of activated carbons is technically feasible and represents a promising opportunity for valorization of the lignin-rich residual stream from the NARA biorefinery. Since market studies show world consumption of activated carbon is expected to increase from 1.2 million metric tons (Mt) in 2012 to 2.3Mt in 2017, and there will be coal precursor shortages in China, we intend to strongly pursue this use for lignin. Chemical activation with alkali metal hydroxides can produce carbons with a high degree of adsorptive capacity, but may be too expensive to implement at the scale envisioned for the NARA biorefinery. A reasonable alternative to chemical activation would be to use a standard steam activation method – the most common method for producing activated carbon on an industrial scale. It is expected that steam activation would produce an activated carbon that would be cost effective and match current market needs. We will be looking at this method next.

The next step in proving the potential of profitable activated carbon production is to obtain more detailed information on the range of AC products that can be produced from NARA residual streams and compare the cost of production at the relevant scale with the potential selling prices for different applications. Mercury emissions and water treatment are the largest scale applications for activated carbon and require a low-to-medium grade product with moderate selling price. To address these markets we propose to first thoroughly investigate the properties of carbonized lignin residuals without any additional activation to determine whether an inexpensive process can produce AC materials with suitable performance. Concurrently, steam activation of carbonized chars will be investigated to generate medium grade activated carbons for these large markets. Furthermore, emerging markets in energy storage (electrochemical capacitors, batteries, gas storage) also offer exciting opportunities for higher grade carbons which will likely be more costly to produce, but may also bring a higher selling price.

More work is needed to confirm any beneficial effect of lignin addition to asphalt binder, although Figure **1** does show a positive effect on the oxidative aging of the binder from the addition of the CLE-HydR. The binder exhibited a greater degree of thermal softening when the temperature was increased from 58-64°C with the addition of CLE-HydR, indicates a lower degree of oxidative degradation of the binder during simulated aging in the RTFO. More testing is being planned for year 3, but will have a lower priority than our activated carbon. The same goes for the lignin in rubber work.

The largest current market application for lignosulfonates is as an ingredient in concrete admixtures to help improve concrete workability before setting. The large difference between the CLE SSL lignin and the commercial grades, require further investigation. Combined with using the HydR for AC and the SSL for cement should present a high value for these by-products of the bio-fuel production.

## Physical and Intellectual Outputs

### Physical

- NARA pretreatment lignins have been characterized.
- A preliminary techno-economic analysis for activated carbon production from lignin has been accomplished.
- Preliminary data on the porosity and effectiveness of activated carbon derived from NARA residuals has been generated.

## Research Presentations

Fox, S.C., and D. Fish. 2012. Isolation and characterization of NARA lignins. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Fox, S.C. and D. Fish. Isolation and characterization of NARA lignins. Poster presentation at the Northwest Bioenergy Research Symposium, Seattle, WA, Nov 13, 2012.

Fox, S.C. and D. Fish. Isolation and characterization of NARA lignins. Poster presentation at Weyerhaeuser Technology Poster Session, Federal Way, WA, Dec 19, 2012.

Fox, S.C. Jet Fuel – And Other Products – From the Forest with NARA. Oral presentation at Oregon State University Dept. of Wood Science and Engineering Graduate Seminar, Corvallis, OR, Mar 6, 2013.

Fox, S.C. and D. Fish. Characterization of Lignin from the NARA Project and Conversion to New Products. Oral presentation at the American Chemical Society National Spring Meeting, New Orleans, LA, Apr 11, 2013.

# Task C-CP-3: Novel Engineering Polymers from Lignin-Derived Building Blocks

| Key personnel | Affiliation |
|---|---|
| Jinwen Zhang | Washington State University |
| Michael Wolcott | Washington State University |

## Task Description

Using lignin for polymer materials has received extensive investigations from academia and industry. However, neither the direct use of lignin as polymeric component nor the use of depolymerized lignin as a monomeric feedstock for polymer materials have achieved significant progress to date. Currently, commercially available lignin is mainly limited to the Kraft lignin (KL) and sulfonated lignin (lignosulfonate). KL and lignosulfonate are recovered from the spent pulping liquids of their respective pulping processes and are available in various product forms. While lignosulfonates are mainly used as industrial dispersants, KL has far fewer practical applications. Nonetheless, in recent years KL has received tremendous interest in polymer applications. As our nation strives to advance the technology of lignocellulosic biorefinery, a huge amount of hydrolysis lignin is expected to be available.

Lignin-to-chemical conversion is a highly desirable approach in lignin utilization and could potentially produce many important aromatic chemicals including intermediate monomeric feedstock. Scientists are striving to explore various technologies to selectively cleave lignin for desirable chemicals. Meanwhile, plant scientists and biochemists also seek means to interrupt the normal biosynthesis of lignin and harvest the precursor chemicals directly. While these efforts may eventually result in significant progress and advance the related sciences, they are *not likely* to achieve breakthrough technologies any time soon.

As seen in the growing number of scientific publications, the presence of both phenolic and alcohol hydroxyls makes lignin an attractive substance to directly incorporate into existing thermosetting resins as a reactive ingredient or extender. *However, compatibility remains the major issue in these applications.* Similar compatibility issues are also present when lignin is used as volume filler for thermoplastic polymers. The poor compatibility between lignin and other systems is rooted in its highly branched molecular structure, which makes it neither miscible with nor accessible to others for good interactions. In addition, lignin as a base material for thermoplastics is another important application but still faces many processing problems.

Complete lignin depolymerization is an energy-negative process aimed at deconstructing what nature has constructed. Instead, i*ncreasing the use of and adding value to the lignin polymer that nature has already provided is more attractive for the chemical industry*. ***In this project, we propose to develop new technologies for the preparation of engineering polymers from hydrolysis lignin and to explore the applications.*** The characteristic structure of lignin makes lignin insoluble in most organic solvents and hinders the access of hydroxyls for modification reactions. As indicated above, to completely disintegrate the lignin structure and use the resulting monomeric chemicals for construction of new polymers is, so far, not practical and may not be economically advantageous. In this project, *our hypothesis* is that partially depolymerized lignin (PDL) with enhanced solubility will provide accessible hydroxyls to enhance modification, thereby converting the lignin into effective building blocks for engineering polymers. Epoxy resin is the target polymer in the current effort, but it will not be the only application interest long-term. Attention will be given to other engineering polymers when an appropriate application is identified. Furthermore, PDL is expected to possess an improved performance when directly incorporated as an active ingredient to thermosets because the reduced molecular weight and increased accessibility and content of hydroxyls promote compatibility and/or even the miscibility. The implementation of this project consists of three major tasks.

### Task C-CP-3.1. Preparation of epoxies using lignomers

Although utilization of lignin-derived monomers is not a favorable route in producing lignin-based polymers, the approach serves as a useful step in route to utilizing lignin. We selected eugenol as the model compound for synthesis of epoxies. Eugenol can be obtained from a number of plant extractives and is also claimed by some researchers to be present in materials produced from a lignin cracking process. We have demonstrated in an earlier task that eugenol can be converted to epoxies with excellent physical and mechanical properties. However, because the current lignin depolymerization technology is not able to economically and efficiently produce eugenol or related chemicals that could be used as feedstock for engineering polymers, this task is not our major focus and is currently complete. *Detailed results and data* on this part of project can be found in our 4th quarterly report. A manuscript has also been submitted recently for publication.

### Task C-CP-3.2. Development of lignin-based epoxies using partially depolymerized lignin (PDL)

First, a thorough review of lignin depolymerization was conducted. Based on the survey, two methods were selected to show potential: (1) base catalyzed depolymerization in supercritical solvent (BCD) and (2) hydrogenolysis under catalysis of Raney nickel. To achieve oligomeric compounds rather than the more commonly targeted monomeric compounds, we focused on cracking methods that could be deployed with milder conditions. The reaction conditions are regulated to selectively cleave ether bonds of lignin to improve the PDL solubility, dispersabiltiy, and functionality. The resulting PDL will be converted to building block chemicals, which are to be used for synthesis of various potential engineering polymers. PDL can be functionalized much more effectively than the native lignin. Furthermore, preparation, processing and performance of the lignin-derived epoxies will be thoroughly studied.

### Task C-CP-3.3. Application development for PDL-based epoxy asphalt

Our central hypothesis is that the PDL-based epoxy resins will demonstrate higher performance than those based on unmodified lignin but incorporating lignin tends to always increase stiffness and brittleness of the resulting polymer. In this project, we plan to explore the application of PDL-based epoxies in an underexplored but increasingly important product, i.e., epoxy asphalt. To this application, the designs of PDL-based epoxies and curing agents will be customized to meet the specific requirements for asphalt application, and formulation and preparation of the epoxy asphalt will be studied. Finally, the performance of the PDL-based epoxy asphalt will be evaluated.

The *specific objectives* of this project are: (1) to investigate the synthesis of important engineering polymers (e.g., epoxies) using lignin as feedstock; (2) to study the structure-property relationship of the resulting engineering polymers and; (3) to explore the application development using the lignin-derived polymers.

## Activities and Results

Task C-CP-3.1 has been successfully accomplished. If eugenol or a similar lignin-derived chemicals can be obtained with high purity and reasonable cost, quality alternative epoxies can be made. Nonetheless, such a lignin-to-chemical technology is not likely any time soon.

Task C-CP-3.2 is currently ongoing. To investigate preparation of partial depolymerization of lignin (PDL) for epoxy synthesis, we initiated our investigation with Kraft lignin (KL) as a model lignin because of its easy availability, relatively low molecular weight and high hydroxyl content. Both base-catalyzed depolymerization (BCD) and hydrogenolysis in mild conditions proved to be successful in partially depolymerizing lignin. The conversion of KL to a soluble compound was successful with a yield ≥70 wt%. In general, BCD performed with NaOH as catalyst at ~250 °C for 90 minutes can result in 70% or higher soluble PDL. The resulting PDL was converted to glycidyl ether type epoxies (LEP) and polycarboxylic acid (LPCA) type curing agents. LEP and LPCA are black viscous liquid or paste-like solid and soluble in many organic solvents. Methods for synthesizing LEPs with high epoxy values are still under investigation. However, curing commercial Bisphenol A (BPA) type epoxies using LPCAs resulted in some promising results. The moderate mechanical and physical properties of the cured resins suggest LPCAs are worth further exploration for curing agent application (Figure 1). Furthermore, the properties of the cured resin could be greatly regulated by using mixed curing agents. Hydrogenolysis under mild conditions proved to be a more effective method to achieve PDL and resulted in ~85% or higher soluble PDL. Compared to the original KL, the hydroxyl value of the hydrogenated KL was increased by 0.85 mmol/g, being 7.19 mmol/g. We studied effects of temperature, solvent and reaction stoichiometry and concentration of reagent on yield of conversion and hydroxyl content.

Partial depolymerization of *NARA lignin* (hydrolysis lignin) was subsequently studied based on the experience learned using the KL. Surprisingly, under various reaction conditions, use of the BCD method generally resulted in low yield for the lignin-to-soluble conversion (<45%). This result was probably due to the high initial molecular weight (MW) of the NARA lignin, which largely resembles the lignin in its native intact state. This reasoning is supported by the fact that there has not been an effective solvent identified to dissolve the NARA lignin for molecular weight (MW) determination.

Mild hydrogenolysis, however, still proves to be an effective approach to partially depolymerizing NARA lignin. In a preliminary experiment, hydrogenolysis of the DA lignin in 10% NaOH aqueous solution exhibited a much high conversion than in 10% NaOH methanol solution (73% vs. 23%). This result might be attributed to the higher solubility of the resulting PDL in water. More hydrogenolysis has been performed in 3% NaOH solution in dioxane/water (1:1) mixture. Hydroxyl content is measured using $^{31}$P NMR. Figure 2 shows the $^{31}$P NMR spectra of NARA dilute acid (DA) lignin before and after hydrogenolysis at different temperatures, while Table 1 shows the hydroxyl content of the resulting PDLs increased continuously with temperature up to 200 °C. Figure 3 shows effects of temperature on conversion of PDL, indicating the conversion peaked at 180 °C. Catalyst concentration and reaction time are also found to significantly influence the conversion.

Task C-CP-3.3 has not started yet.

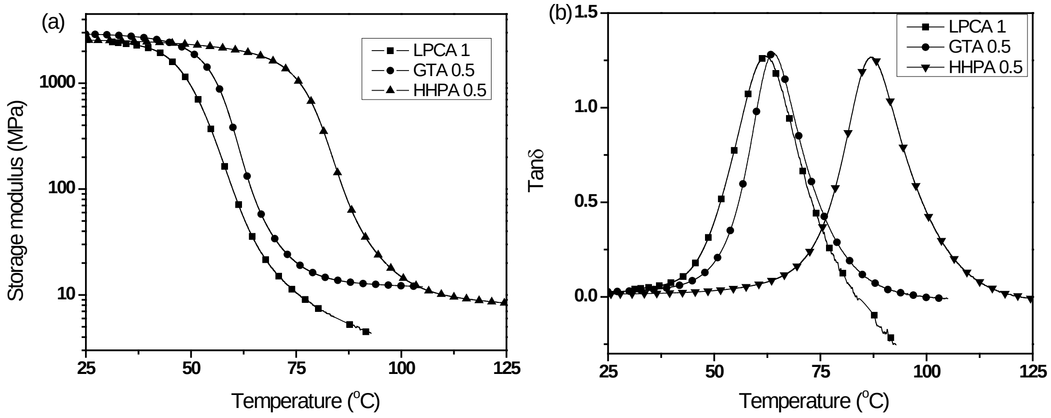


Figure 1. Storage modulus (a) and tan δ (b) versus temperature for the DER 353 cured by LPCA co-curing agents.

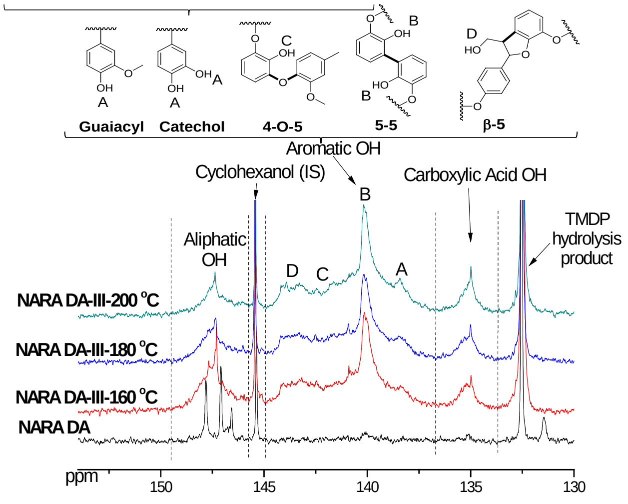


**Figure 2.** $^{31}$P NMR spectra of NARA DA lignin before and after hydrogenolysis at different temperatures.

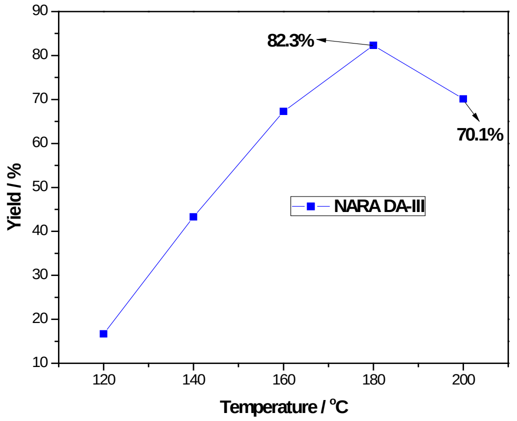


**Figure 3.** Effect of temperature on conversion of partial depolymeriztion of NARA DA lignin by hydrogenolysis.

**Table 1.** Hydroxyl content NARA DA lignin hydrogenolyzed at different temperatures using $^{31}$P NMR

| Structure | δ $^{31}$P NMR | OH value (mmol / g) | | |
|---|---|---|---|---|
| | | 160 $^o$C | 180 $^o$C | 200 $^o$C |
| Aliphatic OH | 145.5-150.0 | 0.81 | 0.71 | 0.66 |
| Aromatic OH | 136.6-144.7 | 2.4 | 2.68 | 3.22 |
| Carboxylic acid OH | 133.6-136.6 | 0.37 | 0.44 | 0.50 |
| Total | | 3.58 | 3.83 | 4.38 |

## Recommendations/Conclusions

In summary**,** the results obtained to date have largely validated our *hypothesis* that the partially depolymerized lignin (PDL) with good solubility/dispersability can be converted into effective building blocks for engineering polymers. Epoxies cured with PDL-based curing agents display promising mechanical and physical properties. Though PDL-based epoxies have not achieved the anticipated performance, the result is more likely due to the methodological approach in the synthesis of glycidyl ether of PDL. In the future, more effort will be made to investigate synthesis of PDL-based epoxies.

Mild hydrogenolysis under the catalysis of Raney Ni can effectively depolymerize both Kraft lignin (KL) and various NARA lignins to produce PDLs. However, the base-catalyzed depolymerization (BCD) approach is only effective on KL. The results obtained suggest that catalyst content, temperature, and reaction medium all greatly influence the conversion, hydroxyl content and molecular weight of the resulting PDLs. Additional efforts are needed to refine individual and combined parameters before the optimum reaction conditions can be identified. This will be one of the prime focus areas for the coming year of research.

In addition, recently preliminary results indicate that phenolation liquefaction is an effective approach to depolymerize (i.e. liquefy) NARA lignin. Interpretation of this result suggests that NARA lignin may also play a role in polyurethanes and phenolic resins in the future. We recommend exploring phenolation liquefaction using lignin-derived total phenol as liquefying agent. If this attempt is proved feasible, a novel and new approach for preparation of lignin-based polyurethanes and phenolics will be introduced.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Qin, J., H. Liu, P. Zhang, M. Wolcott, and J. Zhang. Preparation of biobased epoxy resin from eugenol and rosin and study of curing and performance properties (submitted)

## Conference Proceedings and Abstracts from Professional Meetings

Qin, J., J. Xin, M. Wolcott and J. Zhang. 2013. Use of Lignin as Feedstock for Epoxy Application. 2013 International Wood Composite Symposium, Seattle, WA, April. 3- 4.

Qin, J., M. Wolcott, and J. Zhang. 2012. Diversifying renewable feedstocks for new biobased polymers and applications, Oral presentation at 2012 BioEnvironmental Polymer Society Meeting, Denton, Texas, Sept.18-21, 2012.

## Research Presentations

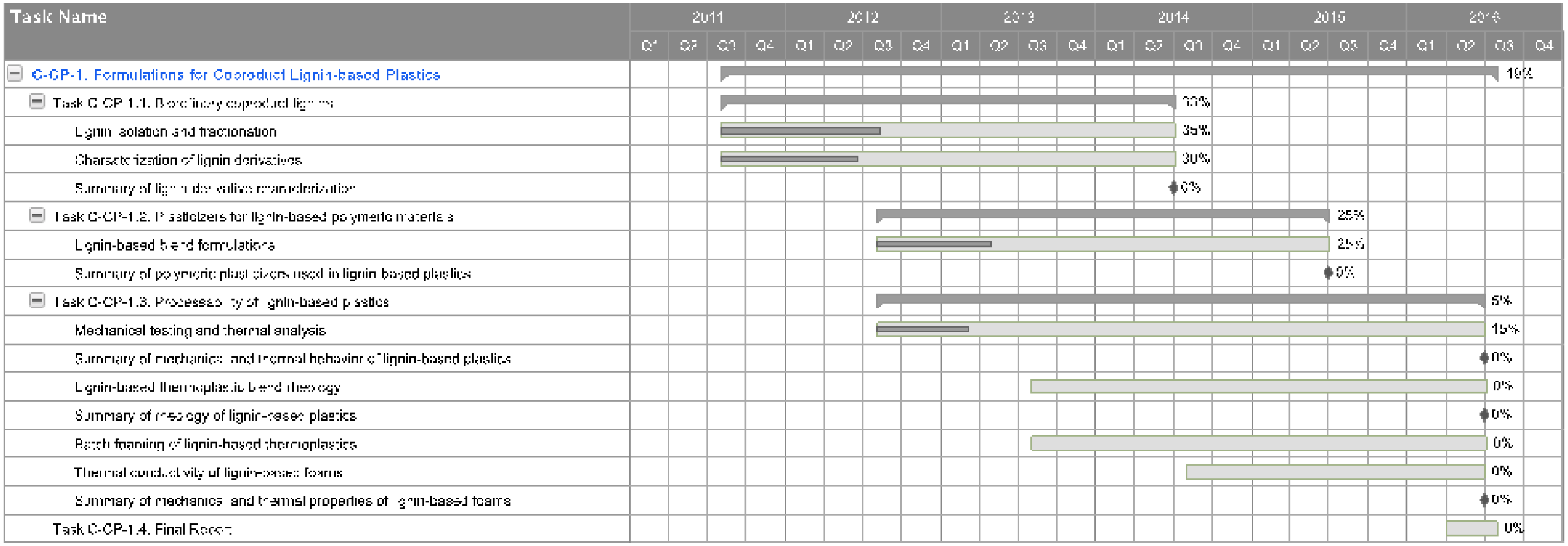
Qin, J., J. Xin, M. Wolcott and J. Zhang. 2013. Use of Lignin as Feedstock for Epoxy Application. Oral presentation at 2013 International Wood Composite Symposium, Seattle, WA, April. 3- 4.

Qin, J., M. Wolcott, J. Zhang. 2012. Diversifying renewable feedstocks for new biobased polymers and applications. Oral presentation at 2012 BioEnvironmental Polymer Society Meeting, Denton, Texas, Sept.18-21, 2012.

Qin, J., M. Wolcott and J. Zhang. 2012. Use of lignin as feedstock for polymer materials: epoxies and curing agents. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

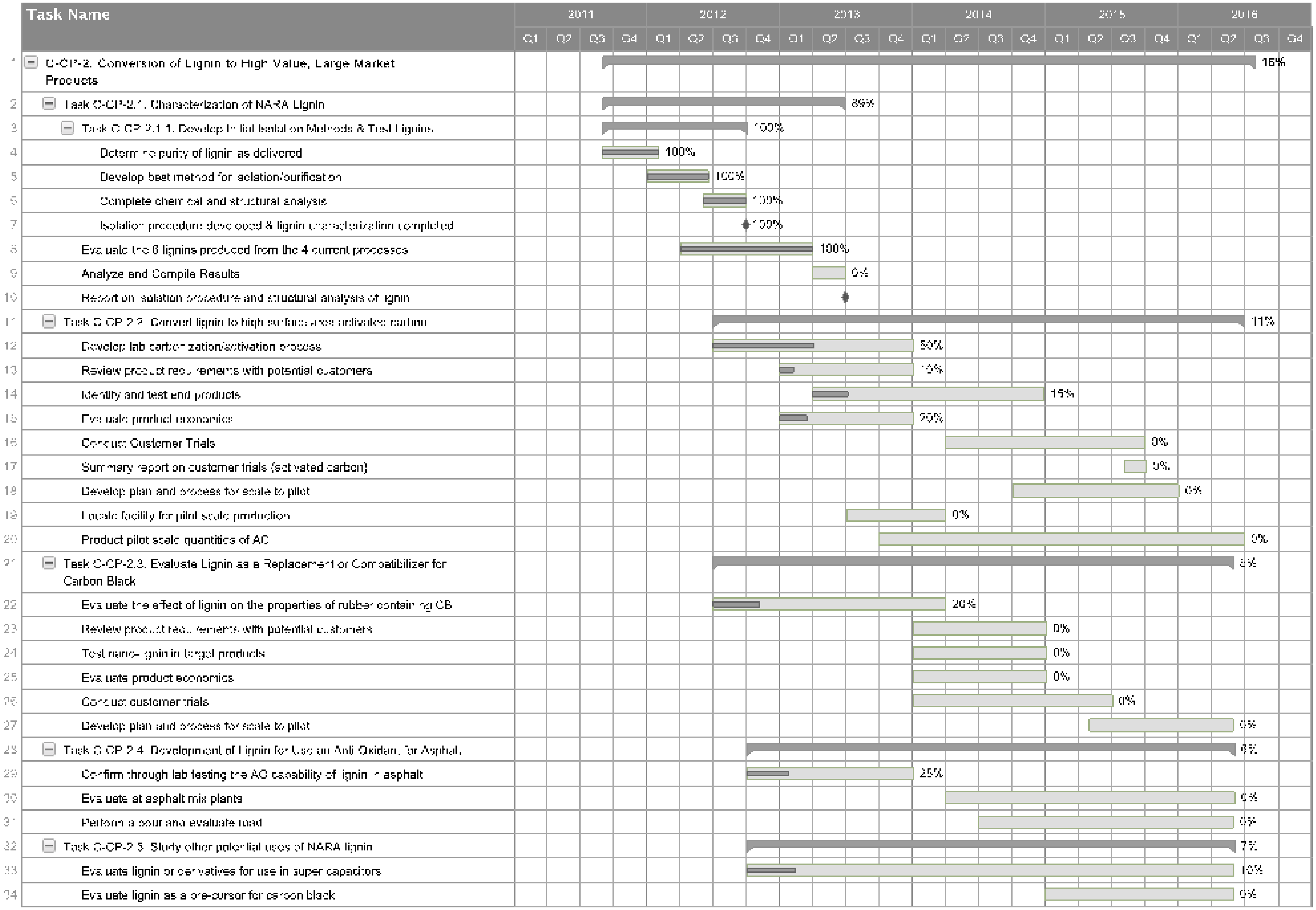
# Conversion-CP_Sarkanen

NARA

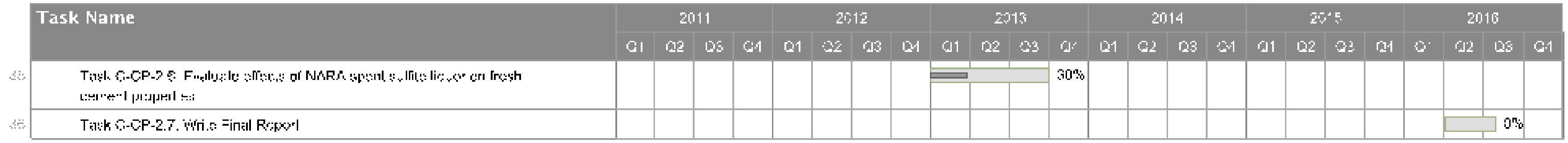


# Conversion-CP_Fish

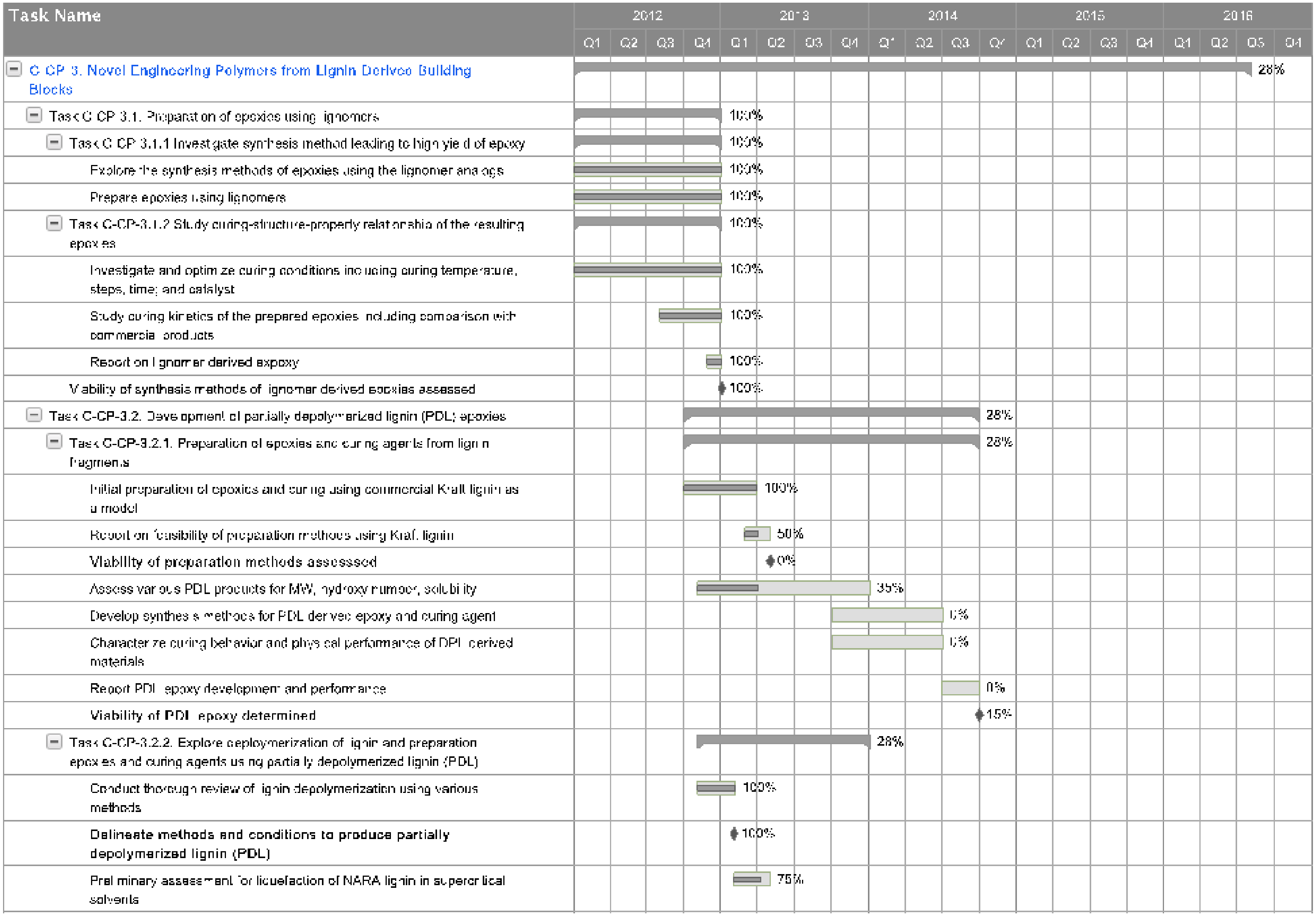
NARA



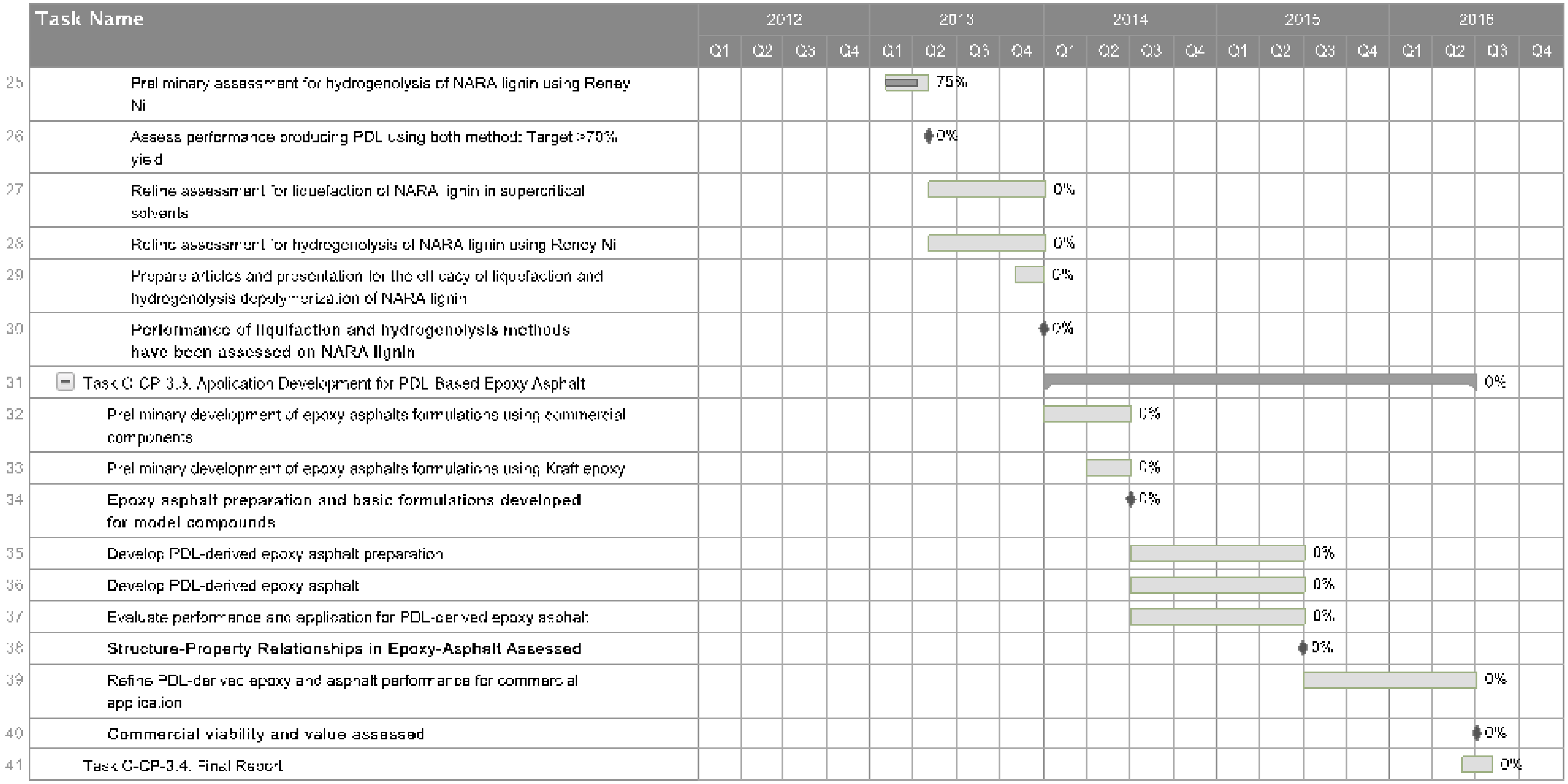
| | Task Name | |
|---|---|---|
| 1 | C-CP-2. Conversion of Lignin to High Value, Large Market Products | 15% |
| 2 | Task C-CP-2.1. Characterization of NARA Lignin | 89% |
| 3 | Task C-CP-2.1.1. Develop Initial Isolation Methods & Test Lignins | 100% |
| 4 | Determine purity of lignin as delivered | 100% |
| 5 | Develop best method for isolation/purification | 100% |
| 6 | Complete chemical and structural analysis | 100% |
| 7 | Isolation procedure developed & lignin characterization completed | 100% |
| 8 | Evaluate the 6 lignins produced from the 4 current processes | 100% |
| 9 | Analyze and Compile Results | 0% |
| 10 | Report on isolation procedure and structural analysis of lignin | |
| 11 | Task C-CP-2.2. Convert lignin to high surface area activated carbon | 11% |
| 12 | Develop lab carbonization/activation process | 50% |
| 13 | Review product requirements with potential customers | 10% |
| 14 | Identify and test end products | 15% |
| 15 | Evaluate product economics | 20% |
| 16 | Conduct Customer Trials | 0% |
| 17 | Summary report on customer trials (activated carbon) | 0% |
| 18 | Develop plan and process for scale to pilot | 0% |
| 19 | Locate facility for pilot scale production | 0% |
| 20 | Product pilot scale quantities of AC | 0% |
| 21 | Task C-CP-2.3. Evaluate Lignin as a Replacement or Compatibilizer for Carbon Black | 8% |
| 22 | Evaluate the effect of lignin on the properties of rubber containing CB | 20% |
| 23 | Review product requirements with potential customers | 0% |
| 24 | Test nano-lignin in target products | 0% |
| 25 | Evaluate product economics | 0% |
| 26 | Conduct customer trials | 0% |
| 27 | Develop plan and process for scale to pilot | 0% |
| 28 | Task C-CP-2.4. Development of Lignin for Use as Anti Oxidant for Asphalt | 6% |
| 29 | Confirm through lab testing the AO capability of lignin in asphalt | 25% |
| 30 | Evaluate at asphalt mix plants | 0% |
| 31 | Perform a pour and evaluate road | 0% |
| 32 | Task C-CP-2.5. Study other potential uses of NARA lignin | 7% |
| 33 | Evaluate lignin or derivatives for use in super capacitors | 10% |
| 34 | Evaluate lignin as a pre-cursor for carbon black | 0% |


Task Name
2011
2012
2013
2014
2015
2016
Q1
Q2
Q3
Q4
45
Task C-CP-2.6. Evaluate effects of NARA spent sulfite liquor on fresh cement properties
30%
46
Task C-CP-2.7. Write Final Report
0%

# Conversion-CP_Zhang_Wolcott



| | Task Name | |
|---|---|---|
| 1 | C-CP 3. Novel Engineering Polymers from Lignin Derived Building Blocks | 28% |
| 2 | Task C-CP 3.1. Preparation of epoxies using lignomers | 100% |
| 3 | Task C-CP 3.1.1 Investigate synthesis method leading to high yield of epoxy | 100% |
| 4 | Explore the synthesis methods of epoxies using the lignomer analogs | 100% |
| 5 | Prepare epoxies using lignomers | 100% |
| 6 | Task C-CP-3.1.2 Study curing-structure-property relationship of the resulting epoxies | 100% |
| 7 | Investigate and optimize curing conditions including curing temperature, steps, time, and catalyst | 100% |
| 8 | Study curing kinetics of the prepared epoxies including comparison with commercial products | 100% |
| 9 | Report on lignomer derived expoxy | 100% |
| 10 | Viability of synthesis methods of lignomer derived epoxies assessed | 100% |
| 11 | Task C-CP-3.2. Development of partially depolymerized lignin (PDL) epoxies | 28% |
| 12 | Task C-CP-3.2.1. Preparation of epoxies and curing agents from lignin fragments | 28% |
| 13 | Initial preparation of epoxies and curing using commercial Kraft lignin as a model | 100% |
| 14 | Report on feasibility of preparation methods using Kraft lignin | 50% |
| 15 | Viability of preparation methods assessed | 0% |
| 16 | Assess various PDL products for MW, hydroxy number, solubility | 35% |
| 17 | Develop synthesis methods for PDL derived epoxy and curing agent | 0% |
| 18 | Characterize curing behavior and physical performance of DPL derived materials | 0% |
| 19 | Report PDL epoxy development and performance | 0% |
| 20 | Viability of PDL epoxy determined | 15% |
| 21 | Task C-CP-3.2.2. Explore depolymerization of lignin and preparation epoxies and curing agents using partially depolymerized lignin (PDL) | 28% |
| 22 | Conduct thorough review of lignin depolymerization using various methods | 100% |
| 23 | Delineate methods and conditions to produce partially depolymerized lignin (PDL) | 100% |
| 24 | Preliminary assessment for liquefaction of NARA lignin in supercritical solvents | 75% |



| | Task Name | |
|---|---|---|
| 25 | Preliminary assessment for hydrogenolysis of NARA lignin using Reney Ni | 75% |
| 26 | Assess performance producing PDL using both method: Target >70% yield | 0% |
| 27 | Refine assessment for liquefaction of NARA lignin in supercritical solvents | 0% |
| 28 | Refine assessment for hydrogenolysis of NARA lignin using Reney Ni | 0% |
| 29 | Prepare articles and presentation for the efficacy of liquefaction and hydrogenolysis depolymerization of NARA lignin | 0% |
| 30 | **Performance of liquifaction and hydrogenolysis methods have been assessed on NARA lignin** | 0% |
| 31 | ⊟ Task C CP 3.3. Application Development for PDL Based Epoxy Asphalt | 0% |
| 32 | Preliminary development of epoxy asphalts formulations using commercial components | 0% |
| 33 | Preliminary development of epoxy asphalts formulations using Kraft epoxy | 0% |
| 34 | **Epoxy asphalt preparation and basic formulations developed for model compounds** | 0% |
| 35 | Develop PDL-derived epoxy asphalt preparation | 0% |
| 36 | Develop PDL-derived epoxy asphalt | 0% |
| 37 | Evaluate performance and application for PDL-derived epoxy asphalt | 0% |
| 38 | **Structure-Property Relationships in Epoxy-Asphalt Assessed** | 0% |
| 39 | Refine PDL-derived epoxy and asphalt performance for commercial application | 0% |
| 40 | **Commercial viability and value assessed** | 0% |
| 41 | Task C-CP-3.4. Final Report | 0% |

# NARA | GOAL THREE

## August 2011 - March 2013 Cumulative Report

RURAL ECONOMIC DEVELOPMENT

Northwest Advance Renewables Alliance

# Goal Three: 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 analysis – 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:

The **Techno-Economic Analysis (TEA) Team** assesses the overall economics of the biofuels production process from feedstock delivered to the mill gate through to biojet sale. This analysis includes the overall production mass and energy balance as well as the value needs for co-products. The TEA models the capital requirement plus the variable and fixed operating costs for producing biojet from forest residuals using our chosen pathways**.**

The **Life Cycle Assessments (LCA) and Community Impact Team** assesses the environmental impact of producing aviation biofuels with our chosen pathway and compares it to the petroleum products for which it will substitute. This assessment covers harvesting options, as well as options for the various production steps. Regional options for harvesting and transportation models are considered. These regional scenarios provide the context to assess the impact of the industrial development on local communities.

To provide more specific information regarding the influence of harvesting 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 the impact of industry feedstock requirements on overall supply chain dynamics. In whole, this team provides a host of primary data to improve and verify a variety of predicted impacts from this new industry.

The **Environmentally Preferred Products Team** 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 determine future production costs (capital required plus fixed and variable operational costs), the **Techno-economic Team** has constructed a complete techno-economic model for the NARA softwood-to-biojet production. An initial analyses generated from this model includes techno-economic spreadsheets with variable products produced (biojet, isobutanol, lignin co-products) and an “improvement opportunities” analysis spreadsheet (waterfall chart) that shows estimated potential gains with 3-year improvement ideas at a 50% probability level. Flow diagrams for the 10 key unit operations in the process, including material costs, were constructed. A yield chain spreadsheet for a key metric—gallons of IPK per BDT feedstock—(including all intermediate stage yields as well) was created (Task SM-TEA-1; each task progress is detailed in progress reports following this summary). Significant internal outputs to date for this team are listed below. Additional outputs are listed at the end of each progress report.

- An initial techno-economic model has been prepared that provides a standard discounted-cash-flow return-on-investment (DCF-ROI, NPV) analysis sheet with input blocks for key variables allowing user interaction for sensitivities. The analysis identifies key leverage points where resources and alternative thinking can be applied to lower the cost of production.

The **Life Cycle Assessment (LCA)** efforts have been primarily devoted to reviewing previous LCA models, conceptualizing an appropriate LCA model for the NARA project, accumulating input data, and generating assessments. To provide baseline data for nitrogen and carbon content in forest soils, soil analyses have been completed at numerous forested sites in the Pacific Northwest. An assessment of 73 sites in the coastal Douglas-fir region from North Vancouver Island to Southern Oregon compares nitrogen levels to harvest activity (Figure 1; Task SM-LCA-1). An assessment of soil carbon levels in 26 sites was conducted and a complementary study of carbon levels in working forests relative to vegetative control was completed (Figure 2; Task SM-LCA-1). Three environmental assessments were generated. One examined the avoided environmental burdens due to a reduction of slash pile burning (Table 3; Task SM-LCA-1); another assessed the relative environmental burdens of various aspects of biomass harvest and transportation (Figure 4 and 5; Task SM-LCA-1); and a preliminary LCA of the forest to fuel process using secondary data has been completed (Table 4; Task SM-LCA-1). An preliminary comparative analysis was completed that compares aircraft emissions impact on ozone depletion, global warming and fossil fuel depletion when burning biojet and fossil fuel (Tables 5 and 6; Task SM-LCA-1).

To assess the level of economic impact to supply chain communities, the **Community Impact** group has completed preliminary social accounting matrices (SAM) that contain the intra-industry relationships. In addition, the capital and labor flows needed to assess the impact from biojet fuel production have been constructed and populated with data from IMPLAN data covering the NARA region (Tables 1 and 2; Task SM-LCA-1).

Significant internal outputs to date are:

- A preliminary Social Accounting Matrix for the Inland Empire region has been completed.
- NARA has developed a significant partnership with Potlatch Corporation which is currently pursuing an Affiliate Member status. As part of this partnership, Potlatch has donated a dataset of a major biomass and pulpwood thinning trial for use in the LCA analysis.
- A collaborative relationship with researchers at the University of Idaho was established that enables access to the IMPLAN economic data (UI work supported under NIFA; grant # 2010-04759) needed to facilitate the community impact assessment for the Inland Empire region.
- The preliminary results of the LCA emissions comparison of aircraft burning biojet or fossil fuel suggest that the overall global warming potential of the NARA bio-jet fuel, measured in kilograms of CO2 emissions, is just 38.4% that of fossil fuel-based jet fuel (Table 5; SM-LCA-1). In addition, the ozone depletion potential of the NARA bio-jet fuel is approximately 12% that of fossil fuel-based jet fuel while the fossil fuel depletion potential is 39.1% of fossil-based jet fuel. In other words, our preliminary analysis suggests that there is a 61.6% reduction in the global warming

potential, an 88.1% reduction in the ozone depletion potential and a 60.7% reduction in fossil fuel depletion by substituting bio-jet fuel for fossil fuel-based jet fuel. This preliminary result is significant in that it exceeds the mandated 60% emission reduction criterion specified in the US Energy Independence Act guidelines.

To evaluate the environmental effects of biomass harvest and use, the **Sustainable Production Team** has established a new Long Term Soil Productivity (LTSP) site in the southern Willamette Valley of Oregon. Site data for pre-harvest conditions have been collected. Harvesting for implementing the various prescribed treatments has begun. (Task SM-SP-1)

To evaluate the potential effects of biomass harvesting on water quality, erosion and water quality, models are being established and an experimental design for validation is underway. The influence of biojet conversion process on regional air quality, emissions data from a regional sulfite pulp mill has been compiled. This mill utilized a sulfite pulping process, fermented sugars in the spent pulping liquor into ethanol, and produced lignin co-products. The stack data from this mill were separated in process steps and will be used as a step in airshed modeling to understanding how changes to the wood product industry due to new biofuel processing might affect air quality. In addition, air emissions produced from the SPORL pretreatment process have been analyzed under laboratory conditions. (Task SM-SP-5)

Silvicultural prescriptions have been developed for various regions, forest types, and owner groups. These tools are aimed at assessing available biomass feedstock supply from these management objectives and to inform biomass estimates generated for a regional supply model. Preliminary predictions of forest growth and quality control of the method have been completed. To direct the silvicultural prescriptions, baseline fire hazard modeling has been completed across Oregon. These models will inform the effectiveness of thinning regimes and biomass utilization to alter landscape level fire hazard. The framework for several dozen Integrated Fireshed-level Adaptive Management Evaluation Sites (iFLAMES) has been developed. (Task SM-SP-2)

The Forest Inventory and Analysis (FIA) plot data for the NARA study region has been assembled, modified and used to estimate log demand elasticity for Oregon and Washington. The Forest vegetation Simulator (FVS) model has been adapted to allow rapid generation of 100-year projections of timber volumes and biomass under user-specified silvicultural regimes. The model has been used to examine both single and multiple hypothetical biomass destination scenarios. An example biomass supply curve has been generated for a single site case. (Task SM-SP-3) To inform this forest econometrics model, primary mill residue and capacity information has been updated for the NARA region and supplied to NARA researchers for model development and GIS applications. To provide logging residue estimates, 1300 felled trees were measured at 56 sites across the region. (Task SM-SP-7) To provide data used to determine sustainable levels of bioenergy feedstock production, components from 199 trees were sampled and chemical analysis is nearly complete. (Task SM-SP-4)

Significant internal outputs to date are:

- A study location for the LTSP experiment was identified and plotted. Pre-harvest data was collected and treatments have begun. This site will be instrumental in determining the effects of biomass removal on soils, vegetation and wildlife. (Task SM-SP-1)

- A series of regional, forest type, and owner group specific silvicultural prescriptions have been developed in order to better inform biomass estimates generated from the regional supply model. (Task SM-SP-2)

- Baseline fire hazard modeling has been completed across Oregon to measure effectiveness of thinning regimes and ability of the utilization of biomass material to alter landscape level fire hazard. (Task SM-SP-2)

- FVS (Forest Vegetation Simulator) variants in the NARA study region were converted to a composite model based on simplified C++ code, allowing rapid generation of 100-year projections of timber volumes and biomass under user-specified silvicultural regimes. A western Oregon example market projection has been run with the model using timber yield inputs from the C++ code and assumptions about biomass extraction and haul costs. The model has been used to examine both single and multiple hypothetical biomass destination scenarios and an example biomass supply curve has been generated for a single site case. (Task SM-SP-3)

- Numerous tree attributes have been measured from 199 trees originating in highly managed stands. This sampling ranged in breast height age from ~9 to ~90 years, in diameter at breast height (dbh) classes from 10-85 cm, and in height classes from 5-58 m. Understory vegetation sampling has been completed across a chronosequence of sites ranging in age from 0-20 years. Biomass equations have been fit to data collected during the first sampling season. These new equations overcome known biases in existing biomass equations with tree size and treatment history (Task SM-SP-4).

- Air emission data have been compiled from the wood products industry and from pretreatment simulations (Task SM-SP-5).

- Forest residual datasets for Idaho (2006), Oregon (2008), Montana (2009), Washington (2010), with updated Idaho sampling (2011) have been compiled and provided to NARA researchers conducting supply chain assessment. In addition, this data is being used to developed tools for predicting woody biomass in landing residue piles (Task SM-SP-5).

To evaluate stakeholder needs and perceptions, the **Environmentally Preferred Products** Team developed a stakeholder survey used to measure their knowledge, concerns, and level of trust related to issues concerning forest management, biomass, and liquid biofuels. With the assistance of the NARA Outreach Team, 325 potential interviewees were identified and data collection is underway. To evaluate community social assets, a preliminary biogeophysical and social asset assessment to inform plant siting and predict public bioenergy behaviors has been completed. The information will be used to identify communities and regions that are viable to development considering a number of factors including biomass availability, physical infrastructure, potential workforce development, and ability to activate social capital for the common good. To assess market opportunities for biojet, this team, with assistance from Gevo, Inc., supervised MBA student projects at Penn State University to generate market opportunities for biojet. In addition, they have generated preliminary data on primary US airports, supply chain alliances and regulatory/environmental impacts. Key governmental policy drivers, voluntary initiatives and standards and aviation biofuels LCA's were thoroughly reviewed and this information are used to structure the NARA LCA and model future environmental assessments. (Task SM-EPP-1) Significant internal outputs to date are:

- A preliminary biophysical and social asset assessment has been completed and is instrumental in developing selection criteria for strategic communities in the supply chain.

- A review of environmental policies, standards, and disclosure/labeling initiatives has been completed. Knowledge gained impacts future work throughout the Systems Metrics Program.

# Outcomes/Impacts:

Events that cause a change of knowledge, actions or conditions for stakeholders and society.

- BBER's logging utilization researchers have provided forest landowners customized reports of the quantities of logging residue left on their lands after timber harvesting. This information has enabled landowners to gauge the efficiency of their forest management operations, learn of woody biomass energy opportunities, and help them predict the impacts of logging operations on wildlife habitat and coarse woody debris inventories. These data will be used by the USDA Forest Service Forest Inventory and Analysis (FIA) Program to update estimates of woody biomass residue inventories in the Resource Planning Act (RPA) Timber Products Output (TPO) database and will result in financial savings to taxpayers and enhanced biomass inventories at varied spatial scales. (Task SM-SP-7)

# Training

| Name | Affiliation | Role | Contribution |
|---|---|---|---|
| Katie Gagnon | PSU, Dept. of Agr. & Biol. Eng. | Staff – 20-hrs./wk. (wages) | Coordinating stakeholder assessment efforts |
| Wenping Shi | PSU, Dept. of Ecosystem Sci. & Mgmt. (ESM) | PhD Student – part-time on the NARA project | Coordinating social asset dataset development, management, and analysis |
| Stephen Wertz | PSU, Dept. of Agr. & Biol. Eng. | PhD Student – to start Sept. '13 | Techno-Market Assessment: Jet Fuels |
| Min Chen | PSU, Dept. of Agr. & Biol. Eng. | PhD Student – started Jan. '13 | Techno-Market Assessment: BioProduct Polymers |
| Stephen Cline | PSU, Dept. of ESM | Undergrad. - 10 hrs/wk. (wages) | Techno-Market Assessment: BioProduct Polymers |
| Jill Maroney | UI, Dept. of Environmental Science | PhD Student – started with EPP Jan. '13 | Stakeholder assessment primary data collection activities and triangulation of CAAM refinements |
| Natalie Martinkus | WSU, Dept. of Civil & Env.Eng. | PhD Student | Biogeophysical asset assessment and mapping via GIS |
| Rylie Olson | UMN, Dept. of Bioproducts & Biosystems | PhD Student | Life cycle and hotspot analyses; Literature review |
| Holly Lahd | UMN, Dept. of Applied Econ | PhD Student | EEIO Assessment of Biopreferred alternatives |

| | | | |
|---|---|---|---|
| Warren Devine | UW, SEFS | Post-Doc | synthesis, data analysis, writing |
| Paul Footen | UW, SEFS | PhD student | field, sampling, lab work, writing |
| Tait Bowers | UW, SEFS | PhD student | LCA surveys, LCA framework analysis, data collection and analysis, writing |
| Austin Himes | UW, SEFS | MS student | field, sampling, lab work, writing |
| Jason James | UW, SEFS | MS student | field, sampling, lab work, writing |
| Marcella Menegale | UW, SEFS | PhD student | field, sampling, lab work, writing |
| Kim Littke | UW, SEFS | PhD student | field, sampling, lab work, writing |
| Erika Knight | UW, SEFS | MS student | field, sampling, lab work, writing |
| Kevin Vogler | OSU, Department of Forest Engr, Resources & Mgmt | Graduate Student | Literature synthesis, GIS layers and model formulation |
| Mindy Crandall | OSU, Applied Economics, Sustainable Forestry | Graduated (PhD) | Developing profit function estimates for WA, ID and MT. Will run alternative biomass processing scenarios and assist in developing biomass supply equations. Examine alternatives for intermediate processing of biomass between forest and refinery. |
| Isabel Guerrero | OSU, Applied Economics | Graduated (MS) | Developed initial estimates of profit functions and associated log demand parameters for Oregon lumber and plywood industries |
| Abraham Rodrigo Gonzalez | WSU, CEE) | Grad Student | Wood product air pollution emission inventory |
| Mark Mettler | WSU, CEE | Undergrad | Evaluation of Biolog system for nutrient evaluation |
| Chad Warren | WSU, CEE | Undergraduate | Initial WEPP model evaluation. |
| Madeline Fuchs | WSU, CEE | Undergraduate | Summer REU student |
| Mohammed Hasan | WSU, CEE | Grad Student | Currently modeling hydrology and soil erosion in targeted watersheds. |
| Vikram Ravi | WSU, CEE | Grad Student | Air quality emissions and simulations |
| Heather Root | Oregon State University | Post-Doc | Beginning modeling and review efforts. |
| Andy Bluhm | OSU, Forest Ecosystems and Society | Research Tech | lab work |

| | | | |
|---|---|---|---|
| Junhui Zhao | OSU, Forest Engr, Resources & Mgmt (FERM) Department | Post-Doc | field work |
| Alexis Danley | OSU FERM | Research Tech | lab work |
| Evelyn Idzerda | OSU FERM | Research Tech | lab work |
| Fantasia Freedom | OSU FERM | Research Tech | lab work |
| Andrew Rose | OSU FERM | Research Tech | lab work |
| Shannon Cox | OSU FERM | Research Tech | lab work |
| Kristin Coons | OSU FERM | FERM Grad Student | field/lab work |
| Nicole Rogers | OSU FERM | FERM Grad Student | field/lab work |
| Mike Shettles | OSU FERM | Undergraduate | lab work |
| Jeremy Mitchell | OSU FERM | Undergraduate | lab work |
| Becky Brenton | OSU FERM | Undergraduate | lab work |
| Brian Pickett | OSU FERM | Undergraduate | lab work |
| Rebecca Burson | OSU FERM | Undergraduate | lab work |
| Georgia Hall | OSU FERM | Undergraduate | lab work |
| John Crandall | OSU FERM | High School student | lab work |
| Tynan Granberge | OSU FERM | Research Tech | lab work |
| Peter Antico | OSU FERM | Research Tech | lab work |
| Charles Gale | Univ. of Montana, Resource Conservation | Undergraduate | Gale served as lead analyst and author for "Oregon's forest products industry and timber harvest, 2008…" (PNW-GTR-868); this manuscript has provided timely and vital information on mill residues, timber harvest, and other critical Oregon TPO data. Gale worked as a NARA logging utilization field crew member in 2011 to 2012. |

| | | | |
|---|---|---|---|
| Micah Scudder | Univ. of Montana, Forestry | MS Student (note- Scudder received his MS degree in December 2012- he now works as a full time research assistant at BBER). | Scudder worked as a logging utilization field crew member across the 4 state NARA area in 2012. Micah has served NARA as our resident wood export specialist- his skills have been particularly useful in understanding the export and substitution effects of wood flows throughout the northwest. Scudder (in collaboration with Josh Meek) has developed a tool that summarizes timber harvest by year by county in MT, , ID, OR, WA, and CA. This innovative web-based application will enable users to quickly understand the spatial and temporal dynamics of timber harvest. |
| Josh Meek | Univ. of Montana, Forestry | MS Student | Meek worked as a logging utilization field crew member across the 4 state NARA area in 2012. Meek (in collaboration with Micah Scudder) has developed a tool that summarizes timber harvest by year by county in MT, , ID, OR, WA, and CA. This innovative web-based application will enable users to quickly understand the spatial and temporal dynamics of timber harvest. |

# Resource Leveraging

| Resource Type | Resource Citation | Amount | Relationship or Importance to NARA |
|---|---|---|---|
| A Grant-In-Aid (GIA) commitment to a PhD candidate (Stephen Wertz) | September 2012 through May 2015, Penn State's College of Agricultural Sciences, Dept of Agricultural and Biological Engr | Approx. $49,000 | The GIA provides matching funds for a NARA grant assistantship |
| Grant-In-Aid (GIA) commitment to a PhD candidate (Min Chen) | January 2013 through December 2015, Penn State's College of Agricultural Sciences, Dept of Agricultural and Biological Engr | Approx. $49,000. | The GIA provides matching funds for a NARA grant assistantship |
| Grant, Becker, | USDA AFRI | Approx. | State-based BioEnergy Policies in the |

| | | | |
|---|---|---|---|
| D. & Smith, T. | | $350,000. | Supply Chain |
| Grant, Smith, T. | Global Environmental Management Initiative | Approx. $100,000. | Sustainable Supply Chain & Sourcing Tool |
| Grant, Smith, T. | USDA McIntire-Stennis funds awarded through UMN College of Food, Ag. & Natural Resource Sciences | Approx. $30,000. | Bioenergy Hotspot Assessments and Policy Integration |
| Grant, Barber, M. (PI), et al. (21 others – including P. Smith, M. Gaffney, J. Perez-Garcia, and M. Wolcott from the NARA team). | NSF Hazards SEES Type 2: Advancing local, regional, and national adaptive capacities for wildfire resilience in an altered climate. Submitted Feb. 2, 2013. | $3,000,000.00. | Plan to leverage development and application of the Community Asset Assessment Model (CAAM) initially derived under NARA. The CAAM will be further refined and recalibrated to examine community adaptation and response to fire hazard. |
| Grant, Cavalieri, R.P. et al. | FAA-COE - Proposal to the Federal Aviation Administration Center of Excellence for Alternative Jet Fuels and Environment. Submitted March 18, 2013 to FAA & Office of Env. & Energy. | $19,897,252.00 | Plan to leverage the NARA work investigating biorefinery intermediate and co-product supply chains. |
| A two-day advanced LCA training session was organized at the University for Washington. | | All the cost associated with the training session was borne by funds outside the NARA project. | All the NARA-LCA team members, including graduate students working on the project, were trained by a SimaPro specialist on the advanced features of the software (SimaPro). With this advanced training, a Simapro database and project has been created and updated. The additional data needed from the NREL database will be implemented over the next six months to one year. The software allows multiple projects to be set up simultaneously, and with this initial set up of processes in the LCI, it will streamline data entry and the analysis of impact assessments in the later stages. |

| | | | |
|---|---|---|---|
| Funding & Fellowship Support | School of Environmental and Forest Sciences, Univ. of Washington | | Substantial leveraging from funding of the Pacific Northwest Stand Management Cooperative, and graduate student fellowship support |
| Data Sharing Agreements | Potlatch, Inc. | | Over the past several years Potlatch Inc. has collected and analyzed various aspects of biomass harvest, collection and its economic implication in the northern ID and Western MT region. Agreements with Potlatch Inc. are being undertaken leveraging data collected by the LCA team through primary data collection techniques. Moreover, Potlatch is in the process of being considered as a NARA member enhancing the role of industry within the NARA project. |
| Contact | Dr. Jennifer Adam | | Dovetailing BioEarth project with respect to nutrient modeling efforts at watershed scale |
| Contact | Bob Bilby at Weyerhaeuser | | Using Trask Creek watershed project as a means of expediting baseline data for runoff and nutrient information |
| | Weyerhaeuser Company | | Utilized existing infrastructure, research equipment, knowledge, and expertise |
| Funding, Maguire | BLM | | Thirty of our young sample trees (<25 yrs of age) were from sites from an existing study being sampled in a manner similar to NARA protocols. Additional funding has been obtained from BLM to cover the cost of sampling older trees (>40 yrs of age). Data from this sampling will be useful for elements of a BLM-funded study, as well as expand the NARA database for producing new biomass equations |
| Funding, Morgan | Logging Utilization, sponsored by USDA-Forest Service-Rocky Mountain Research Station, 07-JV-11221684-326 | | This agreement assisted in paying for measurement of logging residues generated during timber harvest in Idaho and for reporting of findings. The logging residue information will be a component of woody feedstock analysis, and the reports and contacts made with landowners and land managers in Idaho will increase the awareness of the NARA project |

| | | | |
|---|---|---|---|
| Funding, Morgan | Pacific States Forest Industry and Timber Harvest Analysis, sponsored by USDA-FS-Pacific Northwest Research Station, 08-JV-11261979-355 | | Agreement has assisted with gathering and reporting of data related to timber harvest volumes, mill residues, and forest industry infrastructure in OR and WA, and provided various opportunities to share NARA results and discuss NARA project with forest industry as well as private & public forest management professionals |
| Funding, Morgan | On-going Timber Product Output and Forest Industry Analysis for the Interior West States, by USDA FS-Rocky Mtn Res Station, 11-JV-11221638-091 | | This agreement will assist with the gathering and reporting of data related to timber harvest volumes, mill residues, and forest industry infrastructure in Idaho and Montana, and will provide opportunities to share NARA results and discuss NARA with mill & forest owners & managers. |

# SYSTEMS METRICS

## Environmentally Preferred Products Team

### Task SM-EPP-1: Environmentally Preferred Products

| Key Personnel | Affiliation |
|---|---|
| Paul Smith | Pennsylvania State University |
| Timothy Smith | University of Minnesota |
| Tammi Laninga | University of Idaho |
| Michael Gaffney | Washington Sate University |
| Andrew Hawkins | Gevo |

#### Task Description

A socio-market perspective of biorefinery value chain outputs requires an integrated, multi-faceted approach. EPP activities will provide valuable insight into various aspects of the biorefinery supply chain including: (1) public stakeholder assessment via an integrated biogeophysical and social asset dataset development and analysis; (2) environmental performance assessment via review of existing life cycle assessment studies and labeling and disclosure policies and standards; (3) review regional bioenergy stakeholder perceptual issues, develop stakeholder sample frames and create preliminary protocols, constructs, and interview instruments for pre-testing; (4) operationalize the informed stakeholder data collection regarding perceptions of a regional woody biomass-to-biofuels industry; (5) refine operationalization to triangulate informed stakeholder data with biogeophysical and social asset measures into a community asset assessment model (CAAM) for subsequent refinement and use; (6) define the market opportunity for biojet including supply chain perceptions and issues; (7) develop streamlined, hotspot, life cycle-based methods for assessing environmental performance of aviation fuels for policy and private procurement; (8) define the market opportunity for select intermediate and/or co-products including supply chain perceptions and issues; and (9) examine select intermediate products, co-products, and allocation methods influencing the environmental assessment and reporting of aviation fuels.

#### Task SM-EPP-1.1 “Public” stakeholders:

Examination of opportunities and barriers for a regional approach to bio-aviation fuels and co-product system requires an assessment of public and informed regional bioenergy stakeholders to develop a social license. The EPP group will develop multiple empirical quantitative measures for core dimensions of creative capacity and social capital to measure community-level resilience and adaptability to change.

In addition, EPP will contribute to the analysis of physical asset constraints through GIS application, and explore potential NARA community concerns to better understand key supply chain community issues with regard to regional bioenergy infrastructure projects.

### Task SM-EPP-1.2 –. Review sustainability approaches:

Examination of opportunities and barriers for a regional approach to bio-aviation fuels and co-product system also requires an assessment of environmental performance to ensure technologies meet policy and market requirements. The EPP group will review existing life cycle assessment studies of aviation biofuels and related technologies, public and private labeling, disclosure and certification standards, and renewable energy socio-political analyses. Specifically, EPP will examine the role of procurement and pre-commercial procurement policy in facilitating the improvement of environmental performance and market development of aviation biofuel technologies.

### *Task SM-EPP-1.3* – Review regional Bioenergy Stakeholder Perceptions:

While scientific, infrastructure, and community asset development are significant and important to the success of this emerging industry, key questions must also be addressed regarding the perceptions, experiences, trust and potential acceptance/rejection of this emerging industry by local informed stakeholders. This task will examine previous research to better understand salient issues, stakeholder groups, mixed methods measurement constructs and preliminary protocols for conducting relevant stakeholder research.

### Task SM-EPP-1.4

This task operationalizes informed stakeholder mixed-method surveys in the Western Montana Corridor and the I-5 Corridor (West Side).

### Task SM-EPP-1.5

This task is scheduled to begin Q1 – '14. One goal of tasks 1, 3 and 4 is to refine this work into a usable model for subsequent application to addition NARA region and national sites. This will be accomplished through additional community-level stakeholder interviews, as warranted. Ultimately, a refined community asset assessment model (CAAM) is envisioned that may be applied to biofuel development issues throughout the NARA region and to other U.S. regions. This model may then be re-calibrated to apply to other US regions and to additional community asset situations, such as preparedness and response to wildfire.

### Task SM-EPP-1.6 – Techno-Market Assessment: Jet Fuels:

One particular area of the aviation fuels space is biojet. This research will specifically target the supply chain aspect of biojet, from biorefinery to flight. Opportunities for utilizing petroleum industry supply chain networks, and the challenges that must be overcome to bring biojet to commercial scale, will be examined.

### Task SM-EPP-1.7 – Economic, Environmental & Social Assessment: Jet Fuels:

Working closely with the LCA team, streamlined hotspot methods will be developed to estimate likely changes to $CO_2$ and water use performance within the isobutanol pathway and across aviation biofuel pathways likely to be available to procurers.

### Task SM-EPP-1.8 - Techno-Market Assessment: BioProduct Polymers:

This task is scheduled to begin Q3 – ’13; however, due to leadership requests, we are using a Spring semester ’13 graduate course at Penn State to jump-start this effort.

### Task SM-EPP-1.9 – Economic, Environmental & Social Assessment: BioProduct Polymers:

Given the wide variety of design configurations of a regional advanced biorefinery, pathways including intermediate product diversion and co-product production will be assessed through parameterization of the streamlined LCA tool developed in Task 7. Specifically, allocation and displacement methods will be developed to account for energy and non-energy intermediate/co-products. These approaches will inform policy and market programs seeking guidance for procurement and sourcing, as well as improved consequential approaches to LCA (changes to relevant environmental flows in response to possible decisions).

## Activities and Results

To fulfill task EPP-1.1, a preliminary biogeophysical and social asset assessment of the NARA region to predict public bioenergy behaviors has been completed. This work has resulted in two proceedings papers focusing on: (1) the Western Montana Corridor – presented at an international conference of the Society of Wood Science & Technology in Beijing, China (Fall 2012); and (2) the 4-state NARA region – presented at the 2012 Sun Grant Conference in New Orleans, LA, USA. A refined analysis is in progress to target a journal article. Accordingly, we are currently refining the biogeophysical criterion and the social asset dataset which currently contains 525 column variables for all 3,108 US counties. Initial retrospective analysis (RA) is underway. RA utilizes studies previously conducted in the NARA region to demonstrate how the various NARA datasets may provide predictive capacity with respect to high and low sites. Further analysis, validation, refinement and calibration of the NARA region biogeophysical and social assets are in progress. Specifically, RA will be expanded for Community Asset Assessment Model (CAAM) weightings and “ground truthing” via primary data collection (quantitative and qualitative) as required for model validation and calibration. A completed CAAM will assist the NARA project in identifying communities and sites relevant to a biojet supply chain in the Pacific Northwest (PNW) (Figure 1). Identified communities may be viewed as more “physically” and “socially” receptive to potential biojet infrastructure economic development activities.

Task EPP-1.2 has been successfully accomplished. A thorough review of the literature has been completed. Specifically, key governmental policy drivers (RFS2/EISA 2007, FCEA 2008, EO 13514 and 13423, EU Blending Mandate, etc.), voluntary initiatives and standards (USDA Biopreferred, RSB, IATA, ATA, etc.) and aviation biofuel LCAs were reviewed. This review suggests overwhelming evidence of the importance of flexible and scalable life cycle assessment approaches to accommodate the speed of innovation and increased process complexity associated with advanced biorefineries. Our review also confirmed the continued integration of life cycle approaches in current and anticipated public policies aimed at stimulating fossil fuel/product substitution.

Task EPP-1.3 has been successfully accomplished. A thorough review of the literature has been completed, relevant constructs developed and pre-tested, and stakeholder populations within the NARA region identified.

Task EPP-1.4 calls to operationalize informed stakeholder surveys. From the identified informed stakeholder populations derived from multiple sources with expert assistance from NARA Outreach Team members, purposive sampling using maximum variation through touch point coding was employed. Mixed method primary data collection instruments have been developed and pretested in the Western Montana Corridor and the I-5 Corridor (West Side). Approximately 325 potential interviewees have been identified and data collection is currently underway. The data will include demographics plus various psychographic measures, including knowledge, concerns, and trust related to forest management, biomass, and liquid biofuels issues. The EPP team is scheduled to complete informed stakeholder data collection in the second quarter, 2013 with analysis, report and publication writing and presentations in year three. Efforts have been made to coordinate constructs with similar USDA-NIFA AFRI CAP projects underway by Drs. Saul (UI), Dasmohapatra (NCSU - IBSS), and Asah (UW-AHB) with the hope of integrating a “National Biomass to Biofuels SH Assessment” meta-analysis.

Task EPP-1.5 is scheduled to begin in the first quarter, 2014 but we hope to jump-start this activity to commence in the fourth quarter, 2013. Triangulation of stakeholder assessment data is anticipated to further refine, validate and calibrate the biogeophysical and social asset mapping efforts (Task EPP-1.1). In this regard, additional primary data collection in year three may be warranted.

Task EPP-1.6 is to provide a Techno-Market Assessment for Jet Fuels. A poster presentation outlining the work of the Bio-APEX team was prepared for the 2012 Annual NARA Conference in Missoula, MT (Adeniran, et al., 2012) including an updated view of regional aviation fuel demand centers in the NARA region (Fig. 3). An updated, but still preliminary literature review of “Biojet in the US” was provided in the Oct.-Dec. ’12 quarterly report and included a context and background on biofuel and biojet market opportunities, supply chains, environmental impacts and governmental regulations. Preliminary data on primary US airports is being assembled, supply chain alliances examined, and the regulatory/ environmental impacts studied. Due to a variety of concerns with traditional petro-based aviation fuels, the biojet segment has received tremendous attention by various industrial and governmental stakeholders. This research effort specifically targets the supply chain, from the biorefinery-to-flight. Opportunities for utilizing petroleum industry supply chain networks, and the challenges that need to be overcome to bring biojet to commercial scale, are under examination.

Task EPP-1.7 was altered following the year one annual meeting and commenced in the fourth quarter, 2012. Parameterization is scheduled to begin the third quarter 2013, but we hope to jump-start this activity earlier in the summer of 2013. While collaboration with SH NARA toward social hotspots has begun, no efforts are currently planned to include social dimensions from an LCA perspectives (subtasks 43 & 54). However, this integration will be re-visited within Task 10 (years 4 & 5). Similarly, subtasks 45 & 55 will likely be delayed, given more rapid development of co-product LCA models and parameterization. A preliminary model of the isobutanol life cycle using woody biomass has been completed. The model is based on data obtained in the literature, with the exception of the wood harvest stage, which used measured data developed by the NARA LCA team. The model is structured such that measured data taken within other NARA project teams can be substituted as it becomes available, thus improving the accuracy and applicability to the NARA project. This model of the isobutanol production pathway will serve as a baseline technology platform by which variant process design pathways, intermediate product diversions and co-product production modules will be integrated through parameterization

Task EPP-1.8 is scheduled to begin Q3–’13; however, due to leadership requests, we are using a graduate course at Penn State to jump-start this effort beginning Spring semester ’13. [NOTE: We also jump-started Task 6 Spring semester ’12 through a Penn State graduate class 6 months early.] We are currently conducting a review of the literature to examine biorefinery intermediate and co-products with the greatest potential for commercial success with special applications to the NARA project. World bioplasitcs capacity is projected to quadruple from 2011 to 2016. Bio-PET 30, expected to have an 80% market share in 2016, will be driven by branded beverage companies. Other low-hanging bioplastics products, such as PLA and PHA, will likely remain key bioplastic product categories.

Task SM-EPP-1.9 was altered following the year one annual meeting and is scheduled to commenced in the third quarter 2013, however, efforts toward this task began in the first quarter ‘13. No efforts are currently planned to include social dimensions from an LCA perspectives (subtasks 43 & 54). Similarly, subtasks 45 & 55 will likely be delayed, given more rapid development of co-product LCA models and parameterization. Comparisons across intermediate products, co-products and end-use fuel are anticipated to commence in the second quarter, ‘14 for both Tasks SM-EPP-1.7 and SM-EPP-1.9, once parameterized models are further developed.

Based on preliminary findings emanating from the NARA Techno-Economic Assessment (TEA), co-product development (and/or intermediate product diversion) has surfaced as an increasingly important driver of economic viability. In light of these findings, the development of environmental impact modeling for likely co-products has been pushed forward into our current work. In particular, we have begun to explore the development of an LCA module for processes associated with the conversion of lignin to activated carbon. Lignocellulose represents approximately 50% of the wastes from agriculture, municipal sources, forest and agricultural-based industries, yet, less than 2% of the produced lignin is used in commercial applications. Thus, within the last several decades, a variety of researchers have focused interest on lignin as a potential raw material for the chemical industry. Activated carbon is a high-porosity material, very useful in the adsorption of both gases and solutes. Therefore, it has been widely used for the separation of gases, recovery of solvents and removal of organic pollutants from drinking water, as well as a catalyst carbon. As environmental pollution is becoming an issue of increasing concern, the need for activated carbon is growing.

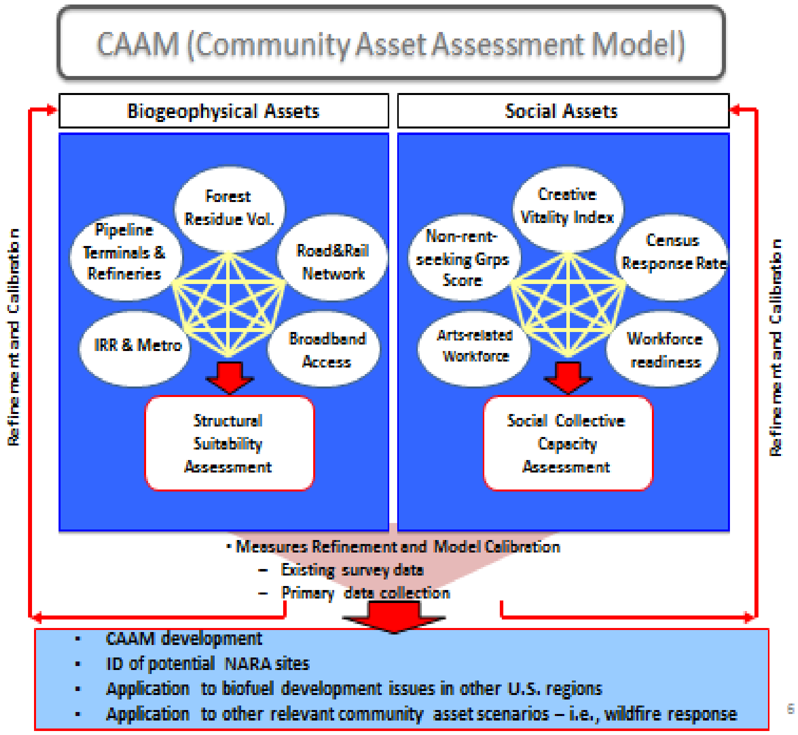


Figure 1. Community Asset Assessment Model Concept.

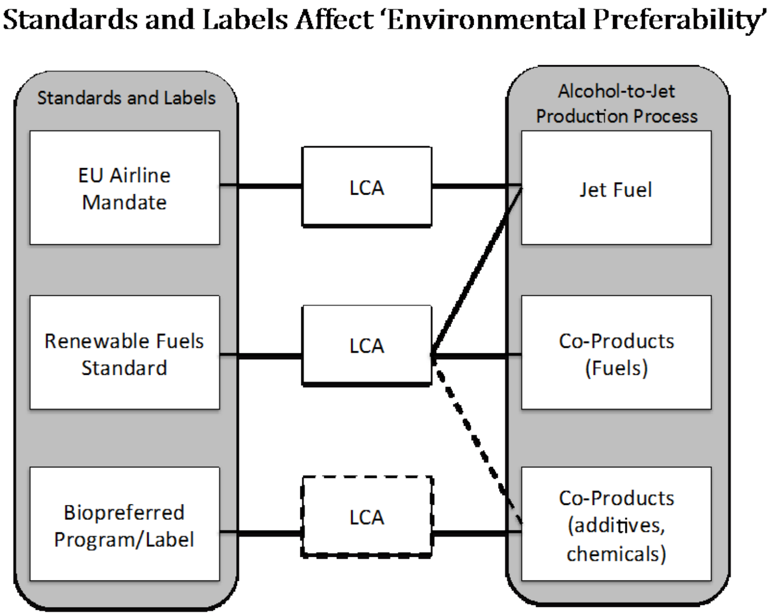


Figure 2. Fuel and product standards influence varying aspects of the alcohol-to-jet fuel production process.

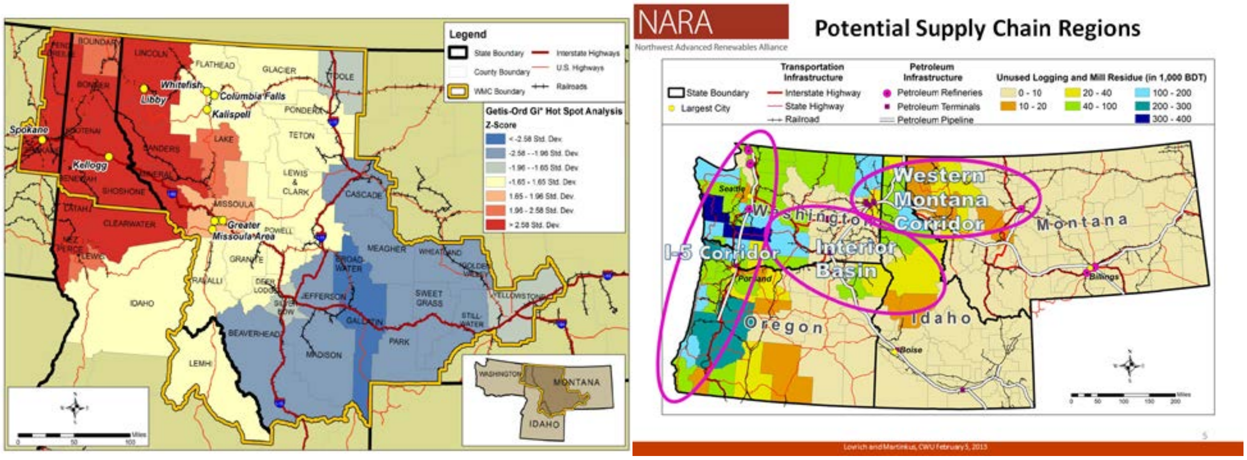


Figure 3. Potential NARA Region Supply Chain Configurations.

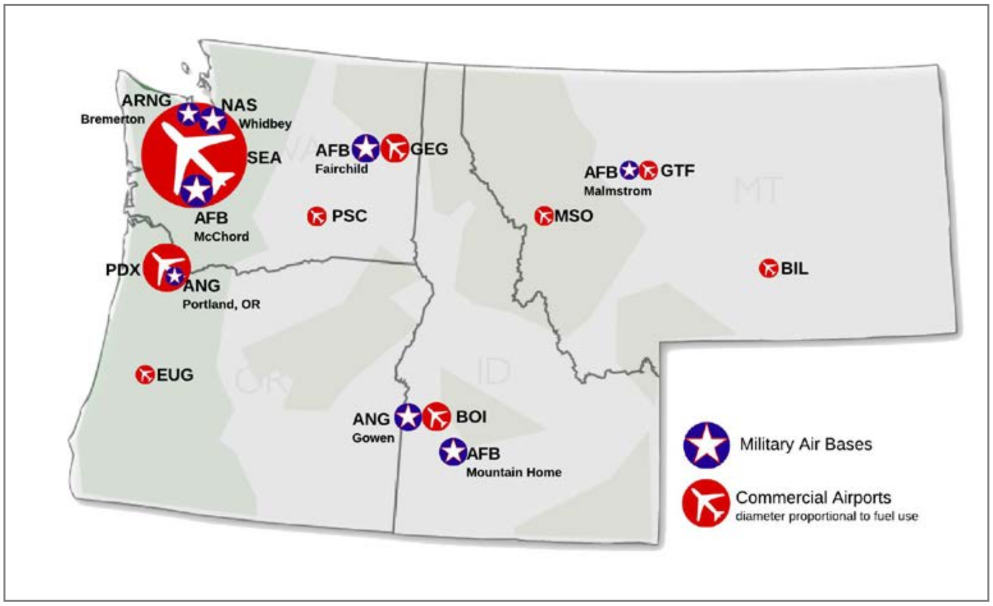


Figure 4: Regional demand centers in the NARA Region in 2011 (circle size represents relevant market size) (Map provided by Martinkus, N., M. Wolcott, P. Smith, and S. Wertz).

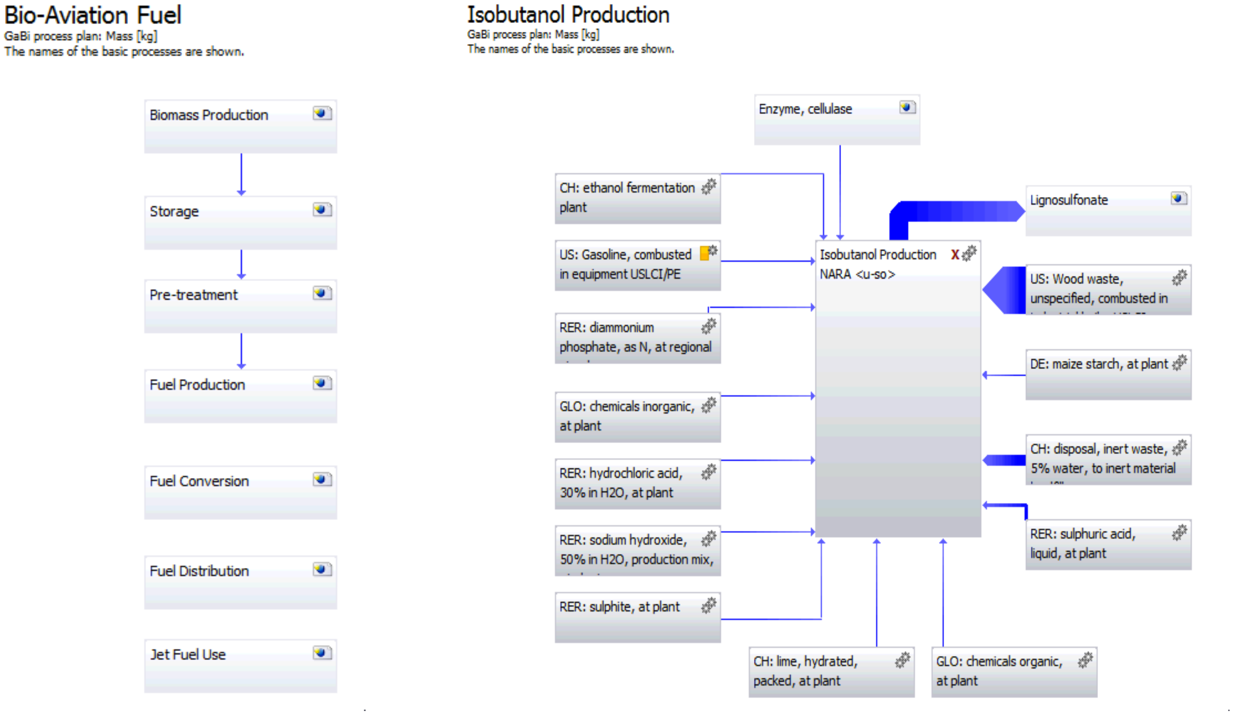


Figure 5. Initial structure of the isobutanol-to-fuel production pathway.

## Recommendations/Conclusions

**Tasks EPP-1.1, 1.3, 1.4, and 1.5:** This work has built an extensive national social asset dataset at the county level. Validation of this dataset has led the EPP team toward retrospective analysis utilizing additional datasets available within the NARA region. Validation work is in progress. A thorough literature review of biofuel-to-energy stakeholder studies has been completed, resulting in the operationalization of a mixed method survey instrument. Data collection from approximately 325 informed stakeholders in the NARA region is in progress. Results will: (1) aid our understanding of the region's knowledge, concerns, and trust related to forest management, biomass, and liquid biofuels issues; (2) provide valuable validation, refinement, and calibration to the Task EPP-1.1 Community Asset Assessment Model (CAAM); and (3) combine with similar USDA-NIFA efforts in other regions of the US for an integrated meta-analysis.

**Task EPP-1.2:** Our review of policies, standards, and disclosure/labeling initiatives have informed future work planned and under developed by EPP. Specifically, the socio-technical nature of renewable energy development in the U.S. will undoubtedly require the integration of mandatory compliance (local direct regulation to state [RSP] and national mandates [RFS]), voluntary market standards (industry emissions reduction targets to governmentally sanctioned voluntary labeling standards), technical viability (cost drivers, resource constraints, supply and distribution compatibility, etc.) and market adoption (pre-commercialization procurement, environmental preference, price, etc.). Our review also informs future environmental assessment methodologies important to determining the viability of advanced biofuels and products in key policy and standards (access to RIN and REC markets, for example). Results have aided in the development of LCA-based methodologies useful to pre-commercialization procurement policies and renewable energy standards.

**Task EPP-1.6:** A definition of the market opportunity for select aviation fuels in the NARA region provided scope and strategic insight into target segments within the aviation market. This led to a more complete literature review of state-of-the-art US biojet including insight into biojet market opportunities and cost drivers, petroleum and biojet supply chain designs, refineries, pipelines, and fuel farms, and environmental impacts and government regulations impacting biojet, capital availability and technology adoption-diffusion (as contained in the Oct. – Dec. '12 quarterly report). As a result, the EPP team has developed a preliminary dataset of primary airports in the US to begin a more in-depth examination of key supply chain issues, from the biorefinery-to-flight, that impact this market space.

**Task EPP-1.7:** Initial work on this task has set the stage for several analyses regarding potential process design pathways and co-product selection. The isobutanol-to-fuel production pathway has several areas where inputs or processes that could be altered (e.g. pretreatment options, pre-process options, feedstock choices, etc.), which have been shown in the literature to potentially, and materially, affect environmental impacts. While current LCA-based models affecting policy implementation (i.e. GREET and EPA-RFS2) provide excellent assessment of individual fuel pathways, they currently do not allow for detailed 'plug-and-play' capabilities, reflective of the complexities of advanced and cellulosic production – particularly biochemical pathways. The streamlined approaches suggested in this task will help inform more in-depth analysis of key process technologies and provide a simplified comparative assessment of fuels to market actors voluntarily seeking lower impact fuels.

**Task EPP-1.8:** A thorough literature review of biorefinery intermediate and co-products, leading to a market definition for these biorefinery value chain ouputs, is in progress.

**Task EPP-1.9:** This task has only recently begun. A central focus of this task is to develop appropriate modified process maps of likely aviation biofuels and parameterized (streamlined) modules for comparison. These comparisons will be instrumental to private voluntary standards, the development of public policy rulemaking and to emergent policy interaction between energy and non-energy products. Our modeling work in this area will focus heavily on the integration of different allocation methods (with regard to co-product development) and "consequential" LCA approaches (with regard to decisions associated with intermediate product diversion).

## Physical and Intellectual Outputs

### Physical

- Stakeholder research instruments have been created and pre-tested, and are currently being operationalized.

- A US biojet market overview has been developed. This document includes insight into biojet market opportunities and cost drivers, petroleum and biojet supply chain designs, refineries, pipelines, and fuel farms, and environmental impacts and government regulations impacting biojet, capital availability and technology adoption-diffusion.

- An isobutanol-to-fuel LCA module, developed in the GaBi software suite. This module will be instrumental to both the EPP and LCA groups and serves as a baseline model for parameterization.

## Intellectual

- A social asset dataset containing 525 columns of data has been developed and is currently being validated via retrospective analysis.
- An "outside-in" hotspot methodology for LCA-based product comparisons (see Pelton et al. 2013).

## Refereed Publications (accepted or completed)

Fischlein, M., Smith, T. 2013. Revisiting renewable portfolio standard effectiveness: policy design and outcome specification matter, Policy Sciences, DOI 10.1007/s11077-013-9175-0.

Smith, T.S., Molina, S., Anderson, B. 2013. Toward the Convergence of Public and Private Forest Policy, in Green Forest Policies, Taylor & Francis. *In press*.

Pelton, R.E.O, Smith, T.M. , Lahd, H. 2013. Assessing Hotspot Assessment: A Procurement Perspective. Journal of Industrial Ecology. *In review*.

## Conference Proceedings and Abstracts from Professional Meetings

Lovrich, N., W. Shi, N. Martinkus, P. Smith, J. Pierce, A. Kulkarni, M. Gaffney, M. Wolcott, and S. Brown. Integrating Social Capital In Biojet Feedstock Facility Siting Decisions. In Proceedings of the Sun Grant Initiative 2012 National Conference: Science for Biomass Feedstock Production and Utilization, Oct. 2-5, 2012 in New Orleans, LA, USA. *In-press.*

Martinkus, N., A. Kulkarni, N. Lovrich, P. Smith, W. Shi, J. Pierce, M. Wolcott, and S. Brown. 2012. An Innovative Approach to Identify Regional Bioenergy Infrastructure Sites. In Proceedings of the 55th International Convention of Society of Wood Science and Technology, August 27-31, 2012, Beijing, CHINA.

## Research Presentations

Gagnon, K., P. Smith, I. Eastin, I. Ganguly. 2012. Stakeholder Perceptions. Presented at the Western Montana Corridor NARA Community Roadmap Development Meeting. University of Montana, Missoula, MT. 13 June.

Martinkus, N., A. Kulkarni, N. Lovrich, P. Smith, W. Shi, J. Pierce, M. Wolcott, and S. Brown. 2012. An Innovative Approach to Identify Regional Bioenergy Infrastructure Sites. Presented at the Western Montana Corridor NARA Community Roadmap Development Meeting. University of Montana, Missoula, MT. 13 June.

Adeniran, P., A. Chatterjee, C. Grassi, A. Kulkarni, J. Quezada, A. Hawkins, J. Scheib, and P. Smith. 2012. Strategic Marketing Plan for Biofuels in the NARA Region. Presented at the Western Montana Corridor NARA Community Roadmap Development Meeting. University of Montana, Missoula, MT. 13 June.

Martinkus, N., A. Kulkarni, N. Lovrich, P. Smith, W. Shi, J. Pierce, M. Wolcott, and S. Brown. 2012. An Innovative Approach to Identify Regional Bioenergy Infrastructure Sites. Presentation to the

Society of Wood Science and Technology International Convention at the International Centre for Bamboo and Rattan, Aug. 27-31 in Beijing, China.

Lovrich, N., W. Shi, N. Martinkus, P. Smith, J. Pierce, A. Kulkarni, M. Gaffney, and M. Wolcott. 2012. Physical and Social/Community Asset Mapping in the NARA Region. Presentation at the NARA Annual Meeting, Sept. 14 in Missoula, MT.

Gagnon, K., P. Smith, T. Laninga, J. Marotz-Maroney, M. Vashon, M. Gaffney, I. Ganguly, I. Eastin, and V. Yadama. 2012. Stakeholder Perceptions. Poster presentation at the NARA Annual Meeting, Sept. 14 in Missoula, MT.

Adeniran, P., A. Chatterjee, C. Grassi, A. Kulkarni, J. Quezada, P. Smith, A. Hawkins, J. Scheib, M. Wolcott, and S. Wertz. 2012. Strategic Marketing Plan for Biofuels in the Pacific Northwest. Poster presentation at the NARA Annual Meeting, Sept. 14 in Missoula, MT.

Nicholas Lovrich, N., W. Shi, N. Martinkus, P. Smith, J. Pierce, A. Kulkarni, M. Gaffney, M. Wolcott, and S. Brown. The Physical and Social Assets Mapping in the NARA Region. Poster presentation at the NARA Annual Meeting, Sept. 14 in Missoula, MT.

Martinkus, N. GIS as a Decision Support Tool for Supply Chain Analysis in the Western Montana Corridor. Presentation at the NARA Annual Meeting, Sept 14 in Missoula, MT.

Martinkus, N., T. Morgan, M. Wolcott. GIS as a Decision Support Tool for Supply Chain Analysis in the Western Montana Corridor. Poster presentation at the NARA Annual Meeting, Sept. 14 in Missoula, MT.

Smith, P. 2012. NARA and Environmentally Preferred Products (EPP). Presentation at the Penn State Dept. of Agricultural and Biological Engineering Fall Seminar Series. Sept. 25.

Smith, P., P. Adeniran, A. Chatterjee, C. Grassi, A. Kulkarni, J. Quezada, A. Hawkins, J. Scheib, S. Wertz and M. Wolcott. 2012. Strategic Marketing Plan for Biofuels in the NARA Region. Presentation at the Penn State Dept. of Agricultural and Biological Engineering Fall Seminar Series. Sept. 25.

Lovrich, N., W. Shi, N. Martinkus, P. Smith, J. Pierce, A. Kulkarni, M. Gaffney, M. Wolcott, and S. Brown. Integrating Social Capital Into Biojet Feedstock Facility Siting Decisions. Presentation at the Sun Grant Initiative 2012 National Conference: Science for Biomass Feedstock Production and Utilization, Oct. 2-5 in New Orleans, LA, USA.

Lovrich, Nicholas and N. Martinkus [with assistance from: P. Smith, J. Pierce, W. Shi, A. Kulkarni, M. Gaffney, M. Wolcott and S. Brown]. 2013. Cultural Assets and Sustainable Economic Development. Presentation at Central Washington University, Hal Holmes Center, Co-sponsored by Kittitas Environmental Education Network (KEEN), Forterra, the Ellensburg Public Library, CWU's College of Arts and Humanities, Academic Service Learning-Faculty Fellows, and the Departments of Political Science, Anthropology, Geography, and the Resource Management Program. Feb. 5.

Smith, T.M., Pickens, R. The Role of Private Governance in the Emergent Global Green Technology Policy Regime, Transnational Governance Interactions (TGI) – Theoretical Approaches, Empirical Contexts and Practitioners' Perspectives, Research Workshop, at the European University Institute in Florence, Italy, May 23, 2011.

Smith, T.M., Lahd, H., Olson, R. Using Life Cycle Assessment to Evaluate Ecolabel Claims, 23rd Annual POMS Conference: Socially Responsible Operations, Chicago, IL, April, 22, 2012.

## Other Publications

Smith, T.M. 2013. Climate Supply Chain Risks: Bringing corporate sustainability out of the basement and into the supply chain, Bulletin of the Atomic Scientists. *In press*.

Olson, R., Smith, T.M. 2012. Exploring the Long-Term Feasibility of Pursuing Bio-Aviation Fuels Land Constraints and the Environmental Implications. Bioproducts and Biosystems Engineering and Institute on the Environment, UMN.

## Videos and Webinars

Initiative in Focus Webinar, "Procurement in Sustainability: from buying green products to creating green solutions," with Kevin Dooley, Chief Research Officer, The Sustainability Consortium, Nancy Gillis, Director, GSA Federal Supply Chain Emissions Program Management Office (PMO), Timothy M. Smith, Director, NorthStar Initiative for Sustainable Enterprise. February 21, 2012. https://umconnect.umn.edu/p21956633/

## Trainings, Education and Outreach Materials

- Bio-Based Sustainable Transformations & Resilient Technologies. Duke University, in collaboration with Yale University and Arizona State University. February 16-17. Approximately 50 people in attendance.
- LCA Modeling Workshop. Julie Sinistore (UW-Madison/Virent Inc.), Dr. Jason Hill, Dr. Tim Smith and Holly Lahd hosted a day-long workshop on LCA Modeling, February 24, 2012. Approximately 20 students, faculty, and local policy makers attended.
- Business Roundtable (~20 participants) and National Security & Our Energy Future Forum (~75 attendees) with Admiral Neil Morisetti, United Kingdom's Climate and Energy Security Envoy. Co-hosted by former State Representative, Jeremy Kalin.
- Biomass Feedstocks: Supply Chain Risks and Rewards, Nov. 29-30, 2012, American Chemical Society, with Duke U. (J. Golden) and Yale U. (P. Anastas), Invitation only: approx. 50 people.

# LCA and Community Impact Team

## SM-LCA-1: LCA Assessment of Using Forest Biomass as a Feedstock for Biofuel

| Key Personnel | Affiliation |
|---|---|
| Ivan Eastin | University of Washington |
| Robert Harrison | University of Washington |
| John Perez-Garcia | University of Washington |
| Elaine O-Neil | University of Washington |
| Indroneil Ganguly | University of Washington |
| Tait Bowers | University of Washington |
| Tim Smith | University of Minnesota |
| Tom Spink | TSI |
| Gevan Marrs | Weyerhaeuser |
| Glenn Johnson | Weyerhaeuser |
| Junyong Zhu | USDA-Forest Products Laboratory |

### Task Description

This research module will provide a definitive Life Cycle Assessment of using woody biomass for the production of bio-jet fuel. Understanding the environmental consequences of this technology is necessary if woody biomass is to be widely used for jet fuel. In addition, an LCA on greenhouse gas emissions will be necessary to qualify jet fuel made from forest biomass under the Energy Independence and Security Act (EISA) of 2007 and the EPA guidelines promulgated to meet the new requirements of the Act (EPA 2009). To meet this objective we will combine biomass growth/yield models and life cycle assessment (LCA) models to develop life cycle environmental profiles for specific woody biomass feedstocks matched with the proposed jet fuel processing technology. The results of this analysis will be used to develop LCAs for greenhouse gases (GHG) and other environmental performance indices for comparisons between cellulosic jet fuel and fossil jet fuels. Alternative technologies, and their impacts on the value chain, will be compared for different forest treatments, harvesting and collection equipment and processing alternatives. Feedstock qualities will be matched with processing alternatives and regional feedstock scales of availability matched with efficient scale processing infrastructure. Alternative configurations and policy assumptions covering a range of scenarios will be used to project potential regional reductions in GHG emissions and energy dependence as well as rural economic impacts. The impacts of different policies and other alternatives will be characterized as sensitivity scenarios to better inform the adoption of appropriate policies, marketing, and investment strategies to reach energy independence goals with reduced GHG emissions while effectively managing cellulosic resources.

This revised scope of work makes several assumptions that need to be explicitly noted:

1) We assume that funding for Gevo's participation in the LCA analysis will be brought forward so that they can begin to participate in the LCA immediately.
2) We assume that the second NARA community will be identified by the end of project year two.
3) We assume that the final pretreatment process will be selected by the end of project year two.

## Activities and Results

### Soil Carbon Team

During the period August, 2011 - March, 2013 we have completed significant work on analysis of the sustainability of additional biomass removal from current production Douglas-fir plantations in the coastal region of the PNW relative to ecosystem nitrogen. Several presentations were made, including at NARA meetings, meetings of the Northwest Stand Management Cooperative, an industry cooperative of the primarily forest landowners and managers in the region, the Pacific Rim Meeting on Bioenergy and Bioproducts in Vancouver, Washington, and the Soil Science Society of America. Presentations will also be made at the upcoming Soil Science Society of America meeting. We have the draft of a journal article written by previous graduate student Austin Himes, who now works for GreenWood Resources, and Postdoctoral Research Associate Warren Devine, who has taken employment as a land manager for Joint Base Lewis-McChord in Washington State. The results show that industrial forest stands are likely resilient to high levels of additional biomass removal for bioenergy (Figure 1). Kim Littke finished her degree and is currently working for Port Blakeley Tree Farms as a research scientist. She continues to work on issues of sustaining and enhancing forest productivity.

We have made significant progress toward completion of a study of the role of deep soil in the functioning of forested ecosystems relative to their potential for sustained productivity with respect to additional biomass removals for biofuel production. We have sampled 26 sites within the primary Douglas-fir production plantation zone in coastal Washington and Oregon to depths of up to 4 meters, something that has never been done in the region. Results indicate deep soil is a substantial carbon and nutrient pool that is typically ignored, in some cases accounting for more than half of ecosystem carbon. The potential for changes in this pool have also been indicated in other studies, but we are not sure how to approach this potential in the NARA work. Graduate student Jason James is working on the draft of a manuscript.

MS graduate student Erika Knight is writing her MS thesis on this topic, and the literature review for Item 12 is part of her MS work. She is expected to complete her thesis work by June, 2013. Some initial results are compelling. For instance, Figure 2 shows that suppressing competing vegetation with herbicides enhances soil carbon, though only deep in the soil profile, probably because of the proliferation of tree roots without competing vegetation. PhD student Marcella Menegale, who started in Fall, 2012, has started working on this project and will continue the literature reviews.

MS graduate student Erika Knight and PhD student Marcella Menegale are continuing cooperative work with Weyerhaeuser, Oregon State University and the U.S. Forest Service, including processing and analyzing soil samples taken from the Fall River long-term soil productivity study for Item 13. The work was initiated by Paul Footen, now employed by the Washington Department of Natural Resources. Daramola Tolulope, a visiting fellow of the International Tropical Timber Organization will also be working on soil carbon field techniques in our NARA sites and studies with the goal of taking what he has learned back to his native country of Nigeria to improve management of tropical forests there in terms of soil carbon sequestration and utilization of forests for bioenergy.

We are adding two additional students that will work on NARA projects this summer/fall, Christiana Dietzgen, a graduate student who was awarded a full fellowship to study at the University of Washington, and Erin Burt, who will start working on her master's degree.

## Community Impact Assessment Team

The goal of this research is to assess the economic impacts associated with the production of bio-jet fuel using forest-based materials in areas within the region encompassed by Idaho, Montana, Washington and Oregon at broad regional and smaller community levels. The study does so by reviewing, developing and using economic models that consider the industries and institutions that make up the economic and social infrastructure in the region. We have examined existing input/output models. We have constructed preliminary social accounting matrices (SAM) that contain the intra-industry relationships as well as the capital and labor flows needed to assess the impact from biojet fuel production. We have reviewed and adapted computable general equilibrium models that utilize the SAMs to analyze taxes, subsidies and programs that may promote or constrain activities related to bio-jet fuel production.

***Input/Output Analysis:*** I/O analyses produce multipliers useful in impact analysis. The multipliers quantify how an external change in final demand will impact the various suppliers of production factors and producers of commodities in the economy. For example, an additional $50 million spent by wood manufacturers in Lakehead County, Montana would raise the value of output from other manufacturing industries by $12.4 million ($50 million x 0.2481) and the total county economy by $28.7 million ($78.7million - $50 million; where $78.7 million represents the sum of multiplier effects across all sectors of the additional spending by the wood manufacturers ($50 million x each multiplier in the highlighted column in Table 1, Wood Manufacturing labeled column). Common multipliers defined include total jobs multipliers, total employment multipliers, labor income multipliers and total output multipliers. Table 1 lists total output and employment multipliers. The employment multiplier can be interpreted to mean that for every new job added in the Wood Manufacturing sector, there would be an estimated 3.13 additional jobs (4.13 – 1.00) created throughout the county economy.

***SAM Analysis:*** Several assumptions limit the applicability of I/O analysis results including the inability of these models to capture internal investment activities funded by tax dollars from government accounts for example. SAM analysis expands the intra-industry transaction tables to include all monetary flows from sources to recipients. A highly aggregated SAM for Lakehead County is presented in Table 2. The table contains data used directly by computable general equilibrium models, and it also allows us to describe the flow of transactions describing Lakehead County's economy. For instance, with the aggregation scheme used to collapse over 400 industrial activities into nine, the data suggests that the county's balance of trade with respect to wood manufacturing activities is negative, i.e., it imports $262.4 million from neighboring counties, states and internationally while it exports $49.4 million. The value of its wood products manufacturing is comparable to food manufacturing, wholesale and retail trade activity each, but it is only a small fraction of other manufacturing activities (see "Total" column values in Table 2 for each sector mentioned). The SAM analysis will allow us to describe the economic activity in those regions where a proposed bio-jet fuel facility may be constructed.

***CGE Modeling:*** A general equilibrium modeling framework has been developed adapting models from Lofgren (2003) and McCullough et al., (2011). The Lofgren model consists of producers and consumers, who maximize profits and utility respectively, subject to production functions and budget constraints. A government sector is included as well as standard assumptions about factor mobility, unemployment and trade. The McCullough model is an adaptation of Lofgren that expands the CGE model to study biofuel related goals in the state of Washington. The policies studied include fuel blend mandates and tax/subsidy regimes. The McCullough study focused on the production of biodiesel using agricultural crops. A representation of the CGE developed for the assessment of bio-jet fuels is presented in Table A1 in the appendix of this report.

***Data Collection:*** The construction of the I/O tables and social accounting matrices requires transaction data. For Washington State, these data are available from the Washington Office of Fiscal Management, and have recently been updated. For other states, these transaction data are available from IMPLAN, Inc. The University of Idaho has recently acquired IMPLAN data for the four states, and we are working collaboratively to produce the community impact assessment.

### Life Cycle Assessment Team

During the first phase of the project (August, 2011 - March, 2013) a comprehensive literature review was undertaken and various LCA approaches were evaluated for the NARA bio jet fuel project. Upon thorough review of the proposed approaches and the compliance requirements it was established that the primary focus will be on attributional LCA. The research team further determined that though consequential LCAs are not required by the ISO standards, it is of prime importance to understand and analyze the long term environmental benefits of the proposed activities. Moreover, the results obtained from the consequential LCAs will play critical role in various advocacy and fundraising activities to economically sustain the program. Accordingly, primary consequential scenarios of the proposed activities are also reviewed and developed for the project. Two primary scenarios identified for Inland Empire are incorporation of (i) avoided environmental cost of slash pile burning and (ii) avoided environmental cost of catastrophic forest fires within the consequential LCA framework. On the pretreatment, final processing and delivery and distribution part of the bio-jet fuel the team will focus on the attributional LCA.

To be able to estimate the overall environmental footprint of the proposed bio-jet fuel, an integration of knowledge and research from the fields of forestry, logistics, energy economics and chemical engineering into energy industry research is crucial. Life cycle analysis (LCA) is a computational tool that transcends the disciplinary boundaries and can be used to evaluate the environmental sustainability of a bio-jet fuel industry. In this regard, we undertake the complete LCA starting from the seedling development up to the bio-jet fuel delivery to the pump. A broad overview of the process is depicted in Figure 3.

## Overview of research findings/papers

**Harvest and transportation scenarios:** This paper presents the results of a series of LCA analyses comparing various harvesting and transportation scenarios associated with forest residuals collection in the Pacific Northwest region as a feedstock for bio-jet fuel. Emissions generated and total energy use was calculated for various harvesting and feedstock transportation scenarios to evaluate the optimal solutions and minimize environmental burdens, measured in terms of global warming and acidification potentials. In these scenario-based comparisons, emissions associated with traditional tree skidding are compared with the alternate harvesting scenarios of cable-yarding and helicopter-yarding. For the transportation scenarios, hauling forest residuals directly to a biomass processing facility is compared with two alternate transportation scenarios: 1) hauling forest residuals to a central landing for chipping and 2) transporting chips to a biomass processing facility. The results reveal that the forest road transportation of loose residue is the primary contributor to global warming potential for woody biomass. Options that reduce the carbon footprint associated with loose residue collection may be critical in reducing the overall environmental burdens of the process. The results further reveal that strategic forest road development may reduce the global warming potential of feedstock collection over the long run. Results are presented in Figures 4 and 5.

**Avoided environmental burdens of slash pile burning:** The results of a comparative LCA analysis of the avoided environmental costs and impacts of using woody biomass residuals for bio-jet fuel instead of slash pile burning are noteworthy. Forest residuals in the Inland West region are typically left in the forest after harvest, but have to be burned to avoid fuel accumulation on the forest floor. Compared to the alternative of burning the left-over slash piles from harvesting, the environmental impacts of extracting and hauling these residuals to market can be measured by the amount of carbon ($CO_2$) emitted into the atmosphere. Emissions generated for both scenarios were calculated to provide additional credence for the utilization of left over residuals instead of burning the piles and polluting the environment with unfiltered smoke and ash. Environmental burdens were measured in terms of global warming, acidification, smog, and ozone depleting potentials. The results reveal that the avoided GHG emissions from slash pile burning balances out the overall GHG emissions from woody feedstock collection and transportation under the assumed scenario. Moreover, there is a net reduction in the environmental impact resulting from extraction of residuals for the bio-jet fuel project by avoiding slash pile burning for the following indicators: Smog formation, Acidification, and Respiratory Effects. The results are summarized in Table 3.

**Pretreatment and GEVO process:** A factory gate-to-IPK storage life cycle impact assessment using TRACI was prepared for the forest residuals-to-IPK process. To facilitate this analysis, it was assumed that the DOE/NREL corn stover to ethanol process model could be adapted and used to convert forestry residues to fermentable sugars. The Gevo GIFT and Alcohol to Jet (ATJ) processes was used to convert the sugar stream to iso-paraffinic kerosene (IPK). A prototype LCA was undertaken to estimate the life cycle environmental performance of the integrated process of producing IPK from forest residuals.

The life cycle assessment has been carried out for a prospective process of producing IPK from forest residuals (primarily slash and trim materials) using a biochemical conversion process developed by Department of Energy and the National Renewable Energy Laboratory (NREL) to produce a fermentable sugar stream from lignocellulosic biomass. Fermentable sugars are converted to isobutanol (iBuOH) using the Gevo GIFT process. Isobutanol is processed through dehydration of the molecule and oligomerization of isobutene to produce IPK, the main product.

For the purposes of this assessment, the NREL process model mass and energy balance has been modified to accommodate a different feedstock (forest residuals). To this end, high-level process area inputs and outputs were extracted from the model and applied to the integrated NREL/Gevo process. Process cooling, steam and electrical power loads for the two Gevo process areas were then incorporated so that the total biorefinery (and supporting auxiliary systems) loads would reflect both a different feedstock and different products of fermentation and back end chemistry. Modifications were made to the processes areas as needed to account for differences in polysaccharide and lignin content between the two feedstocks. In Table 4 we can observe that after accounting for the avoided emissions from burning the feedstock, the net CO2 emissions for the feedstock process is negligible. Notably, the feedstock process has net beneficial impacts on the four highlighted impact categories: acidification potential, eutrophication potential, smog potential and respiratory effects. The overall environmental impact associated with the bio-jet fuel can be better understood when compared against the emissions associated with fossil based aviation fuel. The following section discusses the LCA emissions associated with transporting 1 metric ton of freight for one kilometer in an intercontinental flight using fossil fuel (kerosene) as compared biofuel (Iso-Paraffinic Kerosene -- IPK).

## Comparative Analysis: Environmental Implications of NARA Bio-Jet Fuel vs Fossil Based Bio-Jet Fuel

Comparable aircraft utilizing biofuels or fossil fuel emit similar levels of carbon dioxide (CO2), which is the primary source of greenhouse gas emissions. However, the primary distinction between biofuels and fossil fuels is the source of carbon stored in the fuel. The environmental footprint associated with burning aviation fuels comes from two primary sources. First, the carbon stored in the aviation fuels is released during combustion. Second, there is a large amount of emissions associated with the extraction, transportation and processing of crude oil into jet fuel. The use of fossil aviation fuels releases geologic carbon that has been stored for millions of years, and those emissions represent a net addition of CO2 to the atmosphere. The NARA bio-jet fuel uses wood residue derived from timber harvest operations as the raw material to produce iso-paraffinic kerosene (IPK) jet fuel. Trees use atmospheric carbon dioxide to grow and burning biofuels simply releases this sequestered carbon dioxide back into the environment. With a sustainable resource harvest system, where the biomass extracted from the forest is less than the biomass growth during a specified time frame, the net addition of CO2 into the atmosphere is negative. However, the conversion of forest woody residue to bio-jet fuel requires various inputs from nature (the atmosphere) and industry (the technosphere). Hence, the overall environmental footprint associated with bio-jet fuel includes all the resources used, emissions and waste generated during the process of biomass growth, collection and conversion into biofuel.

In essence, this project will produce IPK jet fuel as a “drop-in” substitute for fossil-based jet fuel by producing the same molecule synthetically from the bioderived iso-butanol molecule. The major difference between the bio and fossil jet fuel is that the bio-jet fuel consists of a higher ratio of pure C10 and C12 molecules. The comprehensive Life Cycle Assessment (LCA) based ‘cradle to grave’ estimation approach used to calculate the overall environmental footprint of these two types of aviation fuels is generally considered to be the most credible. Moreover, the LCA results will be critical in demonstrating that bio-jet fuel produced from forest residuals meets the greenhouse gas (GHG) reduction target specified in the US Energy Independence Act of 2007. The US Energy Information Administration (EIA) requires that the overall GHG emissions of cellulosic biofuel produce 60% lower carbon emissions (H.R.6: http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf; Argyropoulos 2010: http://www.eia.gov/conference/2010/session2/paul.pdf), relative to fossil fuel-based jet fuel, in order to qualify for public procurement.

The NARA project LCA team, comprising of researchers from the University of Washington, Gevo, WSP Environment and Energy, TSI and the University of Minnesota, has completed a preliminary analyses of the “forest to wake” greenhouse gas emissions of the NARA bio-jet fuel process. The preliminary results obtained from the “forest to pump” LCA analysis are carried forward to combustion in a jet engine during an intercontinental passenger flight to provide a “forest-to-wake” analysis. These results are compared to the same results obtained from combustion of fossil fuel-based jet fuel. The preliminary results of this LCA comparison suggest that the overall global warming potential of the NARA bio-jet fuel, measured in kilograms of CO2 emissions, is just 38.4% that of fossil fuel-based jet fuel (Table 5). In addition, the ozone depletion potential of the NARA bio-jet fuel is approximately 12% that of fossil fuel-based jet fuel while the fossil fuel depletion potential is 39.1% of fossil-based jet fuel. In other words, our preliminary analysis suggests that there is a 61.6% reduction in the global warming potential, an 88.1% reduction in the ozone depletion potential and a 60.7% reduction in fossil fuel depletion by substituting bio-jet fuel for fossil fuel-based jet fuel. This preliminary result is significant in that it exceeds the mandated 60% emission reduction criterion specified in the US Energy Independence Act guidelines.

The LCA team assessed the LCIA data to get an initial determination of what individual processes were contributing to the reduced environmental impacts associated with using the bio-jet fuel as a substitute for the fossil-based jet fuel. Following our preliminary evaluation, it appears that the superior environmental performance of the bio-based jet fuel was due in part to the following factors:

1. A minimal amount of fossil fuel is used during the conversion process, because waste biomass (in the form of lignin), can be substituted for coal and/or natural gas to provide the heat and power needed for the IPK process.
2. The avoided environmental burdens associated with not having to burn the slash piles in the forest reduced the overall environmental footprint of the process.

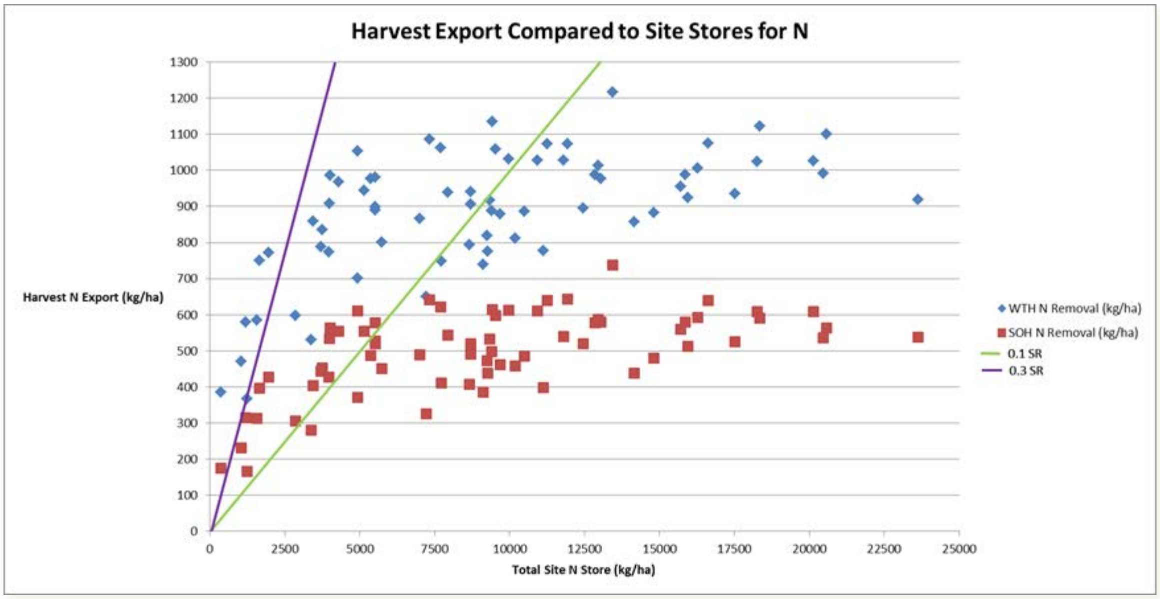


Figure 1. Evaluation of nitrogen removal from 73 forest ecosystems at predicted harvest age for bole-only and whole-tree harvests vs. ecosystem pools of total N to 1 m soil depth.

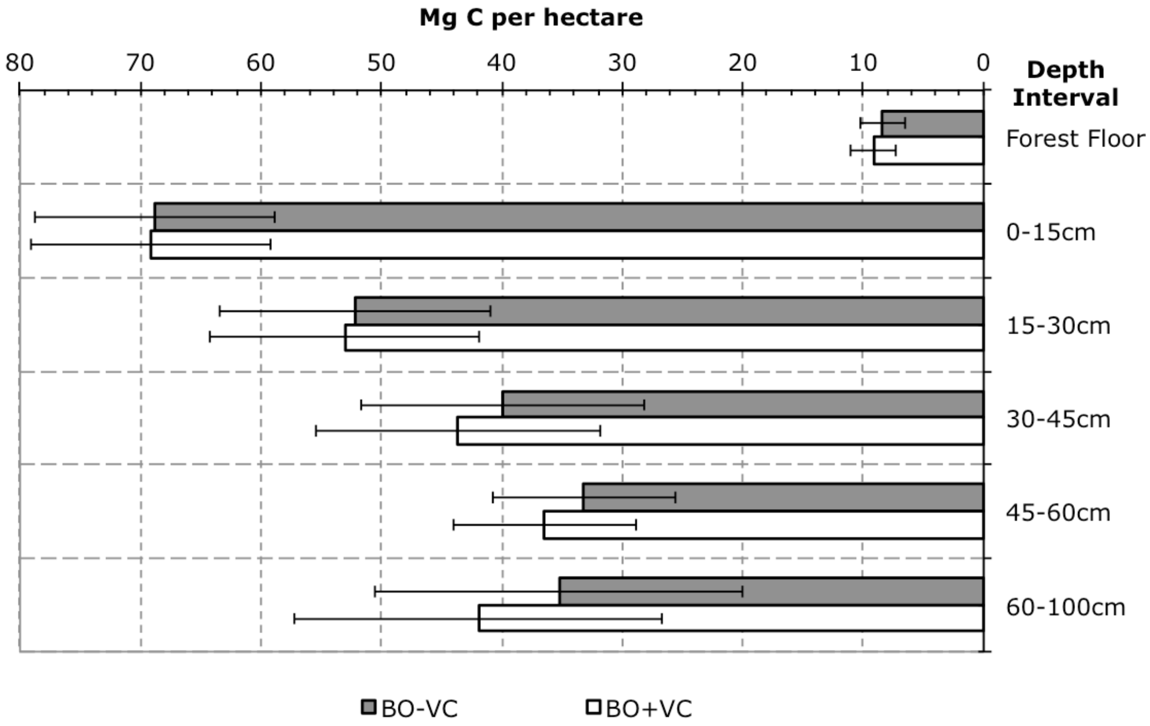


Figure 2. Carbon contents by depth at Fall River LTSP. BO-VC = Bole-only harvest without completing vegetation control, BO+VC = Bole-only harvest with completing vegetation control.

Table 1. Multipliers (Total Dollars of Input Per Dollar of Output) for Lakehead County, Montana

| | Agriculture | Natural Resources | Utilities | Wholesale/Retail Trade | Food Processing |
|---|---|---|---|---|---|
| **Agriculture** | 1.0815 | 0.0176 | 0.0128 | 0.0141 | 0.0995 |
| **Natural Resources** | 0.0615 | 1.0980 | 0.1516 | 0.0290 | 0.0228 |
| **Utilities** | 0.0329 | 0.0709 | 1.0397 | 0.0644 | 0.0131 |
| **Wholesale/Retail Trade** | 0.0241 | 0.0376 | 0.0454 | 1.0823 | 0.0101 |
| **Food Processing** | 0.0382 | 0.0577 | 0.0695 | 0.0852 | 1.0384 |
| **Wood Manufacturing** | 0.1218 | 0.0868 | 0.0888 | 0.0770 | 0.0244 |
| **Manufacturing** | 0.6777 | 1.0471 | 1.0872 | 1.3017 | 0.3160 |
| **Other Services** | 0.0779 | 0.1255 | 0.1531 | 0.1880 | 0.0318 |
| **Transportation** | 0.0852 | 0.1306 | 0.1581 | 0.1640 | 0.0304 |
| **Value Added** | 0.5057 | 0.7804 | 0.9460 | 0.9750 | 0.1815 |
| **Employment*** | 1.81 | 2.69 | 12.06 | 1.82 | 6.10 |
| | **Wood Manufacturing** | **Manufacturing** | **Other Services** | **Transportation** | **Personal Consumption** |
| **Agriculture** | 0.0021 | 0.0103 | 0.0181 | 0.0148 | 0.0224 |
| **Natural Resources** | 0.0117 | 0.0296 | 0.0293 | 0.0254 | 0.0321 |
| **Utilities** | 0.0225 | 0.0362 | 0.0520 | 0.0477 | 0.0617 |
| **Wholesale/Retail Trade** | 0.0084 | 0.0411 | 0.0603 | 0.0533 | 0.0809 |
| **Food Processing** | 0.0120 | 0.0561 | 0.1126 | 0.0905 | 0.1325 |
| **Wood Manufacturing** | 1.0691 | 0.0668 | 0.0784 | 0.0738 | 0.0923 |
| **Other Manufacturing** | 0.2481 | 2.0222 | 1.3432 | 1.3535 | 1.6268 |
| **Other Services** | 0.0265 | 0.1288 | 1.1920 | 0.1779 | 0.2603 |
| **Transportation** | 0.0249 | 0.1252 | 0.2045 | 1.1826 | 0.3046 |
| **Value Added** | 0.1485 | 0.7481 | 1.2166 | 1.0865 | 1.8241 |
| **Employment*** | 4.13 | 2.73 | 1.96 | 2.49 | |

* This multiplier can be interpreted to mean that for every new job in Wood Manufacturing (for example 4.13 under Wood Manufacturing column heading in row labeled Employment) there are an estimated 3.13 (4.13 – 1.00) additional jobs expected throughout the economy.

Table 2. Highly Aggregated SAM( Transaction Table) for Lakehead Co. Montana (Million Dollars)

| | **AGRI-C** | **NATRES-C** | **UTIL-C** | **TRADE-C** | **FOOD-C** | **WOODMAN-C** | **MAN-C** | **OTHSER-C** | **TRANS-C** |
|---|---|---|---|---|---|---|---|---|---|
| **AGRI-C** | $ 5.35 | $ 1.90 | $ 0.00 | $ 0.11 | $ 26.92 | | $ 3.69 | $ 0.63 | $ 0.01 |
| **NATRES-C** | $ 3.17 | $ 19.79 | $ 24.56 | $ 0.74 | $ 3.49 | $ 1.58 | $ 66.57 | $ 3.28 | $ 0.18 |
| **UTIL-C** | $ 0.77 | $ 10.89 | $ 0.01 | $ 8.67 | $ 1.14 | $ 5.00 | $ 45.89 | $ 9.10 | $ 4.95 |
| **TRADE-C** | $ 0.01 | $ 0.21 | $ 0.34 | $ 11.63 | $ 0.31 | $ 0.31 | $ 36.26 | $ 5.11 | $ 1.78 |
| **FOOD-C** | $ 0.07 | $ 0.08 | | $ 4.02 | $ 7.41 | $ 0.30 | $ 5.16 | $ 25.67 | $ 7.02 |
| **WOODMAN-C** | $ 6.04 | $ 9.50 | $ 5.84 | $ 5.05 | $ 0.85 | $ 17.96 | $ 126.85 | $ 10.91 | $ 6.36 |
| **MAN-C** | $ 10.49 | $ 65.73 | $ 28.72 | $ 96.97 | $ 27.96 | $ 24.70 | $ 1,660.42 | $ 202.41 | $ 186.11 |
| **OTHSER-C** | $ 0.08 | $ 2.02 | $ 2.57 | $ 13.04 | $ 0.87 | $ 0.93 | $ 102.80 | $ 15.13 | $ 10.84 |
| **TRANS-C** | $ 0.05 | $ 0.04 | $ 0.01 | $ 0.32 | $ 0.00 | $ 0.01 | $ 1.22 | $ 1.41 | $ 0.68 |
| **LAB** | $ 3.13 | $ 33.04 | $ 16.99 | $ 74.08 | $ 5.26 | $ 9.12 | $ 847.53 | $ 509.05 | $ 248.12 |
| **CAP** | $ 10.12 | $ 45.95 | $ 62.78 | $ 42.87 | $ 2.60 | $ 1.74 | $ 1,026.13 | $ 132.67 | $ 64.47 |
| **INDT** | $ (0.37) | $ 4.59 | $ 20.77 | $ 19.17 | $ 0.82 | $ 0.40 | $ 183.47 | $ 22.73 | $ 6.89 |
| **HH** | | | | | | | | $ 24.14 | |
| **GOV** | $ 0.21 | $ 4.29 | | $ 3.73 | | | $ 4.17 | $ 2.70 | $ 42.30 |
| **INV** | $ 0.00 | $ 0.00 | | | $ 0.48 | $ 0.06 | $ 13.35 | $ 47.03 | |
| **Imports** | $ 39.87 | $ 96.86 | $ 28.84 | $ 57.95 | $ 227.58 | $ 262.36 | $ 2,440.52 | $ 135.25 | $ 101.82 |
| **TOTAL** | $ 77.09 | $ 287.17 | $ 201.37 | $ 332.05 | $ 305.64 | $ 326.21 | $ 6,601.51 | $ 1,121.70 | $ 673.83 |

SAM for Lakehead Co, Montana (con’t)

| | LAB | CAP | INDT | HH | GOV | INV | Exports | TOTAL |
|---|---|---|---|---|---|---|---|---|
| **AGRI-C** | | | | $ 13.60 | $ 0.27 | $ 0.26 | $ 24.36 | $ 77.09 |
| **NATRES-C** | | | | $ 3.46 | $ 0.32 | $ 27.37 | $ 132.65 | $ 287.17 |
| **UTIL-C** | | | | $ 69.71 | $ 4.22 | | $ 41.03 | $ 201.37 |
| **TRADE-C** | | | | $ 114.83 | $ 6.08 | | $ 155.19 | $ 332.05 |
| **FOOD-C** | | | | $ 202.48 | $ 3.92 | $ 0.06 | $ 49.44 | $ 305.64 |
| **WOODMAN-C** | | | | $ 76.31 | $ 10.66 | $ 0.48 | $ 49.40 | $ 326.21 |
| **MAN-C** | | | | $ 1,761.25 | $ 188.84 | $ 812.57 | $ 1,535.34 | $ 6,601.51 |
| **OTHSER-C** | | | | $ 381.19 | $ 393.75 | | $ 198.47 | $ 1,121.70 |
| **TRANS-C** | | | | $ 521.91 | $ 3.29 | | $ 144.88 | $ 673.83 |
| **LAB** | | | | | | | | $ 1,746.31 |
| **CAP** | | | | | | | | $ 1,389.34 |
| **INDT** | | | | | | | | $ 258.48 |
| **HH** | $ 1,506.18 | $ 733.18 | | $ 59.60 | $ 800.12 | $ 694.07 | $ 31.13 | $ 3,848.41 |
| **GOV** | $ 240.13 | $ 26.78 | $ 258.48 | $ 350.29 | $ 451.82 | $ 493.04 | $ 0.00 | $ 1,877.92 |
| **INV** | | $ 760.85 | | $ 293.79 | $ 14.63 | $ 38.70 | $ 897.67 | $ 2,066.56 |
| **Imports** | | $ (131.47) | | $ 0.00 | $ (0.00) | $ 0.00 | | $ 3,259.56 |
| **TOTAL** | $ 1,746.31 | $ 1,389.34 | $ 258.48 | $ 3,848.41 | $ 1,877.92 | $ 2,066.56 | $ 3,259.56 | $ 30,766.25 |

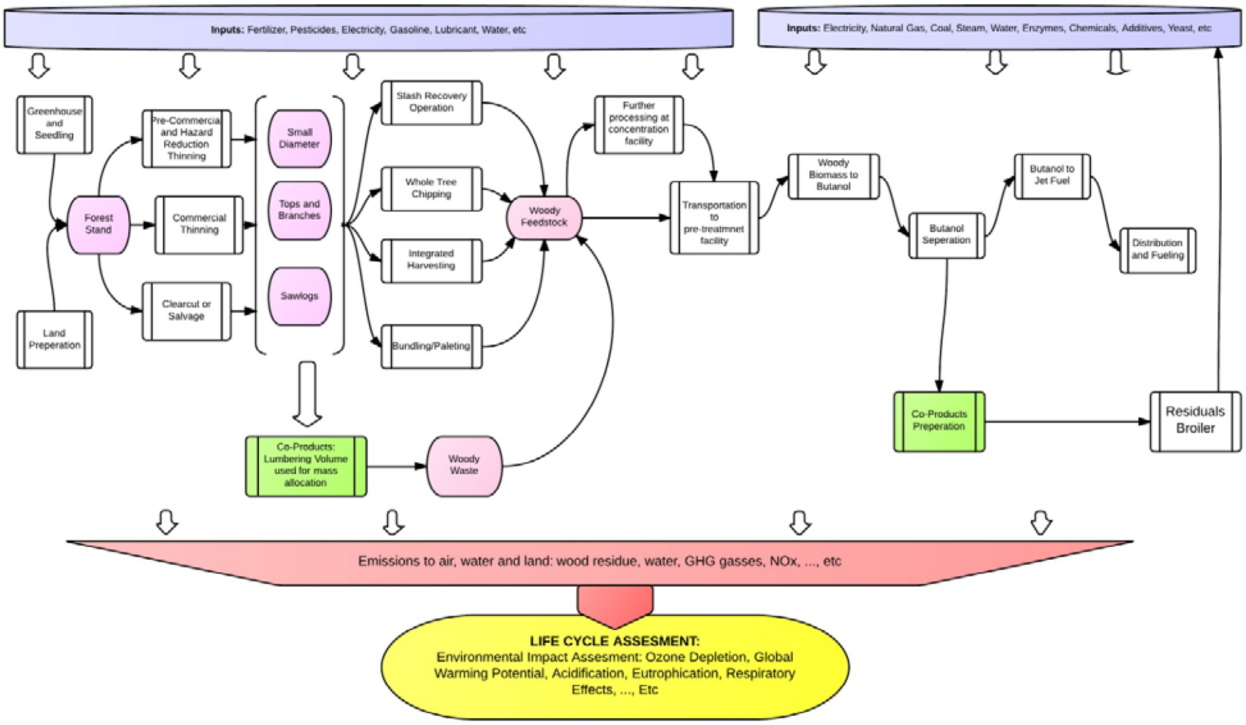


Figure 3: Overall Scope for LCA of woody biomass to bio-jet fuel

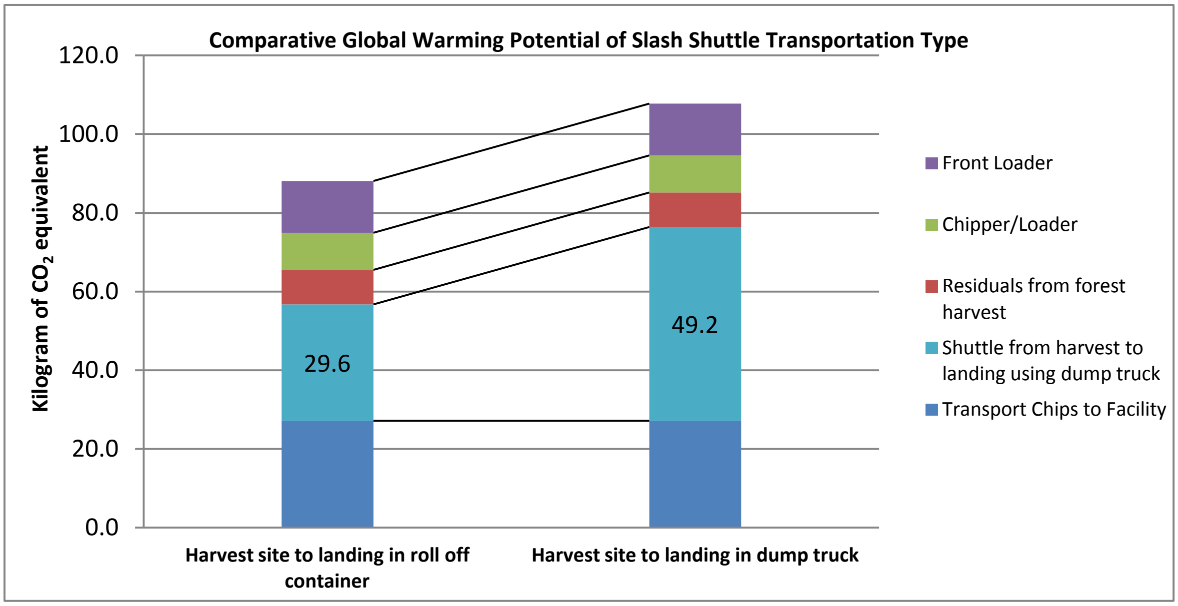


Figure 4: Comparative Global Warming Potential of Shuttle Transportation Type

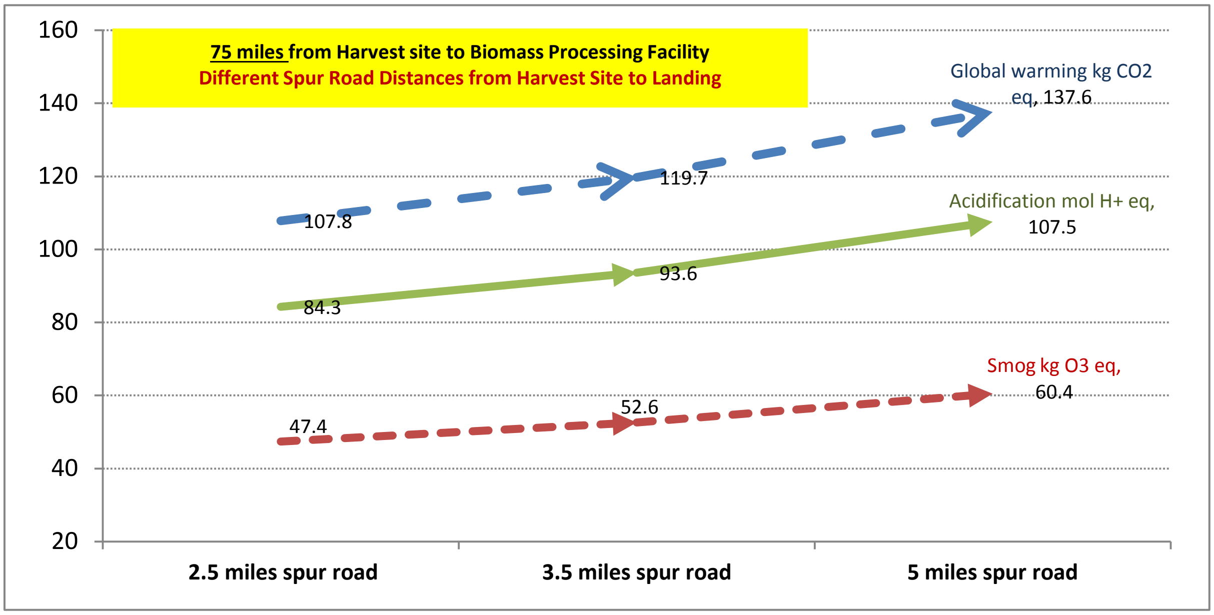


Figure 5: Environmental impact assessments of various forest road distances for hauling slash

Table 3: Environmental Impacts of Residual Extraction and Avoided Impacts of Slash Pile Burning

| | | System Impact | Avoided Impact | Total Impact |
|---|---|---|---|---|
| Global Warming | kg CO2 eq | 65.71 | -65.7 | 0.006 |
| Smog | kg O3 eq | 28.8 | -89.5 | -60.7 |
| Acidification Air | mol H+ eq | 52 | -176 | -124 |
| Ozone Depletion | kg CFC-11 eq | 2.71E-09 | -3.26E-10 | 2.38E-09 |
| Respiratory Effects | kg PM10 eq | 0 | -11.1 | -11.1 |

Table 4:  Complete Forest to IPK Process: Environmental Performance of 1 kg of IPK

| Impact Category | Unit | Total | Contribution from Feedstock process | Contribution from Pretreatment and GEVO process |
|---|---|---|---|---|
| Global warming potential (GWP) | kg CO2 eq. | 1.304708 | 4.38848E-05 | 1.304664 |
| Acidification Potential | H+ moles eq. | -0.83518 | -0.85198225 | 0.016798 |
| Eutrophication Potential | kg N eq. | 0.004714 | -0.000699414 | 0.005413 |
| Ozone depletion Potential | kg CFC-11 eq. | 6E-08 | 1.63197E-11 | 6.00E-08 |
| Smog Potential | kg O3 eq. | -0.27772 | -0.4162199 | 0.138496 |
| Respiratory Effects | kg PM10 eq. | -0.07464 | -0.075427 | 0.00079 |

Table 5: ***Preliminary*** analysis of the emissions associated with aircraft transportation of one person for 1 kilometer on an intercontinental flight.

| | | **Transport, aircraft, passenger, intercontinental** | |
|---|---|---|---|
| **Impact category** | **Unit** | **Bio-Jet Fuel (IPK)** | **Fossil Fuel (Kerosene)** |
| Ozone depletion | kg CFC-11 eq | 1.69E-06 | 1.42E-05 |
| Global warming | kg CO2 eq | 32.32 | 84.22 |
| Fossil fuel depletion | MJ surplus | 65.17 | 165.79 |

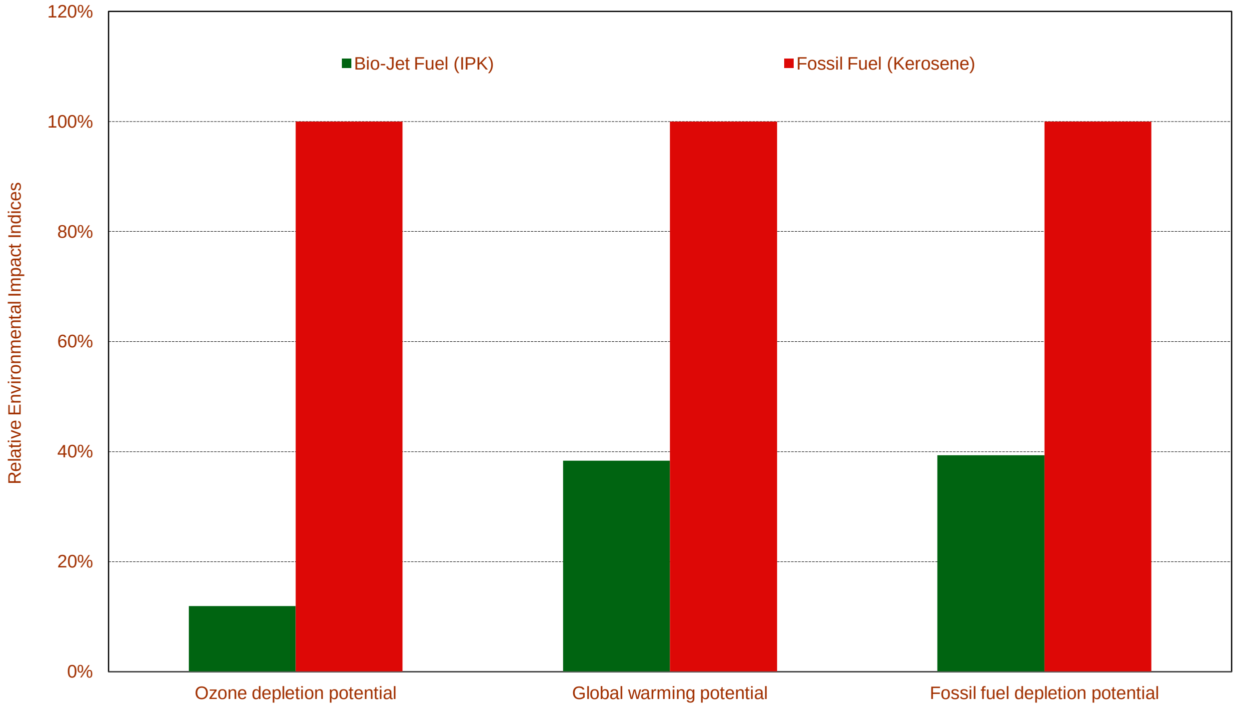


Figure 6. ***Preliminary*** analyses of the emissions reduction associated with bio-jet fuel used as a substitute for fossil-based jet fuel in an intercontinental flight.

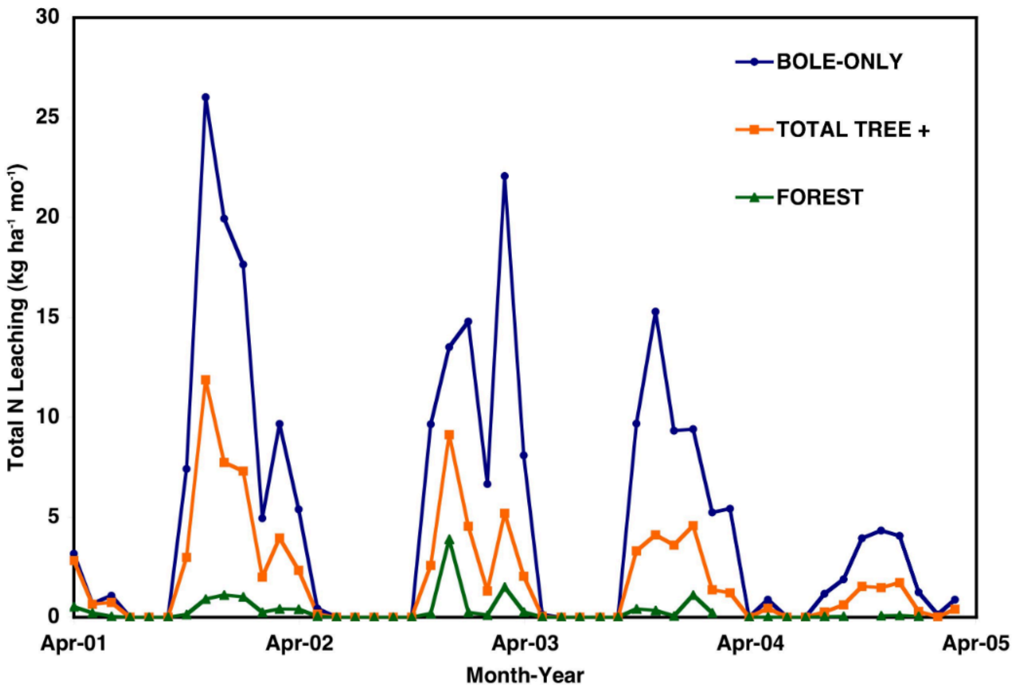


Figure 7. Temporary increase in nitrogen leaching and capture by new plantation growth at 1 m depth at the Fall River LTSP according to biomass removal levels. Note that the total loss is relatively modest compared to the 14,000 kg N/ha soil nitrogen pool.

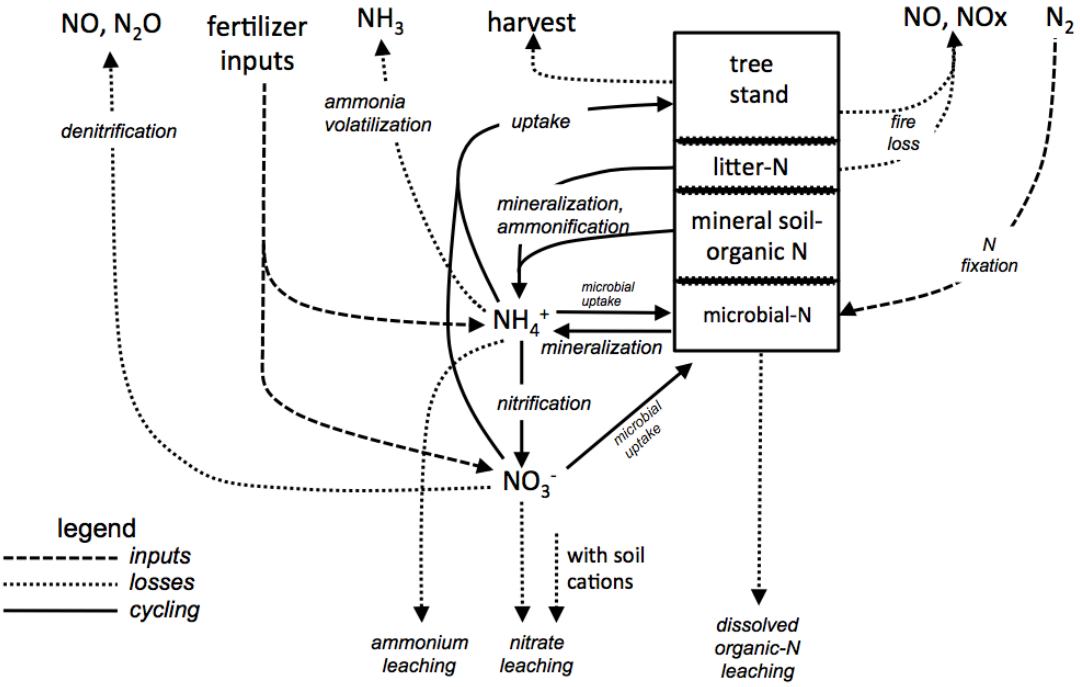


Figure 8. Sum of potential nitrogen pools and fluxes within a forest ecosystem, plantation or otherwise, relevant to sustained productivity.

## Recommendations/Conclusions

**Soil Carbon Team:** We have completed a substantial amount of research relative to the potential for sustained productivity of conventional levels of biomass and increased levels of biomass from Pacific Northwest managed forests. The initial conclusions indicate that these ecosystems are currently highly productive, relatively rich in nutrients, and likely resilient to additional levels of nutrient removal through higher levels of organic matter removals. The assessments of nutrient levels and productivity correlates well with growth studies at the Fall River, Matlock and Molalla long-term soil productivity studies. The assessment of the 73 sites in the coastal Douglas-fir region from North Vancouver Island to Southern Oregon also indicates that most forests have good nitrogen stocks, at least, though some will have to be managed carefully or removals potentially ameliorated through fertilization. We will continue expanding and monitoring current studies, and participate in the new Willamette long-term soil productivity study. We plan to install a full suite of soil lysimeters and soil moisture and temperature monitoring equipment at the new Willamette LTSP in early May, 2013. This will be monitored for a duration sufficient to see the rise in soil nitrogen leaching characteristic of a disturbed ecosystem, as was done at Fall River (Figure 7). In the case of the Fall River LTSP, despite our ability to track the changes in mineralization, and movement of nitrogen into and out of the ecosystem, we found that there were no growth losses, as < 2% of total ecosystem nitrogen was lost at the most extreme treatment level. This and previous work at the new Willamette LTSP will help us to establish where the nitrogen is found in this ecosystem, and any potential adverse impacts that additional removal of biomass might cause, but in the static (pools of nitrogen in the ecosystem), and in the dynamic nitrogen cycle (fluxes into, within and out of the ecosystem) (Figure 8).

**Community Impact Assessment Team:** We have begun to populate our models with data from IMPLAN and will continue to do so in cooperation with the University of Idaho. Over the next two quarters we expect to have completed an impact assessment from the use of forest residuals on western Montana communities which will show us the economic contribution that the increased utilization of forest-based materials (forest residuals and thinnings) could have on communities in western Montana. The impact assessment will also allow us to assess community impacts through additional job creation and economic activity in those rural communities. Similar work is planned for NARA community #2 in western Washington/Oregon as well as the broader impacts to the four state region.

**LCA Team:** Preliminary framework LCA using secondary data is completed for the Inland Empire region and the report will be available by the end of June 2013. Most of the secondary data is sourced from the data generated by the CORRIM group headed by the University of Washington. Moreover, attempts are being made to have access to the Potlatch in-woods biomass program results. Multiple residual transportation and harvesting scenario-based analyses have been conducted and will be expanded over time. A preliminary LCA report structure following the ISO 14044 using simulated data will be available by end of April 2013. The LCA results will be enhanced when the simulated data is replaced with the primary data collected by the research team. Moreover, additional LCA scenarios will be developed based on the interview results increasing the regional specificity of the results. Accordingly, the target groups specific to the NARA Inland Empire project region are identified for the study and the sample frame developed. Four separate surveys developed, one for each of the identified target groups, are currently being pre-tested. The survey for Inland Empire region will be implemented between April-May, 2013. The Preliminary 'Feedstock LCA' report incorporating primary data for Inland Empire will be available by mid June 2013.

Proposed activities in the immediate short term include: (i) coordinating with Tim Smith to integrate the co-product LCA development task into the LCA group, (ii) meetings with the pre-treatment group and Gevo planned for end of April 2013, and (iii) completion of basic forest-to-pump LCA framework by mid June 2013 – *(Contingent on selection of pre-treatment process)*. Given the enhanced role of the LCA team, a new research fellow from Italy with chemical engineering and LCA background has been recruited and will be joining the LCA team in August 2013.

Research Papers: In the attributional LCA section, future research papers will include an enhanced list of harvest and transportation scenarios. In the consequential LCA section, the next phase of research papers will include studies that will account for fire abatement scenarios that involve crew travel, machine travel, additional piling, travel, and fuel use.

## Physical and Intellectual Outputs

### Physical Outputs

Soil Carbon Team

- Assessment of nitrogen pools and potential for depletion at 73 Pacific Northwest plantation sites
- Results on production of new forests after different levels of biomass and nutrient removals
- Assessment of soil carbon in new forests with and without competing biomass control
- Installation of nitrogen leaching in new Willamette LTSP

Community Impact Assessment Team

- Tables of economic output multipliers by county, state and region
- Tables of employment multipliers by county, state and region
- Social accounting matrix by county, state and region

LCA Team

- Updated database on biomass harvest techniques in Interior Empire Region
- Assessment of avoided environmental burdens due to reduction in slash pile burning
- Assessment of relative environmental burdens of various aspects of biomass harvest and transportation.
- Educational and training material on importance of Life Cycle Assessment of Bio-Jet fuel
- Development of training material on LCA calculations for graduate IDeX courses at Washington State University.

## Refereed Publications (accepted or completed)

Devine, WD, P.A. Footen, B.D Strahm, R.B. Harrison, T.A. Terry and T.B. Harrington. 2012. Nitrogen leaching following whole-tree and bole-only harvests on two contrasting Pacific Northwest sites. For. Ecol. Mgt. 267:7-17.
Available at: http://soilslab.cfr.washington.edu/publications/Devine-etal-2012.pdf

Devine, WD, P.A. Footen, R.B. Harrison, T.A. Terry C.A. Harrington, S. M. Holub and P. J. Gould. 2013. Estimating Tree Biomass, Carbon, and Nitrogen in Two Vegetation Control Treatments in an 11-Year Old Douglas-Fir Plantation On a Highly Productive Site. USFS Research Paper PNW-RP-591, March 2013. Available at: http://soilslab.cfr.washington.edu/publications/Devine-etal-2013.pdf

Harrison, R. et al. 2012. Estimating tree biomass, carbon, and nitrogen in an 11-year-old Douglas-fir plantation on a highly productive site. In-preparation.

Austin J. Himes, Rob Harrison, Darlene Zabowski, Eric Turnblom, David Briggs, Warren Devine, Kimberly Hanft. Predicting risk of long-term N depletion due to whole-tree harvesting in the coastal Pacific Northwest. *under review by Soil Science Society of America Journal*

Jason James, Warren Devine, Rob Harrison Eric Turnblom The Importance of Deep Soil Carbon and Nitrogen in Ecosystem Analysis in Rocky Forest Soils of the Pacific Northwest. *In preparation:*

## Research Presentations

Bowers, C. T., Ganguly, I., & Eastin, I. (2013). Avoided Impacts by Utilizing Woody Biomass Residuals for Bio-Jet Fuel: A Comparative LCA Investigating an Alternative to Slash Pile Burning. Poster session presented at the Wood Composites Symposium. April, 2013, Seattle, WA.

Bowers, C. T., Ganguly, I., & Eastin, I. (2013). Avoided Impacts by Utilizing Woody Biomass Residuals for Bio-Jet Fuel: A Comparative LCA Investigating an Alternative to Slash Pile Burning. Poster session presented at the Small Logs Conference. March, 2013, Coeur d'Alene, Idaho.

Bowers, C. T., Ganguly, I., & Eastin, I. (2012). *Scenario based LCA analysis: minimizing environmental burdens associated with collection of woody biomass for bio-jet fuel*. Poster session presented at the Future Forestry Leaders Symposium. December 7th, 2012, Vancouver, B.C., Canada.

Bowers, C. T., Ganguly, I., & Eastin, I. (2012). *Scenario based LCA analysis: minimizing environmental burdens associated with collection of woody biomass for bio-jet fuel*. Poster session presented at the Northwest Bioenergy Research Symposium. November 13th, 2012, Seattle, WA.

Bowers, T., I. Eastin and I. Ganguly. 2012. Pacific Northwest Residual Processing Life Cycle Impact Assessment. Poster presented at the International Wood Composites Symposium, Seattle, WA, April 11-13.

Ganguly, I., Bowers, C. T., Eastin, I., & Oneil, E. (2012). *LCA analysis of transportation scenarios in the woody feedstock supply chain of bio-jet fuel.* Presentation given at the Future Forestry Leaders Symposium. December 7th, 2012, Vancouver, B.C., Canada.

Ganguly, I., Bowers C. T, Eastin I. L., & Oneil, E. (2012). LCA of Feedstock Supply Chain Forest conditions: Inland West, The Northwest Bioenergy Research Symposium, Seattle. November 13, 2012.

Ganguly, I., Bowers C. T, Eastin I. L., & Oneil, E. (2012). LCA of Feedstock Supply Chain, NARA meeting 2012, Missoula, MT.

John Perez-Garcia, Alicia Robbins, Michele Vashon and Phil Watson. 2012. Economic Impact Assessment. Presentation made at the NARA meeting 2012, Missoula, MT

John Perez-Garcia. 2012. Calculating Biomass for Washington State from Forest Residuals. Presentation made at the NCASI West Coast Regional Meeting, October 2012, Kelso, WA

Harrison, R., A. Himes, K. Littke, E. Turnblomi. Evaluation of potential for sustained forest productivity with additional forest harvesting for bioenergy and biofuels. Presented at Pacific Summit on Industrial Biotechnology and Bioenergy. October 10-12, 2012, Vancouver, Canada.

Harrison, R., A. Himes, K. Littke and E. Turnblom. Whole-tree Harvesting N Risk in Coastal PNW. NARA meeting 2012, Missoula, MT.

Harrison, R., A. Himes, K. Littke, E. Turnblom and I. Guerrini. Risk to PNW USA forests from additional forest harvesting for bioenergy and biofuels. Presented at Brazilian Soil Science Society annual meeting, August, 2012, Macaeio, Alagoas, Brazil.

Holub, S, N. Meehan, B. Carrier, R. Meade, G. Johnson, R. Harrison, M. Betts, M. Barber. NARA Long-term Soil Productivity (LTSP) Project. NARA meeting 2012, Missoula, MT.

Littke, Kim, Rob Harrison, Darlene Zabowski and David Briggs. 2012. Effects of climate and soil characteristics on soil moisture in Douglas-fir plantations. Soil Science Society of America Conference in Cincinnati, Ohio Oct.21-24.

Vance, Jean M., Austin Himes, Kim Littke, Robert Harrison, Eric Turnblom, Greg Ettl. Quantifying the fate of applied N fertilizer over a one-year period in Douglas-fir plantations using stble isotope technology. Soil Science Society of America Conference, Cincinnati, Ohio Oct. 21-24.

Knight, Erika, Paul Footen, Robert Harrison, Thomas Terry and Scott Holub. 2012. Effects of organic matter removal and competing vegetation control on soil carbon and nitrogen pools in a Pacific Northwest Douglas-fir plantation. Soil Science Society of America Conference, Cincinnati, Ohio Oct. 21-24.

## Other Publications

Bowers, Tait. 2012. LCA for Forest Residual Processing. Project report for ME 515. 3/6/12

Devine, WD; TB Harrington; TA Terry; RB Harrison; RA Slesak; DH Peter; CA Harrington; CJ Shilling; SH Schoenholtz. 2011. Five-year vegetation control effects on aboveground biomass and nitrogen content and allocation in Douglas-fir plantations on three contrasting sites. Forest Ecology and Management 262:2187-2198. Available at: http://soilslab.cfr.washington.edu/publications/Devine-etal-2011.pdf

Ganguly, Indroneil. 2012. LCA for Forest Thinning. Project report for ME 515. 3/6/12

## Trainings, Education and Outreach Materials

Bowers, T. 2012. LCA for Forest Residual Processing. Project presentation for ME 515. 3/6/12

Bowers, T. 2012. *LCA: An Introduction*. IDex Presentation Online, Washington State University, Pullman, WA, October 9, 2012.

Eastin, Ivan. 2012. Forest to Biofuel: An Overview of the WSU-UW Biofuel Project. Presented to the Environmental Applications of Plants: Bioenergy and Bioremediation class at the University of Washington (ESRM 325). November 20th.

Ganguly, Indroneil et al. 2012. LCA of Feedstock in Western Montana Corridor. Presented at the Western Montana Corridor NARA Community Roadmap Development Meeting. University of Montana, Missoula, MT, 13 June 2012.

Ganguly, Indroneil. 2012. *LCA: An Introduction*. IDex Presentation Online, Washington State University, Pullman, WA, September, 2012.

Perez-Garcia, John. 2012. Economic Assessment of Biofuel Production Within the Western Montana Corridor. Presented at the Western Montana Corridor NARA Community Roadmap Development Meeting. University of Montana, Missoula, MT, 13 June 2012.

## Theses and Dissertations

Footen, Paul. 2011. The Effects of Previous Nitrogen Fertilization on Productivity and Nitrogen and Carbon Pools of Subsequent Stands of Douglas-fir Forests in the Pacific Northwest. Master of Science, School of Environmental and Forest Sciences, University of Washington, Seattle, WA. available at: http://soilslab.cfr.washington.edu/publications/FootenPaul-Thesis-2011.pdf

Himes, Austin Jacob. 2012. Risk to long-term site productivity due to whole-tree harvesting in the coastal pacific northwest. Master of Science, School of Environmental and Forest Sciences, University of Washington, Seattle, WA.
available at: http://soilslab.cfr.washington.edu/publications/HimesAustin-Thesis-2012.pdf

Littke, Kimberly. 2012. The Effects of Biogeoclimatic Properties on Water and Nitrogen Availability and Douglas-Fir Growth and Fertilizer Response in the Pacific Northwest. Doctor of Philosophy, School of Environmental and Forest Sciences, University of Washington, Seattle, WA.
available at: http://soilslab.cfr.washington.edu/publications/LittkeKim-Dissertation-2012.pdf

# Appendix 1.

# Community Impact Assessment

Table A1: BioJet Fuel Computable Equilibrium Model Statement

Import Price: $PM_c = (1 + tm_c) \times EXR \times pwm_c$ $c \in CM$

Export Price: $PE_c = (1 + te_c) \times EXR \times pwe_c$ $c \in CE$

Absorption: $PQ_c + QQ_c = [PD_c \times PD_c + (PM_c \times PM_c)_{|c \in CM}] \times (1 + tq_c)$ $c \in C$

Domestic Output Value: $PX_c + QX_c = [PD_c \times QD_c + (PE_c \times QE_c)_{|c \in CE}$ $c \in C$

Activity Price: $PA_a = \sum_{c \in C} PX_c \times \theta_{ac}$ $a \in A$

Value-added Price: $PVA_a = PA_a - \sum_{c \in C} PQ_c \times ica_{ca}$ $a \in A$

Activity Production Function: $QA_a = ad_a \times \prod_{f \in F} QF_{fa}^{\alpha}$ $a \in A$

Factor Demand: $WF_f \times WFDIST_{fa} = \frac{a_{fa} \times PVA_a \times QA_a}{QF_{fa}}$ $f \in F, a \in A$

Intermediate Demand: $QINT_{ca} = ica_{ca} \times QA_a$ $c \in C, a \in A$

Output Function: $QX_c = \sum_{a \in A} \theta_{ac} \times QA_a$ $c \in C$

Composite Supply Function: $QQ_c = aq_c \times \left(\delta_c^q \times QM_c^{-\rho_c^q} + \left(1 - \delta_c^q\right) \times QD_c^{-\rho_c^q}\right) \rho_c^{\frac{-1}{q}}$ $c \in CM$

Import-Domestic Demand Ratio:

$$\frac{QM_c}{QD_c} = \left(\frac{PD_c}{PM_c} \times \frac{\delta_c^q}{1 - \delta_c^q}\right)^{\frac{1}{1+\rho_c^q}} \qquad c \in CM$$

Composite Supply for Non-imported Commodities:

$$QQ_c = QD_c \qquad c \in CNM$$

Output Transformation (CET) Function:

$$QX_c = at_c \times (\delta_c^t \times QE_c^{\rho_c^t} + (1 - \delta_c^t) \times QD_c^{\rho_c^t})^{\frac{1}{\rho_c^t}} \qquad c \in CE$$

Export-Domestic Supply Ratio:

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PD_c} \times \frac{1 - \delta_c^t}{\delta_c^t}\right)^{\frac{1}{\rho_c^t - 1}} \qquad c \in CE$$

Output Transformation for Non-exported Commodities:

$$QX_c = QD_c \qquad c \in CNE$$

Factor Income: $YF_{hf} = shry_{hf} \times \sum_{a \in A} WF_f \times WFDIST_{fa} \times QF_{fa} \qquad h \in H, f \in F$

Household Income: $YH_h = \sum_{f \in F} YF_{hf} + tr_{h,gov} + EXR \times tr_{h,row} \qquad h \in H$

Household Consumption Demand:

$$QH_{ch} = \frac{\beta_{ch} \times (1 - mps_h) \times (1 - ty_h) \times YH_h}{PQ_c} \qquad c \in C, h \in H$$

Investment Demand: $QINV_c = qinv_c \times IADJ \qquad c \in C$

Government Revenue:

$$YG = \sum_{h \in H} ty_h \times YH_h + EXR \times tr_{gov,row} + \sum_{c \in C} tq_c \times (PD_c \times QD_c + (PM_c \times QM_c)_{c \in CM}) + \sum_{c \in CM} tm_c \times EXR \times pwm_c \times QM_c + \sum_{c \in CE} te_c \times EXR \times pwe_c \times QE_c$$

Government Expenditures: $EQ = \sum_{h \in H} tr_{h,gov} + \sum_{c \in C} PQ_c\, qg_c \qquad c \in C$

Factor Markets: $\sum_{a \in A} QF_{fa} = QFS_f \qquad f \in F$

Composite Commodity Markets:

$$QQ_c = \sum_{a \in A} QINT_{ca} + \sum_{h \in H} QH_{ch} + qg_c + QINV_c \qquad c \in C$$

Current Account Balance for ROW (in Foreign Currency):

$$\sum_{c \in C} pwe_c \times QE_c + \sum_{i \in I} tr_{i,row} + FSAV = \sum_{c \in CM} pwm_c \times QM_c$$

Savings-Investment Balance:

$$\sum_{h \in H} mps_h \times (1 - ty_h) \times YH_h + (YG - EG) + EXR \times FSAV = \sum_{c \in C} PQ_c \times QINV_c + WALRUS$$

Price Normalization: $\sum_{c \in C} PQ_c \times cwts_c = cpi$

## SETS

$a \in A$ activities

{FOR-A forestry activity, AGR-A agricultural activity, NAGR-A nonagricultural activity}

$c \in C$ commodities

{FOR-C forest commodity, AGR-C agricultural commodity, NAGR-C nonagricultural commodity}

$c \in CM\ (C)$ imported commodities

{NAGR-C nonagricultural commodity}

$c \in CNM\ (C)$ nonimported commodities

{FOR-C, forest commodity, AGR-C agricultural commodity}

$c \in CE\ (C)$ exported commodities

{AGR-C agricultural commodity}

$c \in CNE\ (C)$ nonexported commodities

{FOR-C, forest commodity, NAGR-C nonagricultural commodity}

$f \in F$ factors

{LND, land, LAB labor, CAP capital}

$i \in I$ institutions

{F-HHD forest household, U-HHD urban household, R-HHD rural household, GOV government, ROW rest of world}

$h \in H\ (<I)$ households

{F-HHD forest household, U-HHD urban household, R-HHD rural household}

## PARAMETERS

| | |
|---|---|
| $ad_a$ | *efficiency parameter in the production function for activity a* |
| $aq_c$ | *shift parameter for composite supply (Armington) function* |
| $at_c$ | *shift parameter for output transformation (CET) function* |
| *cpi* | *consumer price index (CPI)* |

| | |
|---|---|
| $cwts_c$ | *weight of commodity c in the CPI* |
| $ica_{ca}$ | *qnty of c as intermed. input per unit of output in activity a* |
| $mps_h$ | *marginal (and average) propensity to save for household h* |
| $pwe_c$ | *export price (foreign currency)* |
| $pwm_c$ | *import price (foreign currency)* |
| $qg_c$ | *government commodity demand* |
| $qinvc$ | *base-year qnty of investment demand for commodity c* |
| $shry_{hf}$ | *share for household h in the income of factor f* |
| $te_c$ | *export tax rate* |
| $tm_c$ | *import tariff rate* |
| $tq_c$ | *sales tax rate* |
| $tr_{ii'}$ | *transfer from institution i' to institution i* |
| $ty_h$ | *rate of household income tax* |
| $\alpha_{fa}$ | *share of value-added for factor f in activity a* |
| $\beta_{ch}$ | *share in household h consumption spending of commodity c* |
| $\delta_c^q$ | *share parameter for composite supply (Armington) function* |
| $\delta_c^t$ | *share parameter for output transformation (CET) function* |
| $\theta_{ac}$ | *yield of output c per unit of activity a* |
| $\rho_c^q$ | *exponent* ($-1 < \rho_c^q < \infty$) *for composite supply (Armington) function* |
| $\rho_c^t$ | *exponent* ($1 < \rho_c^t < \infty$) *for output transformation (CET) function* |
| $\sigma_c^q$ | *elasticity of substitution for composite supply (Armington) function* |
| $\sigma_c^t$ | *elasticity of transformation for output transformation (CET) function* |

## VARIABLES

| | |
|---|---|
| $EG$ | government expenditure |
| $EXR$ | foreign exchange rate (domestic currency per unit of foreign currency) |
| $FSAV$ | foreign savings |
| $IADJ$ | investment adjustment factor |

| | |
|---|---|
| $P_c$ | market price of commodity *c* |
| $PA_a$ | price of activity *a* |
| $PD_c$ | domestic price of domestic output |
| $PE_c$ | export price (domestic currency) |
| $PM$ | import price (domestic currency) |
| $PQ_c$ | composite commodity price |
| $PVAa$ | value-added (or net) price of activity *a* |
| $PX_c$ | producer price (excluding sales tax) of commodity c |
| $QA_a$ | level of activity *a* |
| $QD_c$ | quantity of domestic output sold domestically |
| $QE_c$ | quantity of exports |
| $QF_{fa}$ | demand for factor *f* from activity *a* |
| $QFS_f$ | supply of factor *f* |
| $QH_{ch}$ | consumption of commodity *c* by household *h* |
| $QINT_{ca}$ | qnty of commodity *c* as intermediate input in activity *a* |
| $QINV_c$ | quantity of investment demand for commodity *c* |
| $QM_c$ | quantity of imports |
| $QQ_c$ | quantity supplied to domestic commodity demanders (composite supply) |
| $QX_c$ | quantity of domestic output |
| $WALRAS$ | dummy variable (zero at equilibrium) |
| $WF_f$ | price of factor *f* |
| $WFDIST_{fa}$ | wage distortion factor for factor *f* in activity *a* |
| $YF_{hf}$ | income of household *h* from factor *f* |
| $YG$ | government revenue |
| $YH_h$ | income of household *h* |

# Sustainable Production Team

## SM-SP-1: Sustainable Feedstock Production Systems

| Key Personnel | Affiliation |
|---|---|
| Scott Holub | Weyerhaeuser |
| Greg Johnson | Weyerhaeuser |

### Task Description

The importance of ensuring environmental sustainability and carbon benefits of biofuel production cannot be overstated. The sustainability of forest residual biomass harvesting is a potential concern in regions where this primarily branch and needle material is removed to provide a source of renewable energy. Concern arises from the removal of nutrients and carbon present in residual biomass, as well as from heavy equipment trafficking used to collect the material, both of which have potential to be detrimental to forest productivity, water quality, and wildlife habitat.

The long-term goal of this research is to contribute to our understanding of the amount of residual woody Douglas fir biomass that can be removed during timber harvest without detrimental effects on soil sustainability, water quality, and wildlife. Moreover, understanding the effects of woody biomass removals and any associated soil compaction is necessary to demonstrate the sustainability (in a productivity and environmental sense) of harvesting woody biomass forest residuals as a source of biomass for bioenergy feedstock. We address this issue by installing a new Long-Term Soil Productivity (LTSP) site in the southern Willamette Valley of Oregon on Weyerhaeuser ownership, the “NARA LTSP”, to round out our existing regional studies (Figure 1).

Our design aims to examine a range of above-ground biomass removal treatments in combination with compaction, and fertilization. The new installation leverages over ten years of intensive investigation of the effects on productivity and soil properties in the Northwest. We propose to quantify typical LTSP objectives such as forest productivity, soil nutrient and carbon pools and fluxes, and soil compaction. This study is unique in that we also plan to study biomass removal and compaction effects on wildlife and water quality to round out the environmental sustainability picture for biomass harvesting.

### Activities and Results

#### Task SM-SP-1.1. Pre-treatment site selection and assessment

All pre-harvest data have been collected. Extra plots have been dropped. Statistical blocks have been determined (using total soil nitrogen with spatial consideration) and treatments randomly assigned across each block. (Figure 2.) Over 150 physical, chemical, and biological parameters have been recorded for below-ground plot information. Average soil carbon to 1 m depth across the plots is 224 Mg ha$^{-1}$. Soil Nitrogen is 11,250 kg ha$^{-1}$. Rock volume is 1.5%. Clay in the surface 15cm is 30% and 47% to 1-m depth. Above-ground over 40 parameters have been recorded on the plots. Highlights include 156 Douglas-fir stems and 4 other species' stems per ha; quadradic mean diameter of the Douglas-fir was 16.5 inches; tree volume in Douglas-fir was 104 cunits ac$^{-1}$; and tree biomass was 332 Mg ha$^{-1}$.

### Task SM-SP-1.2. Implement Treatments

Harvesting and treatment-implementation began on February 26, 2013. Cutting of trees outside of the plot areas has been completed. 5 plots (of 28 total) have been cut and harvested. Further cutting, logging, and treatments is ongoing.

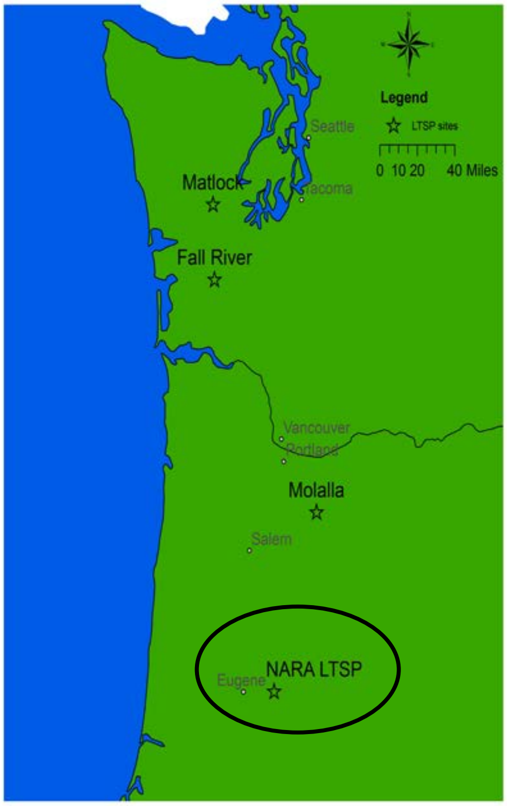


Figure 1. Map of the coastal Douglas-fir LTSP study sites in Oregon and Washington.

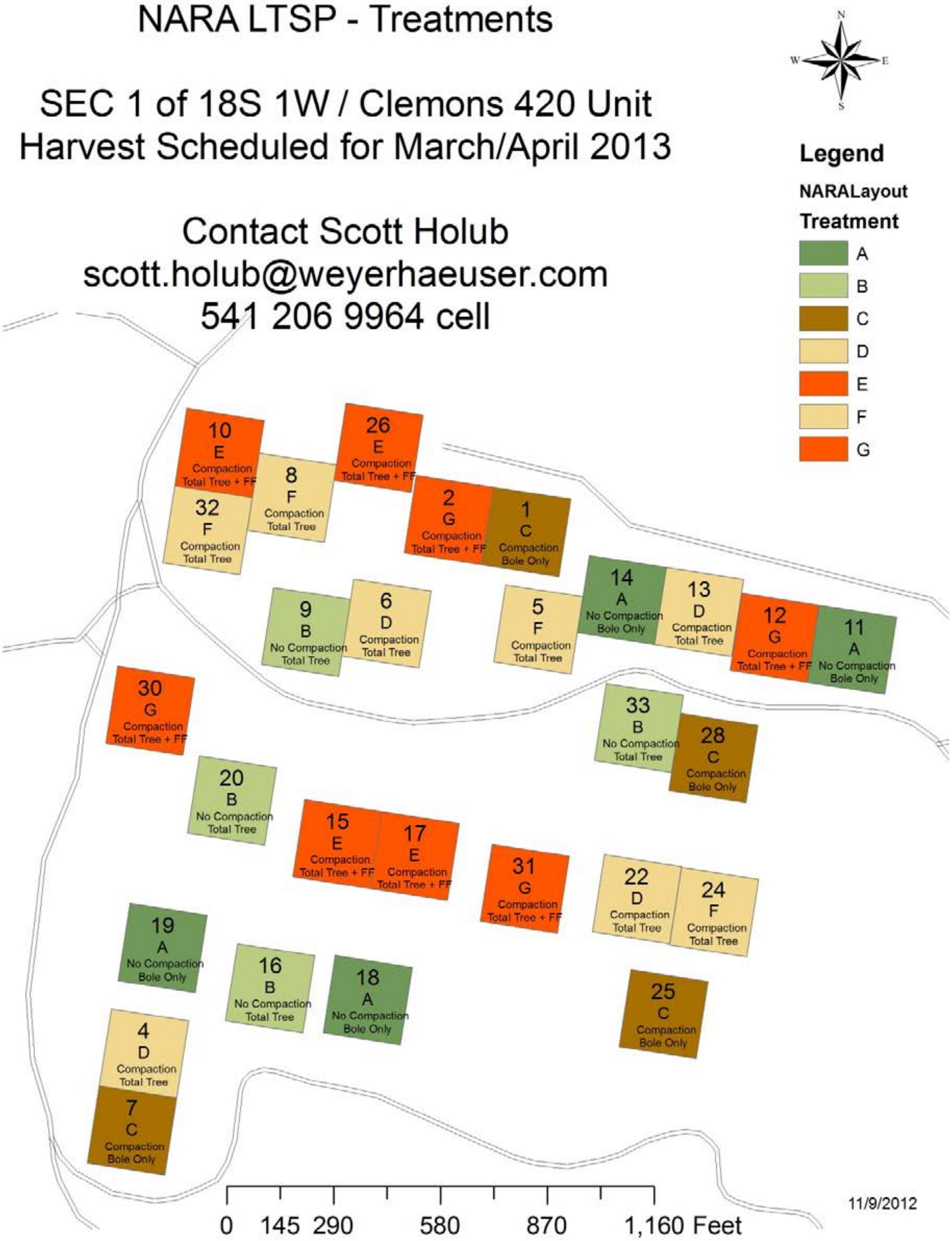


**Figure 2.** NARA LTSP Treatment map.

## Recommendations/Conclusions

Year 3 funding will be critical for this aspect of the NARA study. In years 1 and 2 we began the lengthy process of installing a new study site to address sustainability issues. In year 3, funding will provide the resources needed to complete the required treatments, instrument the site with temperature and moisture probes, and construct a fence to prevent big game browse of seedlings. In year-3 funding will also support the planting, care, and measurement of over 10,000 Douglas-fir seedlings, which are the major bio-indicator of site productivity.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Holub, S.M., T.A. Terry, C.A. Harrington, R.B. Harrison, R. Meade. 2013. Tree growth ten years after residual biomass removal, soil compaction, tillage, and competing vegetation control in a highly-productive Douglas-fir plantation. Forest Ecology and Management – Under Revision. March 14, 2013.

Devine, W.D., P.W. Footen, R.B. Harrison, T.A. Terry, C.A. Harrington, S.M. Holub and P.J. Gould. 2013. Estimating tree biomass, carbon, and nitrogen in an 11-year-old Douglas-fir plantation on a highly productive site. USFS Research Paper PNW-RP-591. March 2013.

### Conference Proceedings and Abstracts from Professional Meetings

Holub, S., N. Meehan, B. Carrier, R. Meade, G. Johnson, R. Harrison, M. Betts, M. Barber. 2012. NARA Long-term Soil Productivity (LTSP) Project. Poster presentation at IUFRO meeting "Nutrient Dynamics of Planted Forests." Vancouver, WA, November 27-28, 2012.

### Research Presentations

Holub, S., N. Meehan, B. Carrier, R. Meade, G. Johnson, R. Harrison, M. Betts, M. Barber. 2012. NARA Long-term Soil Productivity (LTSP) Project. Poster Presentation at NARA annual meeting. Missoula, MT, September 13, 2012.

### Other Publications

Templeton, A. 2013. Leaving behind logging debris could help fight invasive weeds. Scott M. Holub was interviewed on Oregon Public Radio about the role of slash retention on seedling growth. (http://www.nwpr.org/post/leaving-behind-logging-debris-could-help-fight-invasive-weeds) March 15, 2013.

### Awards & Recognition

Scott M. Holub was a winner of the Corporate EcoForum Sustainability Leadership Contest. April 7, 2013. http://corporateecoforum.com/ecoinnovator/?p=7783

# Task SM-SP-2: Sustainable Biomass Supply from Forest Health and Fire Hazard Reduction Treatments

| Key Personnel | Affiliation |
|---|---|
| John Bailey | Oregon State University |
| Kevin Boston | Oregon State University |

## Task Description

The goals of this research are to: quantify the effect of regional land management policy and market trends on the supply of available biomass across ownerships in the western region; analyze the range of forest health and fuel reduction management options and obstacles that will limit feedstock supply over time from given landscapes; develop models and tools for policy makers, businesses and advocacy groups to use in order to consistently assess the potential for feedstock yield from landscapes, which integrate long-term forest productivity and health, land management directions and practices, harvesting technologies and transportation systems; and establish large-scale adaptive management studies that demonstrate and refine the options conceptualized in these models and provide a baseline for evaluation of long-term socio-economic and ecological effects.

## Activities and Results

### Task SM-SP-2.1: Develop Preliminary Prescriptions for Public Landscapes Needed for Regional Supply Model

Task SM-SP-2.1 has been completed. A series of regional, forest type, and owner group specific silvicultural prescriptions have been developed in order to better inform biomass estimates generated from the regional supply model. Prescriptions were generated from a combination of an exhaustive literature of stand reconstruction studies, NEPA harvest planning documents and interviews with local forest managers and certified silviculturists. The developed prescriptions were formally presented at the 5th International Fire Ecology and Management Congress in Portland Oregon as well as at the annual National Advanced Silviculture Program (NASP) workshop in Corvallis, OR. Preliminary model runs may indicate the need for revision prior to the 7/31/2013 due date.

### Task SM-SP-2.2: Develop Models and Tools for Public Decision Makers to consistently assess potential for feedstock yields

Task SM-SP-2.2 is ongoing. We have collaborated regularly with Darius Adams and the economic modeling team in order to gain a greater understanding of cross-disciplinary goals and needs. A sensitivity analysis of model assumptions are currently being completed, including: management entry requirements, characteristics of a successful treatment, re-entry requirements and prescription formulation. This analysis is being performed using the ArcFuels tool bar within ArcGIS. A workshop on the functionality of this toolbar and the assumptions of the software was completed at the 5th International

Fire Ecology and Management Congress in Portland Oregon. Preliminary forest growth model runs have been completed as well as quality control of those results. In addition, baseline fire hazard modeling has been completed across Oregon in order to measure effectiveness of thinning regimes and ability of the utilization of biomass material to alter landscape level fire hazard. Prototype model runs will be available for review soon and conducted in conjunction with Task SM-SP-2.3.

### Task SM-SP-2.3: Establish Large Scale Adaptive Management Studies

The framework for several dozen Integrated Fireshed-level Adaptive Management Evaluation sites (*iFLAMES*) has been developed and initial reactions are positive for participation among federal Collaborative Forest Landscape Restoration Program (CFLRP) groups, states, and tribes. Given current available funding and public land manager interest, we will initiate establishment of these sites early.

### Task SM-SP-2.4: Feedback to Improve Predicative Ability of Task SM-SP-2.2 models

This task is a formative part of designing Task SM-SP-2.3 *iFLAMES* – anticipating the issues upon which we will need to improve in second generation model runs.

## Recommendations/Conclusions

Collaboration with the economics modeling group has been very productive, and that modeling effort is coming together well to support other parts of the project and the third task. The timing is most excellent for now establishing *iFLAMES*, which will be fundamental to model validation and long-term peer-review publication of this work.

## Physical and Intellectual Outputs

### Conference Proceedings and Abstracts from Professional Meetings

Bailey, J.D. "Forest restoration and biomass utilization as a partnership in the Pacific Northwest U.S." Visiting Scientist lecture at *Sveriges Lantbriksuniversitet*, Focus on Soil and Water Graduate Seminar, March 18, 2013 in Uppsala, Sweden.

Vogler, K. "Developed silvicultural prescriptions and overall model framework." Poster presentation at the 5th International Fire Ecology and Management Congress, Portland, OR, December 4, 2012.

Bailey, J.D. "Scaling up our understanding of fire risk and fuels management." Presentation at the 5th International Fire Ecology and Management Congress, Portland, OR, December 5, 2012.

Bailey, J.D. "Stocked Stands to Standing Stocks: Sustainable Forest Management and Bioenergy. Presentation at Northwest Bioenergy Research Symposium, Seattle, WA, November 13, 2012.

## Research Presentations

Vogler, K. “Regional Biomass Assessment of the Deschutes National Forest.” Oral presentation to colleagues in Forest Biometrics course at OSU. Corvallis, OR, March 15, 2012.

Vogler, K. “Current Fire Hazard of Forested Lands in Oregon.” Poster presentation to colleagues in Advanced Application in GIS course at OSU. Corvallis, OR, March 21, 2013.

# Task SM-SP-3: Biomass Modeling and Assessment

| Key Personnel | Affiliation |
|---|---|
| Darius Adams | Oregon State University |
| Greg Latta | Oregon State University |

## Task Description

The goals of this task are to : develop expanded biomass volume/weight accounting from existing measurements on regional FIA annual inventory plots; expand forest inventory representation to all public lands in western study region; expand timber market and resource models to Idaho and Montana as necessary; coordinate with researchers in logistics and economics of harvest and transport to establish biomass removal and haul costs for plots and potential plant locations; coordinate with silvicultural researchers to establish stand structure targets for post-biomass harvest stands; expand market model format to include both fixed price biomass revenue and price-flexible biomass demand relations for each sub-region and plant location option; extend current work, that models the role of biomass supply potential of large-scale regional forest fire fuels treatment in stimulating rural economies in Oregon and Washington to include the full range of biomass supply and the wider regional area identified in this proposal; and generate scenario projections of future resource supplies and costs under alternative assumptions about:  biomass processing plant locations and capacities, as well as biomass supply volumes under alternative biomass prices.

## Activities and Results

This project has three major parts: (i) develop an efficient and flexible means to use the Forest Vegetation Simulator (FVS) model to project biomass available tributary to timber harvesting and to simulate large numbers of alternative silvicultural regimes (designed in some cases to increase biomass production); (ii) modify existing regional timber market models to recognize sale of biomass from harvests (including costs of collection, chipping and transportation to hypothetical refinery locations); and (iii) development of biomass supply curves at hypothetical locations under a broad range of scenarios on potential collection technology, constraints on types and sources of biomass, and other conditions affecting the cost of delivered biomass. As a first step we assembled all the Forest Inventory and Analysis (FIA) plot data for the NARA study region, devised methods for estimating key site quality (plant association) measures not collected (or erroneously collected) in FIA sampling, and constructed methods to screen extraneous portions of the FIA database and detect errors in critical parts of the tree and condition class data. We assembled key data on production, output prices, input use and input prices for lumber and plywood mills in the NARA region and began estimation of profit functions by industry and region to provide critical log demand elasticity parameters for the market models. Demand elasticities have been estimated for Oregon and Washington.

In a major step, we successfully converted all the FVS variants in the NARA study region to a composite model based on simplified C++ code. This allows rapid generation of 100-year projections of timber volumes and biomass under user-specified silvicultural regimes. As a quality assurance step we compared yields from the C++ code with results derived directly from FVS across the roughly 4000 condition classes of timberlands sampled in western Oregon and found only modest differences. Yield computations have been augmented to provide estimates of three components of harvest: sawlog/veneer logs, pulpwood, and residual biomass. The latter category comprises estimates of weight by tops, branches and broken portions of logs, as would be encountered in residual slash piles.

The timber market model has been revised to include biomass collection from harvested sites and sales at user-specified locations together with extraction and sale of roundwood pulpwood volumes. The model determines flows to pulpwood and biomass destinations endogenously based on costs and prices. Pulpwood can be downgraded to biomass if price/cost conditions warrant. A western Oregon example market projection has been run with the model using timber yield inputs from the C++ code and assumptions about biomass extraction and haul costs. The model has been used to examine both single and multiple hypothetical biomass destination scenarios and an example biomass supply curve has been generated for a single site case.

## Recommendations/Conclusions

Over the next few months we will refine our work by elaborating details in the model's treatment of biomass harvesting (using more complex cost structures to represent alternative extraction and hauling methods), developing better estimates of biomass delivery cost components (in conjunction with other projects in NARA), and adding a milling residues component (to have a more complete materials balance picture, though these residues are unlikely to find their way into biofuels use). We plan to demonstrate the overall modeling system's capabilities on two areas: western Oregon, which has high timber volumes per unit area, rapid timber growth, and a relatively dense network of milling facilities with expanding capacity and the "western Montana corridor" with lower timber densities, slower growth and a relatively sparse milling network with contracting capacity. We will construct example delivered biomass supply curves for these regions under various background assumptions on facility location(s).

In conjunction with the NARA sub-project developing silvicultural regimes, we will simulate the impact of these regimes on near and long-term timber and biomass supply. We will also begin coordination with elements of the overall NARA project dealing with the environmental and ecosystem services impacts of wide-scale biomass harvesting.

## Physical and Intellectual Outputs

### Thesis and Dissertations

Guerrero, Isabel. 2012. An econometric analysis of output supply and input demand in the Oregon softwood lumber and plywood industries. Paper submitted for MS (without thesis) in Applied Economics, Oregon State University.

# Task SM-SP-4: Long Term Productivity Studies

| Key personnel | Affiliation |
|---|---|
| Doug Maguire | Oregon State University |

## Task Description

The goals of this task are to: replace existing biomass equations developed for unmanaged forests with new versions that account for wide variation in stand density and corresponding allometric relationships; quantify nutrient content of different biomass components including tree, shrub and herbaceous vegetation; estimate nutrient and carbon removals under varying levels of biomass harvesting and harvesting systems; develop and apply simulation models to determine sustainable levels of bioenergy feedstock production under a range of silvicultural intensities; and estimate changes in long-term productivity under different rates of biomass removal and different climate change scenarios.

## Activities and Results

Two seasons of field sampling have been completed, including sampling of numerous tree components from 199 trees ranging in breast height age from ~9 to ~90 years, in diameter at breast height (dbh) from 10-85 cm, and in height from 5-58 meters. Processing the biomass components of these trees in the lab is ~80% complete, and chemical analysis of component tissue has been completed on about 60% of the samples. In addition, understory vegetation sampling has been completed across a chronosequence of sites ranging in age from 0-20 years. Biomass equations have been fit to data collected during the first sampling season, and are currently being incorporated into a Master's thesis.

## Recommendations/Conclusions

Progress has been steady and is on schedule. When all of the data are available from the two seasons of field sampling, final equations will be fit, enabling their use for simulations.

## Physical and Intellectual Outputs

### Research Presentations

Coons, K., D. Maguire, and D. Mainwaring. 2012. The nutrient harvest limits of biofuel production from Douglas-fir biomass in coastal Pacific Northwest forests. Poster presented at 2012 Oregon Society of American Foresters Meeting, Seaside, OR. April 25-26, 2012.

Coons, K., D. Maguire, and D. Mainwaring. 2012. Sustainable biofuel production from forest biomass. Poster presented at NARA 2012 Annual Meeting, Missoula, MT. September 12-13, 2012.

## Other Publications

Coons, K., Mainwaring, D., Bluhm, A., Maguire, D., Harrison, R., and Turnblom, E. 2012. Response of allometric relationships to stand density regime and nitrogen fertilization. Pp. 39-42 in D.A. Maguire and D.B. Mainwaring (eds). 2011 CIPS Annual Report, Center for Intensive Planted-forest Silviculture, College of Forestry, Oregon State University, Corvallis, OR, USA.

# Task SM-SP-5: Environmental Impact Analysis to Support NARA Biofuel Development in the Pacific Northwest

| Key Personnel | Affiliation |
|---|---|
| Michael Barber | Washington State University |
| Brian Lamb | Washington State University |

## Task Description

Land use and residuals management changes associated with biofuel growth, harvesting, and processing may pose unique environmental issues related to air and water quality. There is a need to investigate both air and water quality, as well as water quantity. The work will determine impacts that biofuel harvesting may have on short- and long- term changes in air pollution, sediment and nutrient loadings, and hydrologic dynamics within the project watersheds at scales ranging from field scale to regional scale. The *specific objectives* of this project are to: (1) examine tree harvesting options at field-scale test plots to examine potential alteration of the ecological environment through measurement of runoff, nutrient export, and sediment erosion; (2) collect and examine macroinvertebrate communities at the test plots; (3) develop predictive water quantity and quality models that can be used to evaluate watershed-scale regional impacts; and (4) develop an air quality model of the region.

## Activities and Results

### Water Quality and Resources

We have been examining erosion and runoff modeling to evaluate the impacts of additional biomass removal from logged areas and evaluated several model options before selecting the WEPP model. Processes in WEPP erosion include rill and interrill erosion, sediment transport, and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration and erodibility, climate, and effect of soil random roughness. The basic equation for sediment erosion:

$$\frac{dq_s}{dx} = D_r + D_i \qquad (1)$$

where $q_s$ is the sediment load (kg/s-m), x is the longitudinal downslope distance (x), $D_r$ is the rill erosion rate (kg/s-m$^2$), and $D_i$ is the interrill erosion rate (kg/s-m$^2$). Equations for the rill and interrill erosion can be expressed as:

$$D_r = K_{rb}(\tau_f - \tau_{cb})\left(1 - \frac{q_s}{T_c}\right) \qquad (2)$$

and

$$D_i = K_{i\,adj}\ I_e\ \sigma_{ir}\ SDR_{rr}\ F_{nozzle}\ {}^{R_s}\!/_{W_e} \qquad (3)$$

where $K_{r\ adj}$ is the adjusted baseline erodibility (s/m), $\tau_f$ is the shear stress of the flow (Pa), $\tau_{cb}$ is the baseline critical shear stress (Pa), $T_c$ is the transport capacity (kg/s-m), $K_{i\ adj}$ is the adjusted baseline interrill erodibility, $I_e$ is the equivalent rainfall intensity (m/s), $\sigma_{ir}$ is the interrill runoff rate (m/s), $SDR_{rr}$ is the interrill sediment delivery ratio, $F_{nozzle}$ is the sprinkler nozzle energy factor, $R_s$ is rill spacing (m), and $W_e$ is the equilibrium rill width (m).

The interrill erodibility equation in (3) can be adjusted for local conditions including ground cover ($Ki_{gc}$) as follows:

$$K_{i\,adj} = K_{ib}K_{ican}K_{igc}K_{idr}K_{ilr}K_{isc}K_{isl}K_{ift} \qquad (4)$$

The ground cover coefficient is given by

$$K_{igc} = e^{(-2.5 * Fgc)} \qquad (5)$$

This study considers existing logging operations as the baseline for comparison and focuses on the changes directly related to the removal of slash materials. Other researchers have concluded that ground cover would impact erosion more than runoff although both parameters would respond in similar ways. Figure 1 shows the exponential decrease predicted by Equation 5.

We are in the process of designing field experiments that will begin later this summer to improve Equation 5 by developing an improved method linked to biomass removal.

## Air Quality Assessment

The focus is on developing air pollution emission inventories related to potential biojet supply chains in the Northwest so that regional air quality modeling simulations can be conducted to assess the impacts of biojet production on local air quality. We have followed two tracks in this assessment: compilation of emission inventory information and laboratory studies of biomass pre-treatment emissions. In this first case, the starting place is our regional air quality forecast system, AIRPACT, which operates daily to produce detailed, hourly concentration maps for the region with a focus on ozone (a summertime issue) and particulate matter (PM2.5) (http://lar.wsu.edu/airpact/gmap/ap4.html). AIRPACT emissions are taken from compilations by the state agencies and the Environmental Protection Agency (EPA) and account for virtually all anthropogenic and natural sources, including detailed emissions for various segments of the wood product industry. As a first step, we have compiled the emissions from the wood product industry with the intent of using these emissions as a first step in understanding how changes to the wood product industry due to new biofuel processing might affect air quality. A graphic of these emissions is shown in Figure 2.

In the second track, we have initiated laboratory studies of what gas phase pollutants are produced as a result of pre-treatment of wood chips using a digestion process similar to that envisioned for the biofuel process. This process is shown in Figure 3. Results from the laboratory tests, based on measurements of the headspace of the digestion chamber after a treatment process, are shown in Figure 4. These measurements were collected using a Proton Transfer Reaction Mass Spectrometer. The results show the wide range of organic compounds produced by the process. Further work will be focused on identification of the key species.

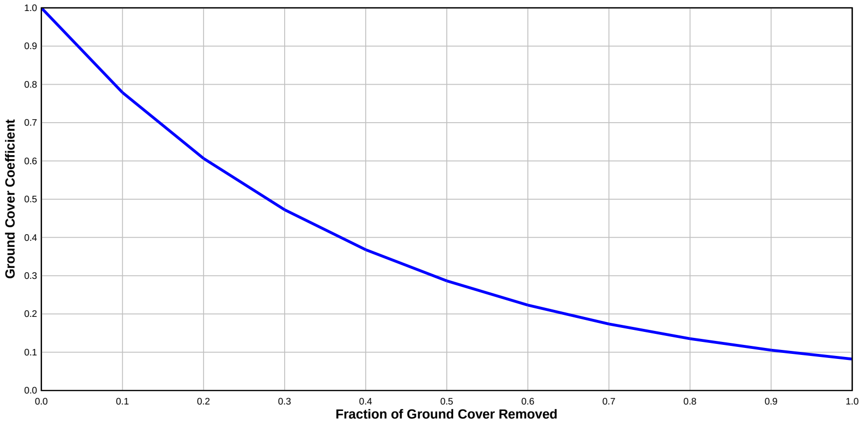


Figure 1. Impact of ground cover on interrill erosion.

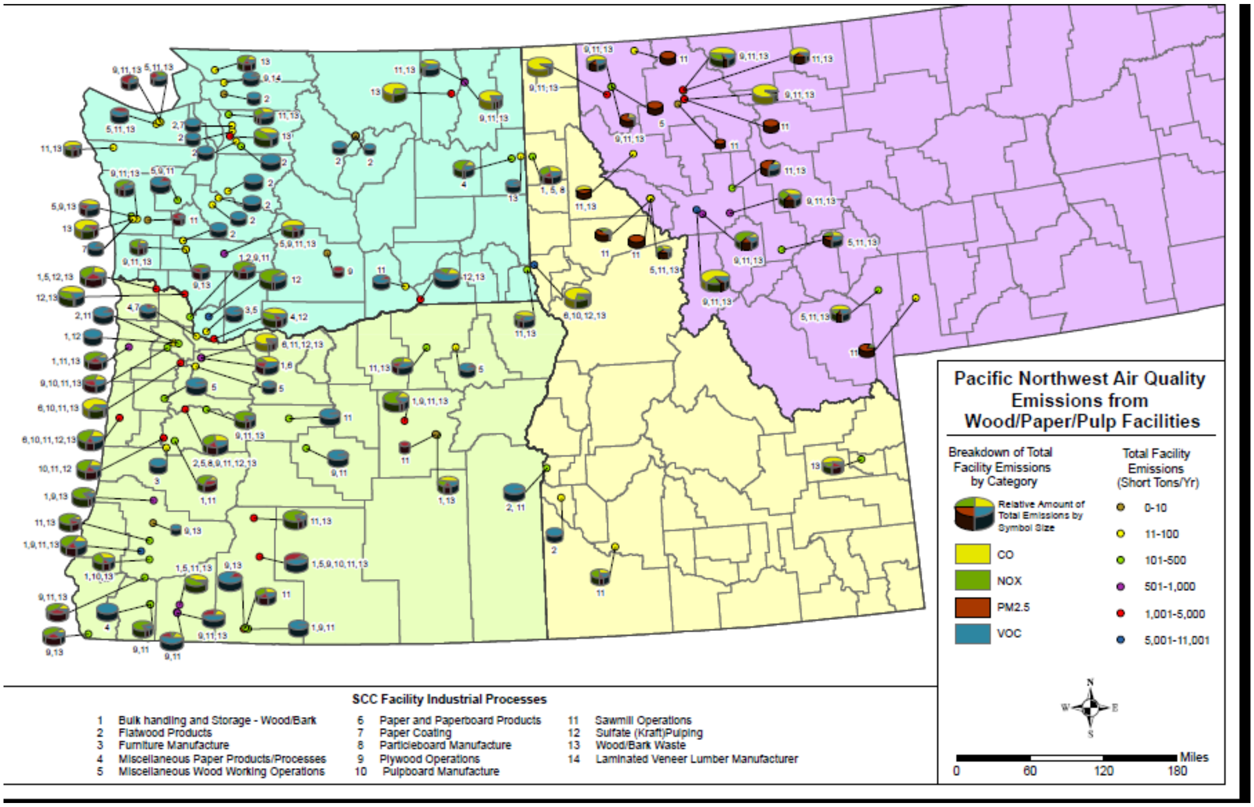


Figure 2. Compilation of air pollution emissions from wood product facilities.

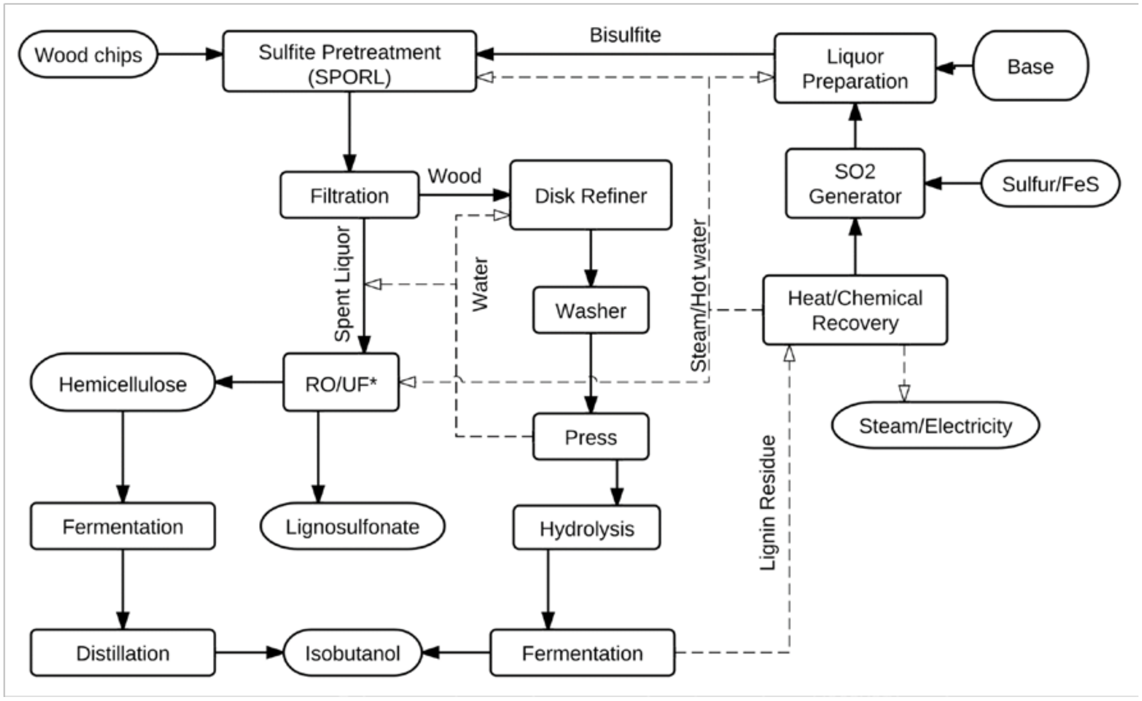


Figure 3. Flow diagram of the biofuel treatment process, including the SPORL pre-treatment step.

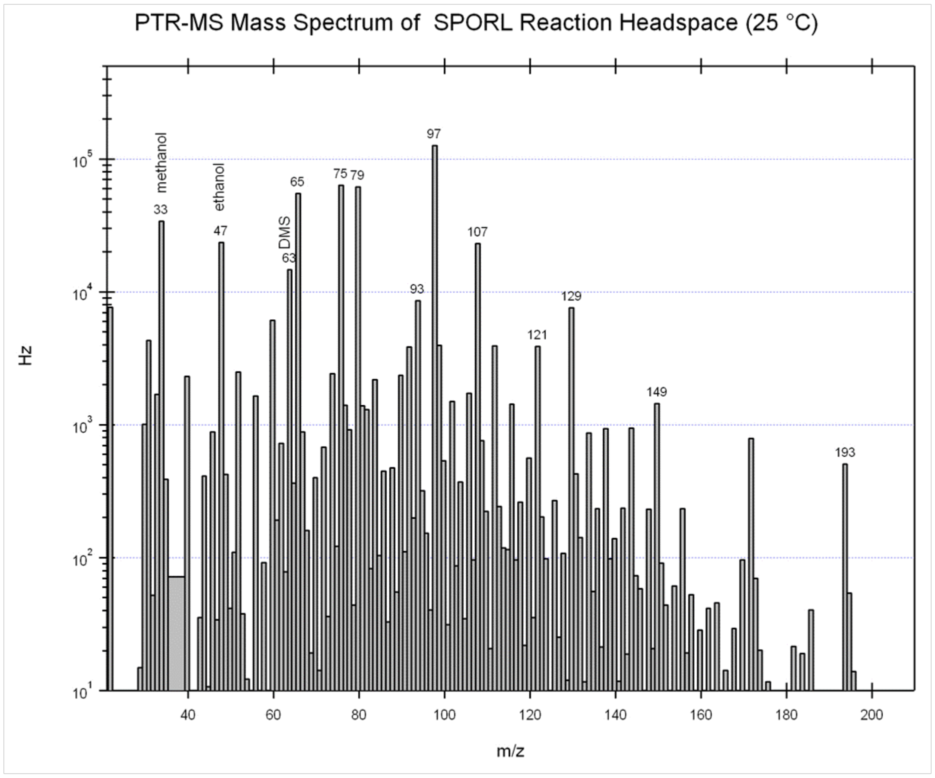


Figure 4. PTR-MS spectra of organic compounds in the off-gas of the SPORL treatment process

## Recommendations/Conclusions

While Figure 1 was developed for agricultural ground, if the data from forested lands follows a similar trend then the difference between traditional logging and biojet fuel processing will result in small changes that would likely impact only the steepest and most erodible soils. This result would mean that only small sections of harvested areas would be excluded from biomass.

## Physical and Intellectual Outputs

### Research Presentations

Fuchs, M., M. Wolcott, T. Jobson, B. Lamb, N. Martinkus, J. Jiang, and P. Gray. 2012. NARA Biofuels Production Emissions. Northwest Advanced Renewables Alliance Summer Undergraduate Research Experience (NARA SURE). Poster presentation, August 3.

Fuchs, M., M. Wolcott, T. Jobson, B. Lamb, N. Martinkus, J. Jiang, and P. Gray. 2012. NARA Biofuels Production Emissions. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Barber, M. and M. Mettler. 2012. Evaluating ecosystem responses to harvesting small diameter biomass. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Task SM-SP-6: Local and Regional Wildlife Impacts of Biomass Removals

| Key Personnel | Affiliation |
|---|---|
| Matthew Betts | Oregon State University |

## Task Description

Silvicultural regimes proposed will be reviewed to reduce fire hazard and improve forest health. Existing data from the Pacific Northwest (PNW) on the relationship between species and stand structures (e.g., downed woody material, snags) will be used to estimate the potential impact of regimes on vertebrate abundance. Also, using existing published research, we will conduct a meta-analysis that tests the influence of species life-history traits on sensitivity to proposed silvicultural regimes. Landscape patterns resulting from regional models of biomass collection and removal will be reviewed. We will test for potential population level consequences of biofuel harvest at the regional scale via demographic models for species with a range of life history traits (e.g., dispersal abilities, longevity, fecundity). These simulation models will be used as a way of generating hypotheses about species most likely to be at risk from biofuel treatments.

## Activities and Results

A new post-doc, Heather Root, began work on the project in mid-January. We have reviewed silvicultural regimes proposed for biomass harvest in the Pacific Northwest and compared these with other regions and biomass feedstock. We have consulted with other NARA participants and potential collaborators including Darius Adams, Andrew Moldenke, and Tom Spies to discuss economic model outputs, soil diversity and function and landscape-level models.

Currently, we are reviewing the literature to understand which habitat characteristics are the most likely to be affected by biofuel harvesting, in particular loss of woody debris and soil disturbance and compaction. Through our literature review, we are determining which woody debris characteristics, such as exposure, decay class, and size, are important habitat features. We are reviewing wildlife and botany literature to identify species most likely to be affected by these practices both in relation to their habitat needs and life-history patterns.

Betts and Root are working to establish a conceptual model and directions for future biodiversity – biofuel harvest research. Our model includes a web of impacts to diversity and ecosystem services as well as the magnitude of scientific knowledge and potential impact.

## Recommendations/Conclusions

Our brainstorming and literature review have suggested several avenues through which forest biofuel harvest may affect biodiversity in the short- and long-term. We anticipate that our conceptual model will allow a concrete context for future modeling efforts and identify knowledge gaps to focus future research.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Betts, M.G., Verschuyl, J., Stokely, T., Giovannini, J. and Kroll, A.J. In Review. Initial effects of herbicide on bird abundance in plantation forests. Forest Ecology and Management.

### Research Presentations

Betts, M.G. 2013. Environmental Considerations in Forest Biomass Harvesting. Invited presentation to the Starker Lecture Series, May 2, 2013, Oregon State University, Corvallis, Oregon.

# Task SM-SP-7: Supply Chain Analysis

| Key personnel | Affiliation |
|---|---|
| Todd Morgan | University of Montana |

## Task Description

Land managers and bioenergy specialists lack definitive knowledge of woody biomass inventories and availability in the Pacific Northwest. This information is key to understanding the social, economic, and environmental impacts and sustainability of producing new wood-based energy products. To answer these needs, The University of Montana's Bureau of Business and Economic Research's Forest Industry Research Program will characterize the composition, quantities, and spatial distribution of varied sources of woody biomass across the NARA four-state area. The *specific objectives* of the Feedstock Supply Chain Analysis Phase are to identify and provide primary data necessary to assess the woody biomass inventory with particular emphasis on mill and logging residue in the 4-state region and standing forest inventory in Montana and Idaho.

## Activities and Results

### Task SM-SP-7.1. Coordinate new and existing Idaho & Montana ("east-side") forest inventory and other data for use in "west-side" models

The University of Montana's Bureau of Business and Economic Research (BBER) Forest Industry Research Group has provided fellow NARA researchers with forest industry and timber products output (TPO) data for modeling and GIS applications throughout the four-state area since the project started in September 2011. BBER specialists have answered dozens of information requests from NARA researchers and stakeholders. These responses have included estimates of standing forest volumes, timber harvest volumes, mill residues, and logging residues.

BBER researchers have worked with colleagues at Oregon State University (OSU) and Washington State University (WSU) to derive innovative ways to use BBER's data products, particularly BBER's logging residue data. For example, OSU scientists have developed tools to predict woody biomass found in landing residue piles. They plan to create ratios of landing pile versus total stand-level residue biomass using BBER's utilization data. These ratios could then serve as variables in biomass forecasting models. BBER investigators continue to seek ways for our NARA colleagues to use our extensive logging utilization data set.

### Task SM-SP-7.2. Enhance and update primary mill residue and capacity information for 4-state region

BBER staff have continually updated primary mill residue and capacity information since the start of the NARA project. Specifically, BBER has provided fellow NARA scientists with Timber Product Output (TPO) data for Idaho (2006), Oregon (2008), Montana (2009), Washington (2010), with updated Idaho (2011) data scheduled for delivery in the fall of 2013.

We can provide estimates of mill residues produced (and used/not used) annually for each of the 4 NARA states based on our mill census data, annual lumber production, and other information.

### Task SM-SP-7.3. Enhance and update logging and other forest residue for 4-state region

Logging utilization fieldwork has continued across the four-state region and is progressing on-schedule, with more than 1,300 felled trees measured at 56 sits across the region (Table 1).

We can provide logging residue estimates for the NARA regionat the state and county levels based on our logging utilization fieldwork and ancillary information. We can also supply summarized annual county-level timber harvest data obtained from other sources.

Table 1: Logging utilization field work progress through March 31, 2013

| State | Sites | Percent complete |
|---|---|---|
| Idaho | 14 | 40 |
| Montana | 14 | 40 |
| Oregon | 14 | 40 |
| Washington | 14 | 40 |
| Total | 56 | 40 |

## Recommendations/Conclusions

### Conclusions

*Mill Residues:* BBER's recent TPO research (Gale et al. 2012; McIver et al. 2012; Brandt et al. 2012) confirms preliminary observations: 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 pre-treatment plants) will face competition for mill residues from current residue users. However, mill residue production will increase as primary product (i.e., lumber, veneer, etc.) outputs increase in response to improving economic conditions and increases in domestic new home construction.

*Logging Residues:* BBER's recent summary of Idaho logging utilization research (Simmons et al. 2013) clearly shows 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. Improved technology, such as mechanized processing, helps ensure that more of each felled tree is utilized. BBER analysts have found that more than half of the variation in the logging residue fraction is related to 1. method of harvest- by hand or mechanical, 2. Presence/absence of pulp removal, and 3. broad geographic differences in site quality (Berg et al. 2012). Landing residue "slash" piles offer an important source of woody material for potential conversion to bio-jet and ancillary products.

*Timber Harvest:* Timber harvest volumes have declined through time across all four NARA states (Gale et al. 2012; McIver et al. 2012; Brandt et al. 2012; Smith et al. 2012). Private lands timber harvest declined in response to low demand for logs at domestic mills during the U.S. housing bust and Great Recession. Some recovery of private lands harvest has been indicated in western Oregon and Washington as a result of increased overseas demand for logs. As domestic demand for housing and wood products increases, private and state-owned timber harvest is also expected to rise. We believe it unlikely that federal lands will substantially increase timber harvest levels in the future, regardless of wood products demand. Public support for forest restoration and fire hazard reduction treatments has fostered hope that we will see minor increases in federal harvest over the next several years. However, current legal, policy, and silvicultural barriers suggest federal lands are an unreliable source of long-term biomass supply.

## Recommendations

Data management: We should organize NARA data so that it can be readily accessed and understood by both NARA researchers and the public.

*Cooperation:* We should improve collaboration and communication among NARA scientists. We have much to offer each other! The recent change in NARA's team structure has fostered better communications among team members; we need to continue seeking innovative ways that our colleagues can use BBER's TPO, logging utilization, timber harvest, forest industry, delivered log prices, and timber harvesting and hauling cost information in their work.

*Logging utilization studies:* We should continue collecting logging utilization data across the NARA project area through Year-5 of the project. The overall BBER logging utilization study plan calls for sampling 5 to 7 logging sites per state per year, resulting in a grand total of 25 to 35 measured sites per state by project completion. This "rotating sampling" scheme helps ensure that spot market influences on utilization are minimized. Stopping short of four years of data collection would substantially reduce the total number of sample sites per state and would jeopardize the utility of the data. BBER intends to focus Year-3 logging utilization sampling efforts on coastal Washington and Oregon and western Montana. We have now sampled 33 sites in Idaho (14 funded by NARA, 19 by Interior West FIA); we plan on returning to Idaho in years 4 & 5 of the project to "freshen our database" and gain information on 5 to 8 additional Idaho logging sites.

## The Future

In Year 3, the BBER team will conduct logging utilization fieldwork, analyze and report logging utilization and other forest industry data, and share information with NARA Teams and stakeholders.

In order to provide NARA Teams with current information on the production and potential availability of woody biomass from the residues of commercial timber activities, BBER's Year-3 efforts will include:

- Measuring logging utilization at active logging sites across the four-state NARA region;
- Processing, summarizing, and sharing those logging utilization data and results with other members of NARA, regional stakeholders, and others;
- Collecting, analyzing, reporting, and otherwise sharing a variety of forest industry information in the region, including timber harvest levels by county and ownership, timber use, production of primary wood products, and production & disposition of mill residue.

Given proposed budget changes (i.e., direct expenses reduced to accommodate increased indirect costs) BBER is reducing the number of active logging sites to be measured in the third year from 5-7 sites per state to 3-6 sites per state. Measurement efforts will be prioritized in Oregon and Washington to ensure adequate samples per state. We anticipate being able to complete 5-6 more sites (each) in Washington and Oregon. Neither state has had a comprehensive logging utilization study conducted in 20 years, and more up-to-date information is critically needed in both states. Measuring 3-5 sites in Montana is the second priority, and we do not expect to measure more than three sites in Idaho during the third year.

## Physical and Intellectual Outputs

### Refereed Publications (accepted or completed)

Simmons, E., E. Berg, T. Morgan, S. Zarnoch, S. Hayes and M. Thompson. 2013. Logging utilization in IDAHO: an investigation of current and past trends. Draft USDA Forest Service Rocky Mountain Research Station Resource Bulletin.

### Research Presentations

Berg, E., E. Simmons, S. Zarnoch, S. Hayes, T. Morgan, and C. Gale. 2012. Logging Residues: preliminary predictive models. Poster presented at the NARA Annual Meeting, Missoula, MT, September 12-14, 2012.

Berg, E., E. Simmons, T. Morgan, C. Gale, S. Zarnoch and S. Hayes. 2012. Estimating logging residues in the State of Idaho: preliminary predictive models. Presentation to the Society of American Foresters 2012 national convention, October.

Hayes, S. 2012. Presentation to US Forest Service Region One Timber Management Staff. Logging cost analysis. March 29, 2012. (not funded by NARA).

Morgan, T., E. Simmons, E. Berg, C. Gale, S. Hayes, C. Sorenson. 2012. Characterizing logging residues as potential feedstock for the manufacture of biojet. Presentation at the Western Forest Economists Meeting in Newport, OR, June.

Morgan, T., E. Simmons, E. Berg, C. Gale, S. Hayes. 2012. Forestry is rocket science: quantifying logging residues as feedstock for bio-jet and other uses. Poster presented at the International Wood Composites Symposium, Seattle, WA. April 11-13, 2012.

Morgan, T. 2012. Presentation to Montana Department of Natural Resources. Biomass utilization potential: presentation included the role of NARA-funded logging utilization data in predicting biomass. Feb. 6, 2012.

Morgan, T. 2012. Presentation to Oregon Forest Industry Council. Dynamics of the Oregon forest products industry; included prediction of logging residue. Jan. 5, 2012. (not funded by NARA).

Morgan, T. 2012. Presentation to US Forest Service Region One Timber Management Staff. The status of the inland northwest forest industry; presentation included predicting forest residues through logging utilization studies. March 28, 2012. (not funded by NARA).

Simmons, E., J. Meek, E. Berg, T. Morgan, S. Hayes, and C. Gale. 2012. Idaho Logging Utilization, 2008/2011. Poster presented at 2012. International Wood Composites Symposium, Seattle, WA. April 11-13, 2012.

Simmons, E., J. Meek, E. Berg, T. Morgan, S. Hayes, and C. Gale. 2012. Idaho Logging Utilization, 2008/2011. Poster presented at the NARA Annual Meeting, September 12-14, 2012. Missoula, MT.

Simmons, E., E. Berg, T. Morgan, C. Gale, and S. Hayes. October 2012. Logging Utilization in the State of Idaho 2008/2011. Presentation at the 2012 Society of American Foresters national convention.

Simmons, E., J. Meek, E. Berg, T. Morgan, C. Gale, S. Hayes. 2012. Logging Utilization in the State of Idaho 2008/2011. Poster presented at the USDA Forest Service Forest Inventory and Analysis Science Symposium held December 2012.

Sorenson, C. and C. McIver. *Mill Residue Production and Use in Montana, 2009*. Poster presented at the NARA Annual Meeting, September 12-14, 2012. Missoula, MT.

## Other Publications

Brandt, J., T. Morgan, C. Keegan, J. Songster, T. Spoelma, L. DeBlander. 2011. Idaho's forest products industry and timber harvest, 2006. USDA Forest Service Rocky Mountain Research Station Resource Bulletin RMRS-RB-12. (not funded by NARA).

Gale, C., C. Keegan III, E. Berg, J. Daniels, C. Sorenson, T. Morgan, P. Polzin, and G. Christensen. 2012. Oregon's forest products industry and timber harvest, 2008. Industry trends and impacts of the Great Recession though 2010. USDA Forest Service PNW Station PNW-GTR-868. (not funded by NARA).

McIver, C., C. Sorenson, T. Morgan, Montana's Forest Products Industry and Timber Harvest, 2009. Draft tables posted at: http://www.bber.umt.edu/forest/regionalreports.asp). (not funded by NARA).

Meek, J. 2012. Bureau of Business and Economic Research Chip Sample Study. Forestry 435/436 Term Paper. College of Forestry and Conservation. University of Montana. Missoula, MT.

# Techno-Economics Team

## Task SM-TEA-1: Techno-Economics Analysis

| Key Personnel | Affiliation |
|---|---|
| Gevan Marrs | Weyerhaeuser |
| Tom Spink | TSI |

### Task Description

Weyerhaeuser and TSI will work cooperatively to construct a complete techno-economic model for the NARA softwood-to-biojet production. The model will define a base case for key elements:

- Feedstock cost estimates at various facility scales
- Key process blocks
- Mass and energy balances for each block, tracking
    - Wood polysaccharides to bio-jet
    - Wood lignin residuals to co-products
    - Other wood components (volatiles, ash: waste) where appropriate
- Operating costs for each block (materials, energy)
- Capital cost for each process block
- Total Capex vs. scale, optimization against feedstock costs at scale, selection of base case facility scale.
- Other financial incentives (RINS for RFS2, tax incentives, etc.)
- Financial assumptions (cost of capital, facility life, depreciation, etc.)

These will be assembled in a standard discounted-cash-flow return-on-investment (DCF-ROI, NPV) analysis sheet with input blocks for key variables allowing user interaction for sensitivities. The key outputs will be:

1. Base Case Executive Summary: A one page base case summary including key values
2. Cost Components Analysis: Depiction of major cost elements with interpretations for main leverage points for improvement opportunities.
3. Sensitivity Analysis: Using equal-probability estimates from experts in each key area, assess which elements have the most potential to improve overall economics (e.g., Capex, Feedstocks, Yields, etc.)

~~4.~~ Perform a Lignin Co-Products Valuation: Quantify a realistic return on lignin co-products, and/or an analysis to define what would be needed to bring the entire project to profitability

5. Pretreatment Alternatives Evaluation: the base case model will need variations to estimate the impact(s) of each contending pretreatment option. This comparison will be a key determinant in down-selecting for a preferred route.

It is expected that the analysis will be iterative, as an “initial” overall model is needed to identify key leverage points for subsequent refinement. Once the initial base case assumptions are reviewed and digested, it is highly likely that additional refinements will be desired to improve the resolution of key assumptions that are driving the output results. The basic tasks for this project are as follows:

Task SM-TEA-1.1. Build and populate first-cut NARA project TEA model framework

Task SM-TEA-1.2. Obtain and assemble first-cut capital cost estimates

Task SM-TEA-1.3. Obtain and assemble first-cut process flow and operating cost estimate

Task SM-TEA-1.4. Construct first-cut pass at overall economics

Task SM-TEA-1.5. Summarize reporting elements and communicate with stakeholders

Task SM-TEA-1.6. Evaluate the pretreatment options on an equitable basis

Task SM-TEA-1.7. Solicit process improvements in key leverage areas and update economics

Task SM-TEA-1.8. Refine and update model for process and siting specificity

Task SM-TEA-1.9. Further refine and update model for process and siting specificity

Task SM-TEA-1.10. Further refine and update model to *pro forma* balance sheet level

## Activities and Results

In order to rapidly have a fully constructed techno-economic analysis (TEA) model framework and to take advantage of the significant prior work on structure and assumptions, the NREL 2011 Corn Stover to Ethanol TEA model was obtained and used as a starting model template and a logic check for our work. Feedstock sourcing curves for a hypothetical optimum sourcing location (lowest cost) for either western Oregon or Washington softwood forest harvest residuals were generated. The rising average feedstock delivered cost with scale tonnage was compared against capital efficiency of increasing conversion facility scale to yield a target facility scale of 770,000 bone dried ton (BDT) feedstocks per year. A full chain of process yield by stage for softwood to biojet blendstock (iso-paraffinic kerosene, IPK) was built for the base case using demonstrated results from each area expert participant in the project conversion chain, giving a final base case yield of 45.6 gallons IPK per BDT feedstock and 35 million gallons per year. The overall process flow was mapped and material mass balances calculated for the entire conversion process. Capital, operating and fixed costs estimates were made for each process step by the project experts for each process area. These were assembled into an entire process mass balance and operating costs and with capital incorporated into the TEA model.

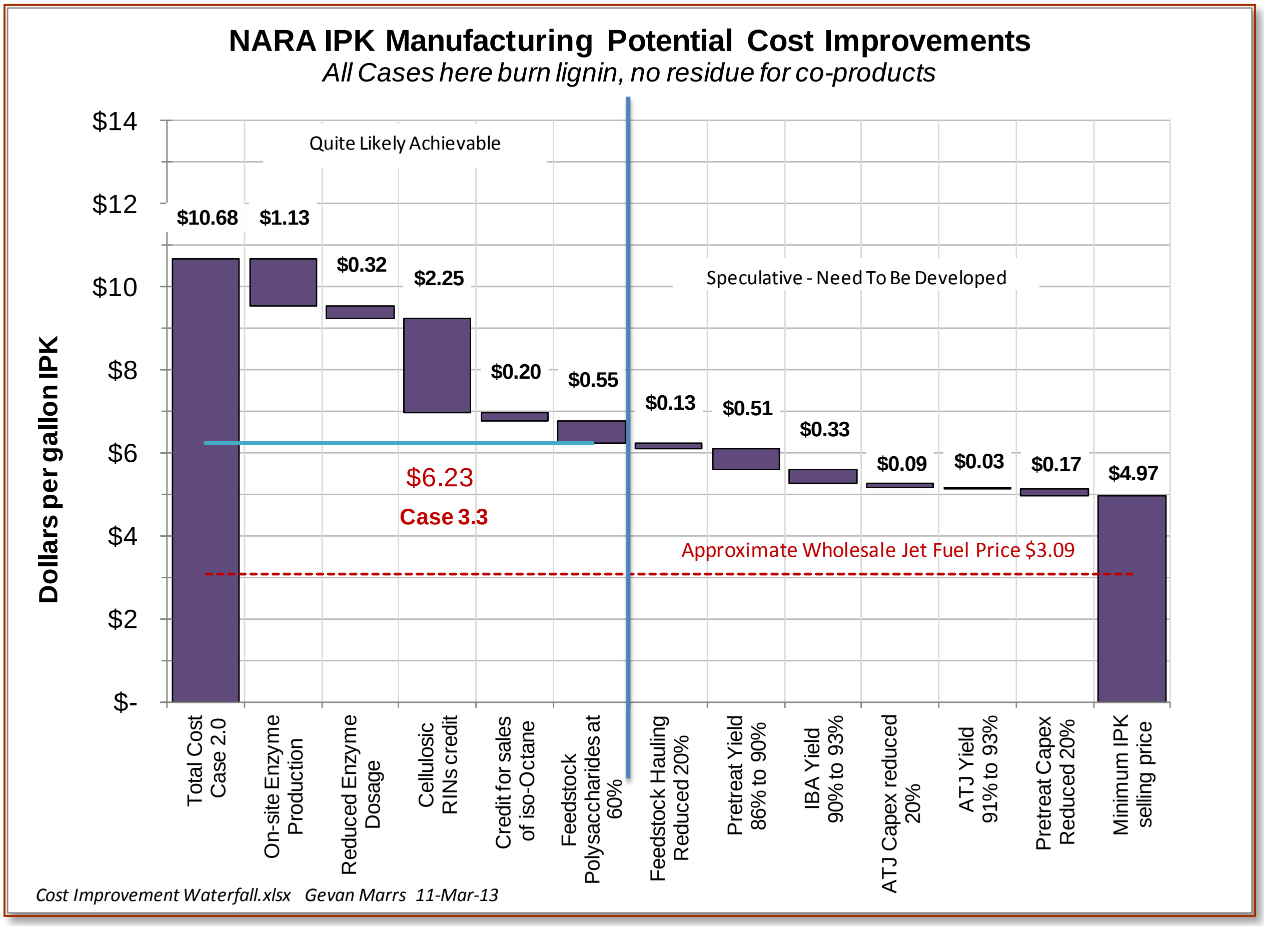
Total capital investment for the conversion facility to produce just IPK (biojet), burning the lignin residue for power, was $881 million, and with operating and fixed costs, the total manufacturing costs were calculated to be $8.91/gal IPK. Cellulosic RINs were estimated for the IPK product, and were valued at $2.25/gal, resulting in a net total manufacturing cost of $6.66/gal IPK. This is considerably higher than the current wholesale jet fuel price trend price of $3.09/gal. The full key results for this case are shown in Figure 1.

Estimates were made for all identifiable improvements that were believed to be 50% probable within three years of development work. The cumulative effect of all of these together only improved the manufacturing costs to $4.97/gal (Figure 2). Accordingly, to be commercially viable, additional sales of high-value lignin co-products was deemed necessary. A model based upon reserving all lignin residue for co-products preparation, instead of burning for power, was calculated. Overall manufacturing cost for IPK(after C-RINs) was increased to $7.21/gal IPK, but now there is a considerable annual mass of lignin residue from which we can potentially generate a high-value co-product.

An initial potential lignin-based co-product has been identified at the speculative level. This is production of a high-value activated carbon (AC) from the lignin fraction of the residue left from fermentation and distillation. A rough estimate of the case where the lignin residue was not burned for power, but reserved and sent to an AC lignin co-products facility, is estimated to possibly generate revenue in considerable excess of the AC manufacturing costs~~.~~ This case, based upon these very early indications, would appear sufficient to bring the overall conversion facility into positive returns, and therefore warrant considerable further investigation of production feasibility, cost, yield, market size and selling price.

This information is potentially proprietary and has been omitted. Please contact members of the NARA Executive Committee for further information.

Figure 1. Overall Summary Techno-Economics of Bio-Jet production from softwood.



*Cost Improvement Waterfall.xlsx Gevan Marrs 11-Mar-13*

Figure 2. Potential impact of plausible improvement options for IPK-only manufacturing.

## Recommendations/Conclusions

1. Given the feedstock supply of softwood forest harvest residuals, locating a facility in an optimum feedstock location in western Washington or Oregon, delivered feedstock costs at optimized facility scale (777,000 BDT/year) are estimated to be $68 per BDT. We do not find major opportunities to reduce this to a dramatic degree.
2. The net yield of IPK is estimated to be 45.6 gallons per BDT feedstock to conversion mouth, yielding 35.1 million gallons IPK production per year. Compared to many other published cellulosic ethanol or hydrocarbon product yields (70 to 90 gal/BDT) this imposes a significant cost hurdle on IPK (biojet).
3. Total capital investment for a facility producing only IPK as a primary product (no lignin co-products – burn the lignin residue for power) is estimated to be $881 million dollars. This puts the Total Invested Capital at $25/annual gal IPK production capacity, which is roughly double published production cost figures for cellulosic biofuels. This mostly reflects a difficult feedstock (recalcitrant softwood) and a relatively low final product yield, all for a fairly low-priced commodity product (jet fuel).

4. Under the “IPK-only” case, with all manufacturing costs, amortized capital costs, including recovery of capital, plus fixed costs, the per gallon manufacturing costs for IPK are $8.91—considerably above a likely wholesale jet fuel price of about $3.09/gal.
5. Cellulosic RINS for IPK (assuming qualifying renewable feedstocks and adequate greenhouse gas (GHG) reductions are very significant—estimated to be about $2.25/gal IPK. This would bring net manufacturing costs down to $6.66/gal IPK—still considerably above what jet fuel users have stated as their willingness to pay, about $3.09/gal (that is, there is no buyer premium paid for renewable fuel standard (RFS) biojet).
6. With all identified “plausibly achievable” improvements on the “IPK-only” case, we have identified improvements that if achieved in total would bring manufacturing costs down to about $4.97/gal IPK—still considerably above the $3.09 target. Accordingly, we conclude that we MUST utilize some fraction of the biomass flow not going to IPK (“lignin residue”) to generate additional profit if the currently envisioned venture is to be commercially viable.
7. Generating revenue from co-products in addition to IPK is most likely to derive from lignin fractions, hence a preliminary speculative case for *not* burning the lignin residue and reserving it for manufacturing of co-products was generated. One potential high-value co-product has been speculatively identified—a specialized activated carbon (AC) used for mercury amelioration applications. This market for AC appears to be in a significant growth phase as the result of a significant new use for AC, prompting market prices for AC to be in the range of $2.50/lb. Initial laboratory work indicates that an AC from NARA lignin is compatible with this new market. Preliminary financial estimates for AC from NARA lignin suggest it may be produced at a cost that could bring the entire IPK & AC facility to a positive return.
8. Overall, it would seem that evolutionary improvements in even multiple areas of the process cost or yield are *not* going to be sufficient to bring the bio-jet production facility into commercially viable range if only IPK is produced. We need to review these TEA results with all team area-experts for “revolutionary” improvement options not yet considered. Included among these might be:
    a. High-value co-products, as described tentatively above.
    b. Significant shift in value-chain construct, such as distributed production of intermediate products at lower scale (perhaps sugars or indole-3-butyric acid (IBA)) such that there are multiple potential customers and products, beyond just biojet fuel.
    c. Examination of the scale efficiency impact of the current pre-treatment options that scale like pulp mills, leading to very large capital costs and feedstock demands to a central site, adding to average feedstock costs.
    d. Identification of dramatic cost-reduction elements such as brown-field site utilization and state and/or local incentives.

## Physical and Intellectual Outputs

### Physical

- A facility scale optimization spreadsheet that takes estimated feedstock costs with scale from the Feedstock Sourcing task and combines with facility capital scale efficiency estimates to target base case facility optimum scale.

- A documented and reconciled process yield chain spreadsheet for a key metric—gallons of IPK per BDT feedstock—(including all intermediate stage yields as well).

- A full set of process hand-drawn and calculated flow diagrams, mass and energy balances for all 10 unit operations in the process, including material costs.

- Produced multiple techno-economic spreadsheet models for production of:
    - Biojet fuel as the only product, burning the residual lignin fraction for power.
    - Biojet fuel and reserving the lignin residue for high-value co-products production.
    - Iso-butanol intermediate as our product, rather than IPK.

- Each model contains as key ouput:
    - Summary sheet for all key metrics (unit production costs, total capital, Opex by dept., etc.)
    - Two-way cost breakdown table and charts by process area and cost type (Capex, Opex, Fixed).
    - Capital costs bar charts by process area to identify big-hitters.
    - Case history and data sources all documented internally to each spreadsheet.

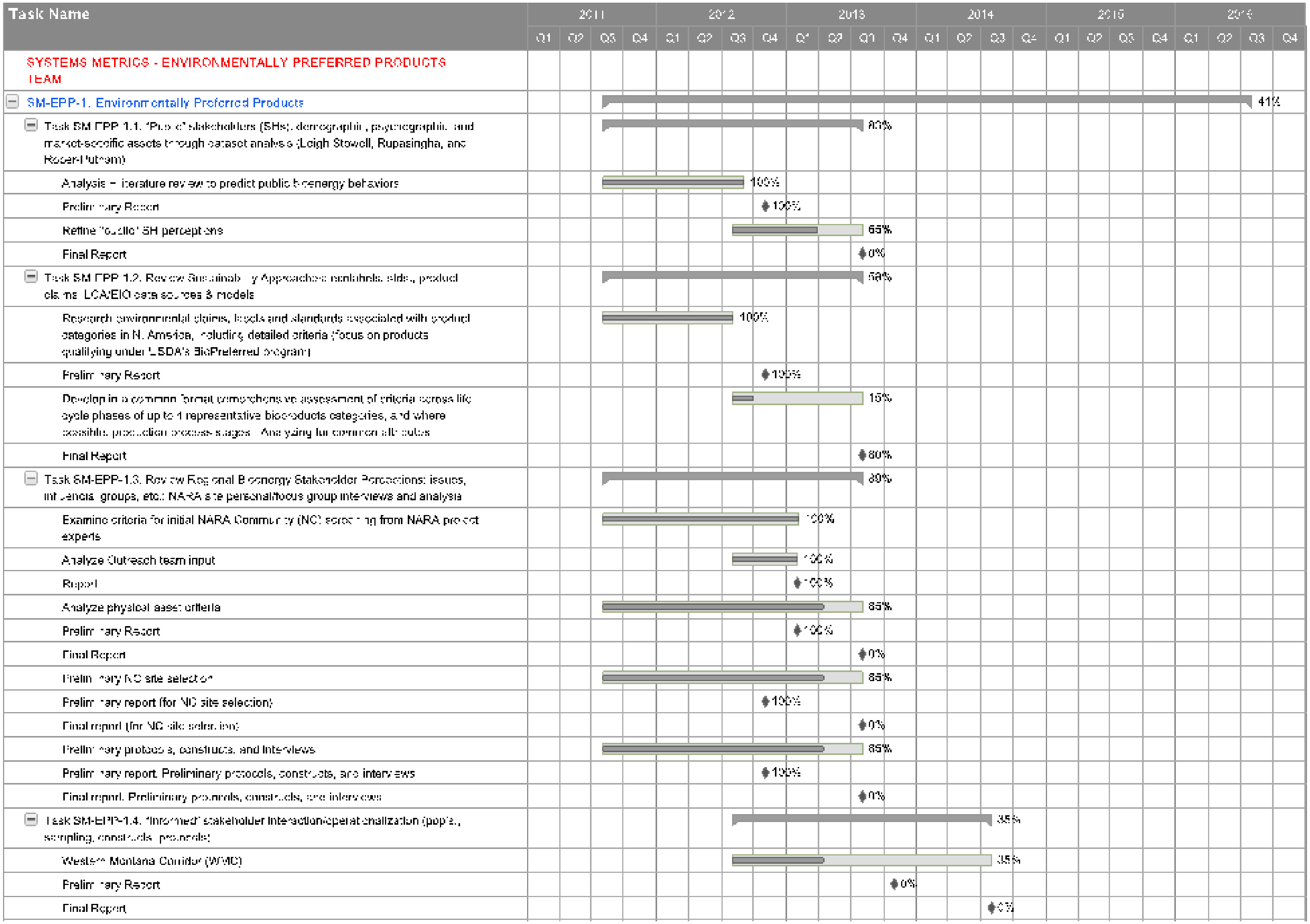
- For each key case, a summarized presentation with background, approach, key results, conclusions and recommendations.

- An “improvement opportunities” analysis spreadsheet (waterfall chart) that shows estimated potential gains with 3-year improvement ideas at a 50% probability level.

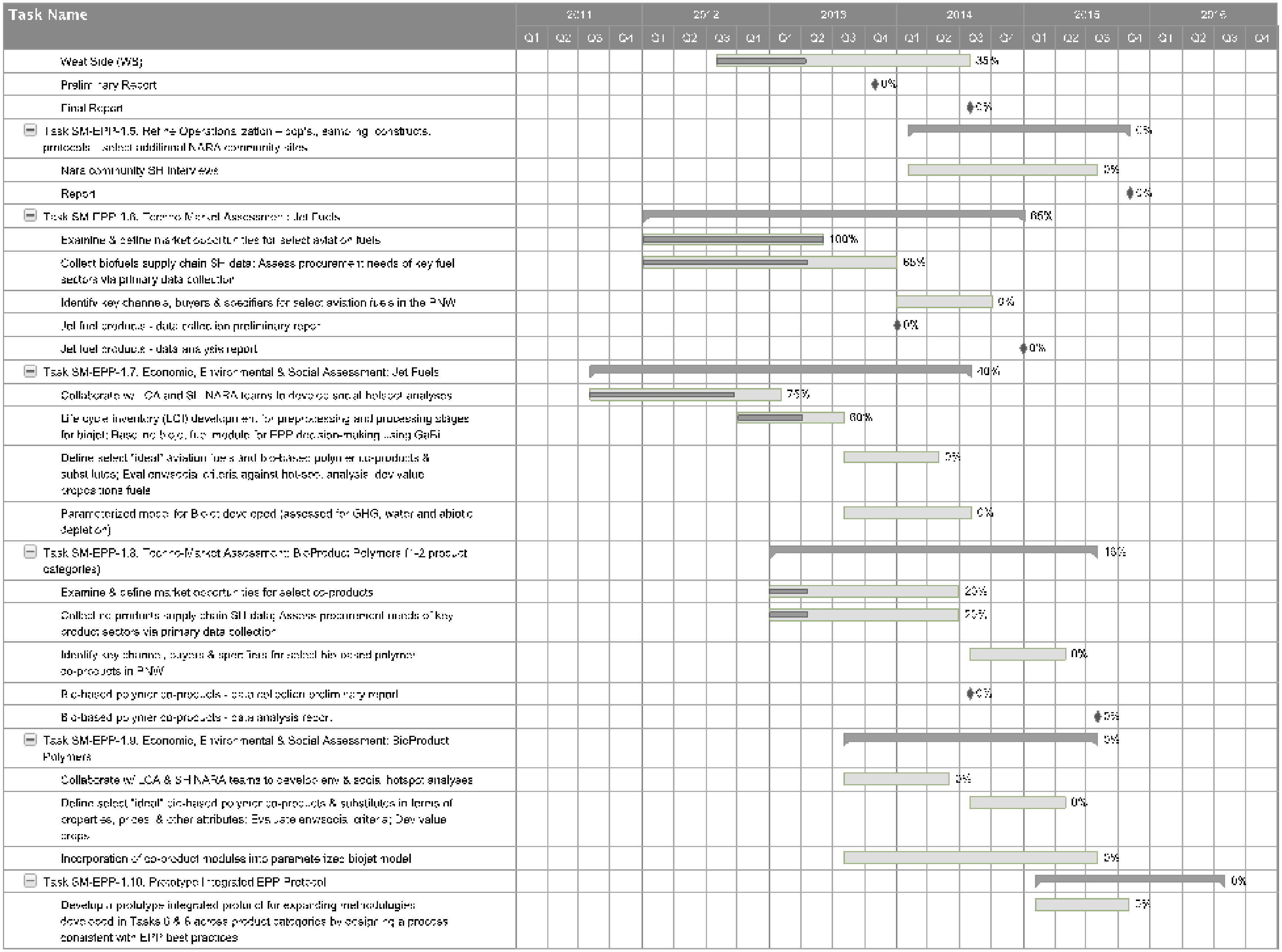
## Intellectual

- An understanding of the basic (challenging) economic feasibility of producing biojet from softwood, the criticality of qualifying for the C-RINs, and the need for breakthrough improvements like high-value co-products or very significant feedstock and capital cost reductions.

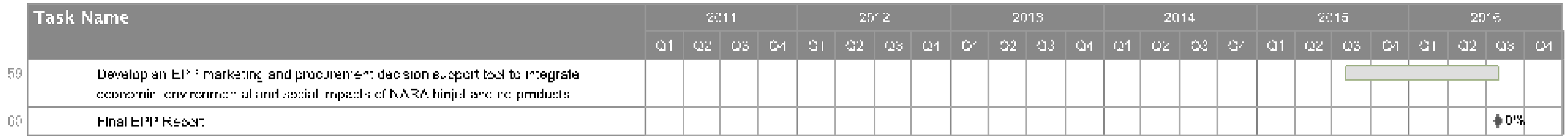
# SystemsMetrics_EPP



| | Task Name |
|---|---|
| 1 | SYSTEMS METRICS - ENVIRONMENTALLY PREFERRED PRODUCTS TEAM |
| 2 | SM-EPP-1. Environmentally Preferred Products |
| 3 | Task SM-EPP-1.1. "Public" stakeholders (SHs): demographic, psychographic, and market-specific assets through dataset analysis (Leigh Stowell, Rupasingha, and Roper-Putnam) |
| 4 | Analysis – literature review to predict public bioenergy behaviors |
| 5 | Preliminary Report |
| 6 | Refine "public" SH perceptions |
| 7 | Final Report |
| 8 | Task SM-EPP-1.2. Review Sustainability Approaches: ecolabels, etc., product claims, LCA/EIO data sources & models |
| 9 | Research environmental claims, labels and standards associated with product categories in N. America, including detailed criteria (focus on products qualifying under USDA's BioPreferred program) |
| 10 | Preliminary Report |
| 11 | Develop in a common format comprehensive assessment of criteria across life cycle phases of up to 4 representative bioproducts categories, and where possible, production process stages. Analyzing for common attributes |
| 12 | Final Report |
| 13 | Task SM-EPP-1.3. Review Regional Bioenergy Stakeholder Perceptions: issues, influencial groups, etc.: NARA site personal/focus group interviews and analysis |
| 14 | Examine criteria for initial NARA Community (NC) screening from NARA project experts |
| 15 | Analyze Outreach team input |
| 16 | Report |
| 17 | Analyze physical asset criteria |
| 18 | Preliminary Report |
| 19 | Final Report |
| 20 | Preliminary NC site selection |
| 21 | Preliminary report (for NC site selection) |
| 22 | Final report (for NC site selection) |
| 23 | Preliminary protocols, constructs, and interviews |
| 24 | Preliminary report. Preliminary protocols, constructs, and interviews |
| 25 | Final report. Preliminary protocols, constructs, and interviews |
| 26 | Task SM-EPP-1.4. "Informed" stakeholder interaction/operationalization (people, sampling, constructs, protocols) |
| 27 | Western Montana Corridor (WMC) |
| 28 | Preliminary Report |
| 29 | Final Report |



| | Task Name | |
|---|---|---|
| 30 | West Side (WS) | 35% |
| 31 | Preliminary Report | 0% |
| 32 | Final Report | 0% |
| 33 | Task SM-EPP-1.5. Refine Operationalization – sop's., sampling constructs, protocols – select additional NARA community sites | 0% |
| 34 | Nara community SH Interviews | 0% |
| 35 | Report | 0% |
| 36 | Task SM-EPP-1.6. Techno-Market Assessment: Jet Fuels | 65% |
| 37 | Examine & define market opportunities for select aviation fuels | 100% |
| 38 | Collect biofuels supply chain SH data: Assess procurement needs of key fuel sectors via primary data collection | 65% |
| 39 | Identify key channels, buyers & specifiers for select aviation fuels in the PNW | 0% |
| 40 | Jet fuel products - data collection preliminary report | 0% |
| 41 | Jet fuel products - data analysis report | 0% |
| 42 | Task SM-EPP-1.7. Economic, Environmental & Social Assessment: Jet Fuels | 40% |
| 43 | Collaborate w/ LCA and SH NARA teams to develop social hotspot analyses | 75% |
| 44 | Life cycle inventory (LCI) development for preprocessing and processing stages for biojet; Baseline biojet fuel module for EPP decision-making using GaBi | 60% |
| 45 | Define select "ideal" aviation fuels and bio-based polymer co-products & substitutes; Eval env/social criteria against hot-spot analysis; dev value propositions fuels | 0% |
| 46 | Parameterized model for Biojet developed (assessed for GHG, water and abiotic depletion) | 0% |
| 47 | Task SM-EPP-1.8. Techno-Market Assessment: BioProduct Polymers (1-2 product categories) | 10% |
| 48 | Examine & define market opportunities for select co-products | 20% |
| 49 | Collect co-products supply chain SH data; Assess procurement needs of key product sectors via primary data collection | 20% |
| 50 | Identify key channels, buyers & specifiers for select bio-based polymer co-products in PNW | 0% |
| 51 | Bio-based polymer co-products - data collection preliminary report | 0% |
| 52 | Bio-based polymer co-products - data analysis report | 0% |
| 53 | Task SM-EPP-1.9. Economic, Environmental & Social Assessment: BioProduct Polymers | 0% |
| 54 | Collaborate w/ LCA & SH NARA teams to develop env & social hotspot analyses | 0% |
| 55 | Define select "ideal" bio-based polymer co-products & substitutes in terms of properties, prices & other attributes; Evaluate env/social criteria; Dev value props | 0% |
| 56 | Incorporation of co-product modules into parameterized biojet model | 0% |
| 57 | Task SM-EPP-1.10. Prototype Integrated EPP Protocol | 0% |
| 58 | Develop a prototype integrated protocol for expanding methodologies developed in Tasks 0 & 6 across product categories by designing a process consistent with EPP best practices | 0% |

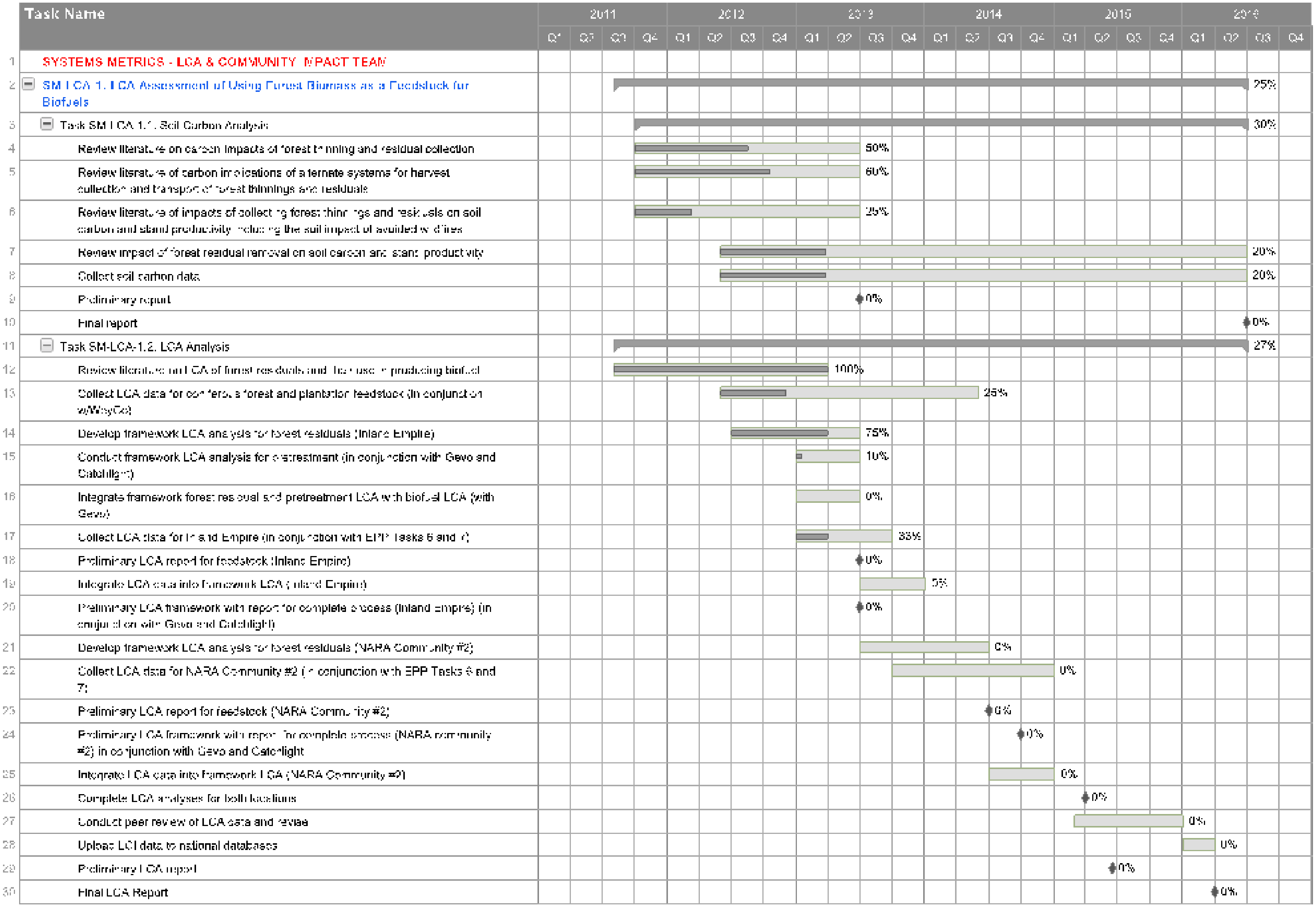


59 Develop an EPP marketing and procurement decision support tool to integrate economic, environmental and social impacts of NARA biojet and co-products

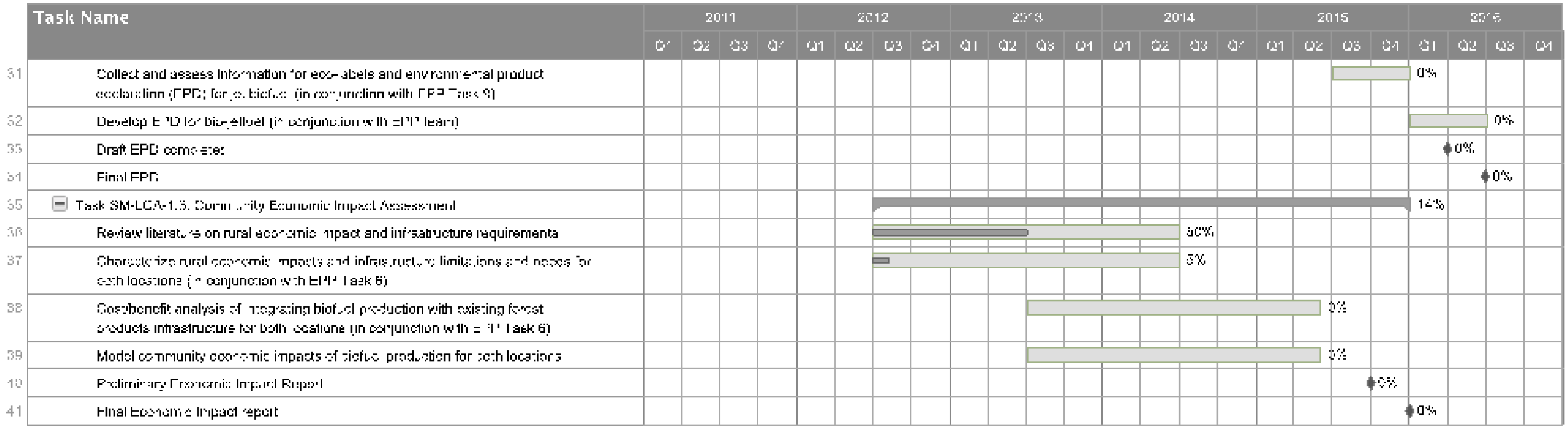
60 Final EPP Report

# SystemsMetrics_LCA

NARA



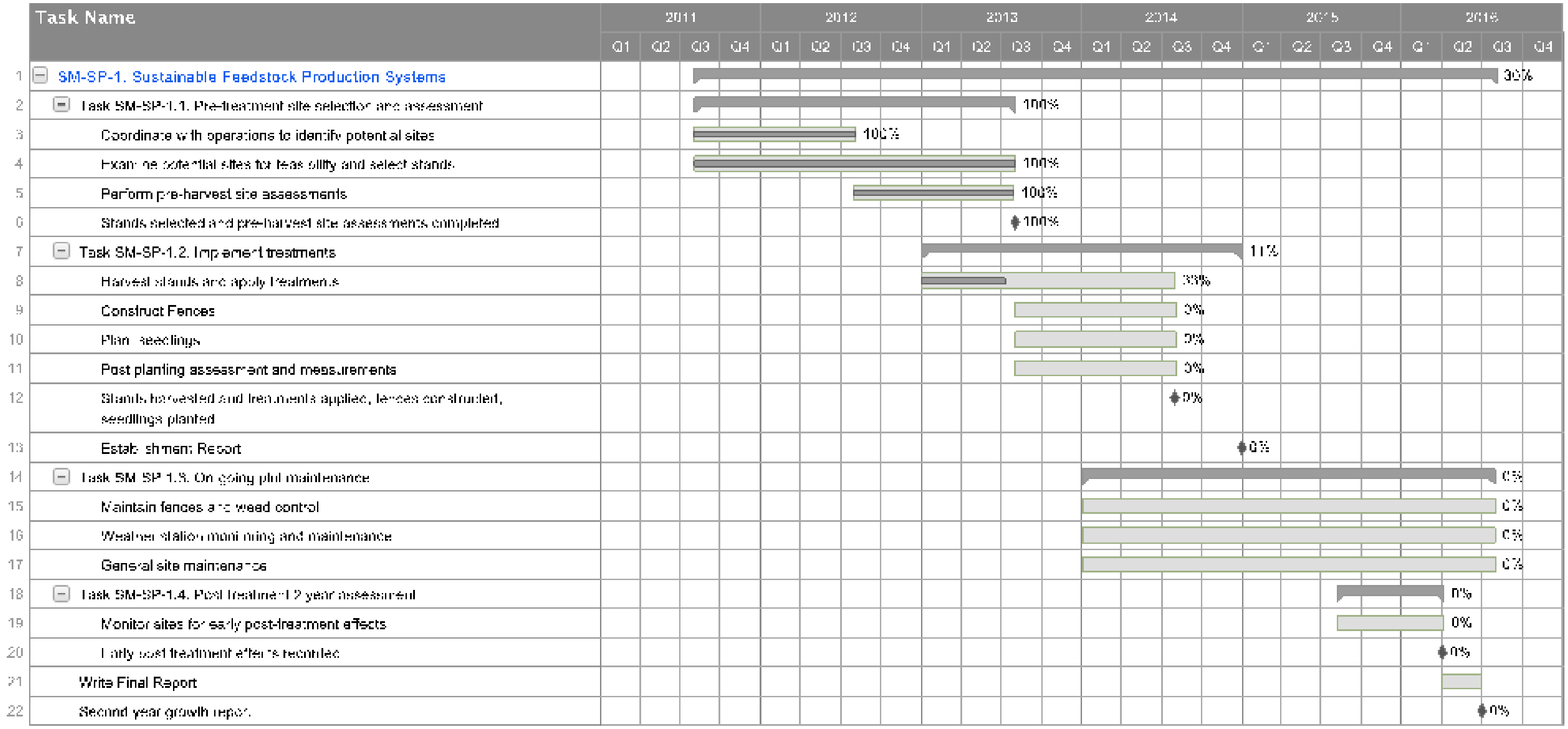
| | Task Name | |
|---|---|---|
| 1 | SYSTEMS METRICS - LCA & COMMUNITY IMPACT TEAM | |
| 2 | SM LCA 1. LCA Assessment of Using Forest Biomass as a Feedstock for Biofuels | 25% |
| 3 | Task SM LCA 1.1. Soil Carbon Analysis | 30% |
| 4 | Review literature on carbon impacts of forest thinning and residual collection | 50% |
| 5 | Review literature of carbon implications of alternate systems for harvest collection and transport of forest thinnings and residuals | 60% |
| 6 | Review literature of impacts of collecting forest thinnings and residuals on soil carbon and stand productivity including the soil impact of avoided wildfires | 25% |
| 7 | Review impact of forest residual removal on soil carbon and stand productivity | 20% |
| 8 | Collect soil carbon data | 20% |
| 9 | Preliminary report | 0% |
| 10 | Final report | 0% |
| 11 | Task SM-LCA-1.2. LCA Analysis | 27% |
| 12 | Review literature on LCA of forest residuals and their use in producing biofuel | 100% |
| 13 | Collect LCA data for coniferous forest and plantation feedstock (in conjunction w/WeyCo) | 25% |
| 14 | Develop framework LCA analysis for forest residuals (Inland Empire) | 75% |
| 15 | Conduct framework LCA analysis for pretreatment (in conjunction with Gevo and Catchlight) | 10% |
| 16 | Integrate framework forest residual and pretreatment LCA with biofuel LCA (with Gevo) | 0% |
| 17 | Collect LCA data for Inland Empire (in conjunction with EPP Tasks 6 and 7) | 33% |
| 18 | Preliminary LCA report for feedstock (Inland Empire) | 0% |
| 19 | Integrate LCA data into framework LCA (Inland Empire) | 5% |
| 20 | Preliminary LCA framework with report for complete process (Inland Empire) (in conjunction with Gevo and Catchlight) | 0% |
| 21 | Develop framework LCA analysis for forest residuals (NARA Community #2) | 0% |
| 22 | Collect LCA data for NARA Community #2 (in conjunction with EPP Tasks 6 and 7) | 0% |
| 23 | Preliminary LCA report for feedstock (NARA Community #2) | 0% |
| 24 | Preliminary LCA framework with report for complete process (NARA community #2) in conjunction with Gevo and Catchlight | 0% |
| 25 | Integrate LCA data into framework LCA (NARA Community #2) | 0% |
| 26 | Complete LCA analyses for both locations | 0% |
| 27 | Conduct peer review of LCA data and revise | 0% |
| 28 | Upload LCI data to national databases | 0% |
| 29 | Preliminary LCA report | 0% |
| 30 | Final LCA Report | 0% |



| | Task Name | |
|---|---|---|
| 31 | Collect and assess information for eco-labels and environmental product declaration (EPD) for jet biofuel (in conjunction with EPP Task 9) | 0% |
| 32 | Develop EPD for bio-jetfuel (in conjunction with EPP team) | 0% |
| 33 | Draft EPD completed | 0% |
| 34 | Final EPD | 0% |
| 35 | Task SM-LCA-1.5: Community Economic Impact Assessment | 14% |
| 36 | Review literature on rural economic impact and infrastructure requirements | 50% |
| 37 | Characterize rural economic impacts and infrastructure limitations and needs for both locations (in conjunction with EPP Task 6) | 5% |
| 38 | Cost/benefit analysis of integrating biofuel production with existing forest products infrastructure for both locations (in conjunction with EPP Task 6) | 0% |
| 39 | Model community economic impacts of biofuel production for both locations | 0% |
| 40 | Preliminary Economic Impact Report | 0% |
| 41 | Final Economic Impact report | 0% |

# SustainableProduction_Holub

NARA



# SustainableProduction_Bailey_Boston

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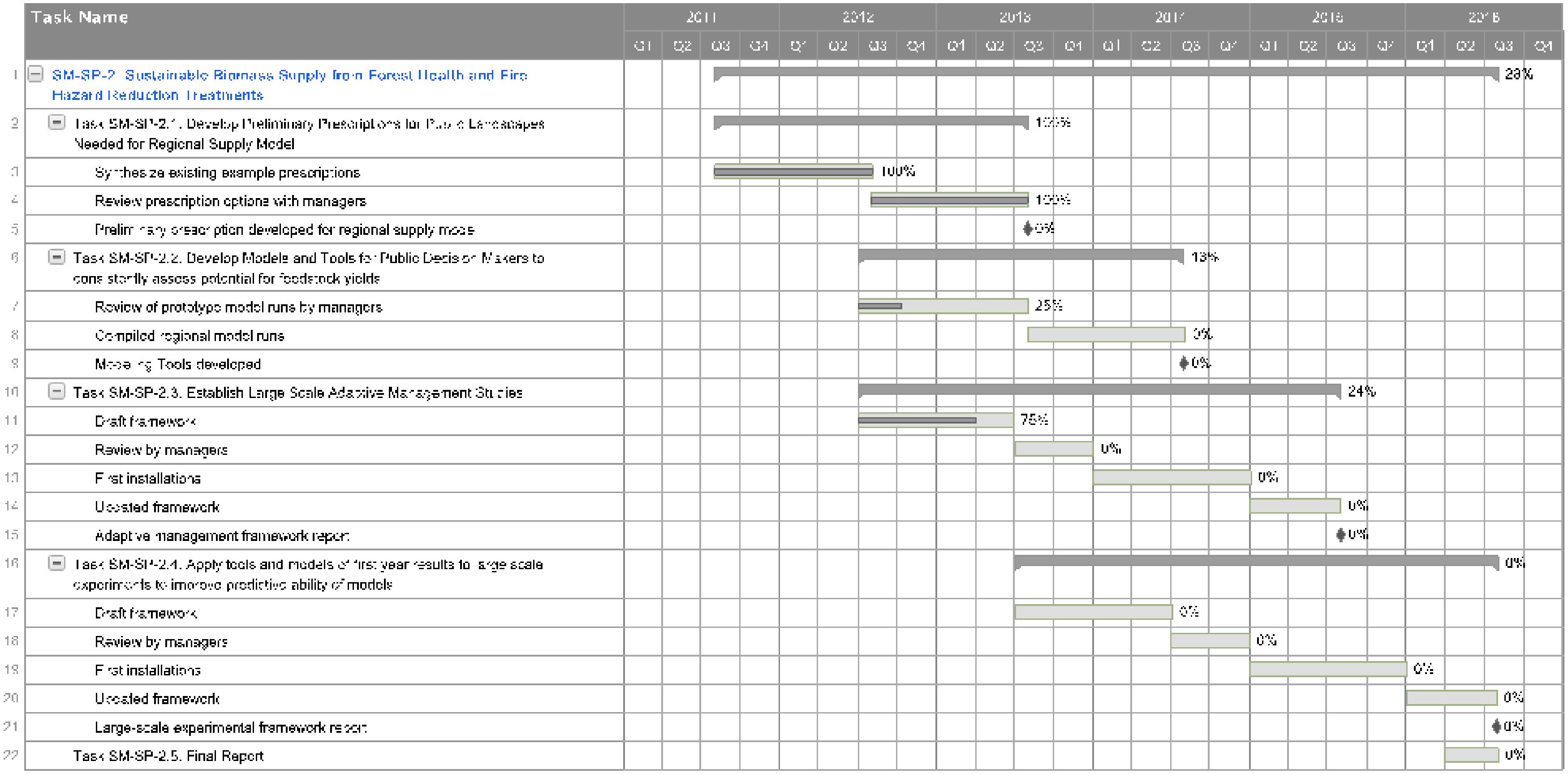
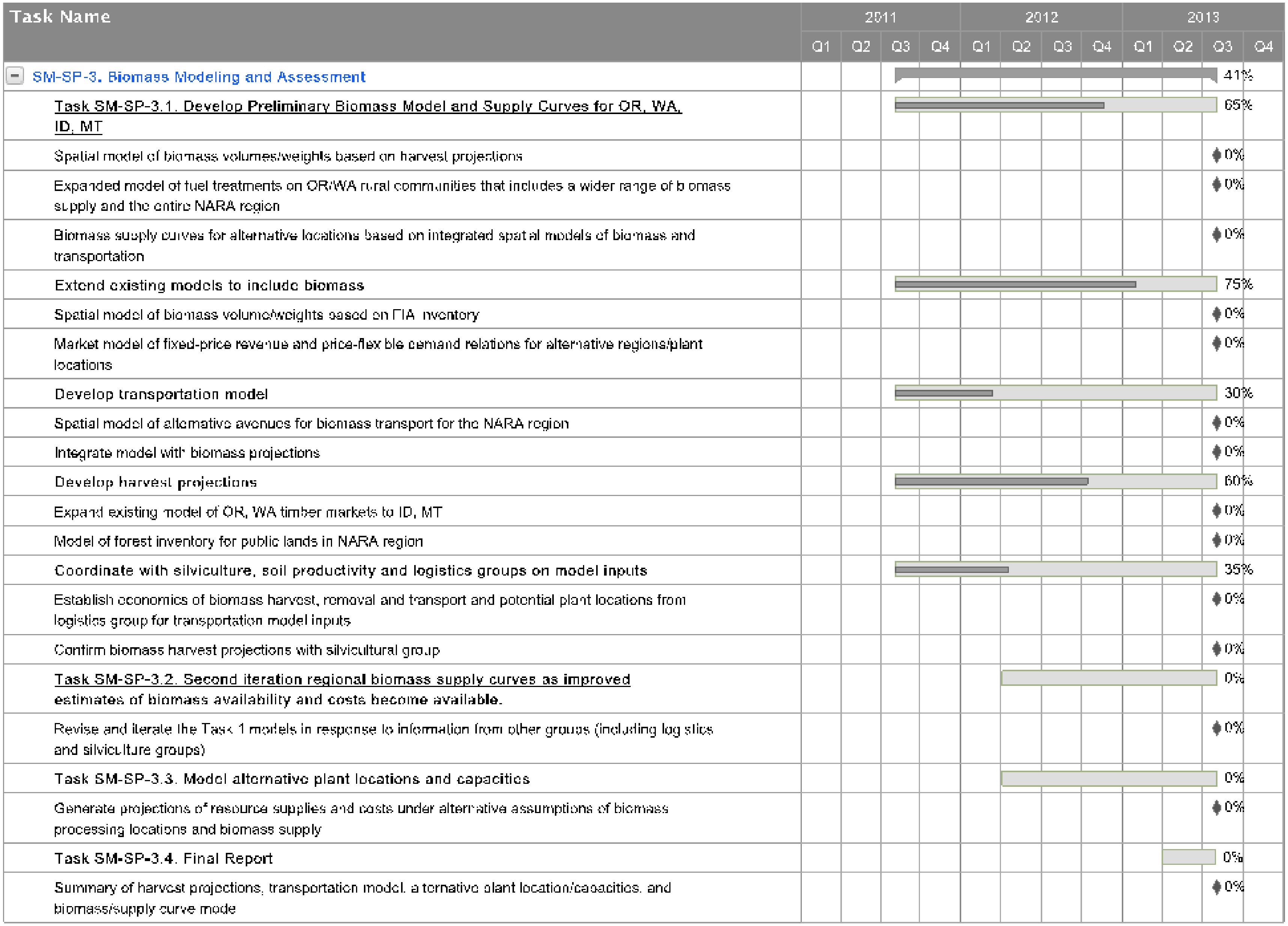


| | Task Name | |
|---|---|---|
| 1 | SM-SP-2. Sustainable Biomass Supply from Forest Health and Fire Hazard Reduction Treatments | 28% |
| 2 | Task SM-SP-2.1. Develop Preliminary Prescriptions for Public Landscapes Needed for Regional Supply Model | 100% |
| 3 | Synthesize existing example prescriptions | 100% |
| 4 | Review prescription options with managers | 100% |
| 5 | Preliminary prescription developed for regional supply mode | 0% |
| 6 | Task SM-SP-2.2. Develop Models and Tools for Public Decision Makers to consistently assess potential for feedstock yields | 13% |
| 7 | Review of prototype model runs by managers | 25% |
| 8 | Compiled regional model runs | 0% |
| 9 | Modeling Tools developed | 0% |
| 10 | Task SM-SP-2.3. Establish Large Scale Adaptive Management Studies | 24% |
| 11 | Draft framework | 75% |
| 12 | Review by managers | 0% |
| 13 | First installations | 0% |
| 14 | Updated framework | 0% |
| 15 | Adaptive management framework report | 0% |
| 16 | Task SM-SP-2.4. Apply tools and models of first year results to large scale experiments to improve predictive ability of models | 0% |
| 17 | Draft framework | 0% |
| 18 | Review by managers | 0% |
| 19 | First installations | 0% |
| 20 | Updated framework | 0% |
| 21 | Large-scale experimental framework report | 0% |
| 22 | Task SM-SP-2.5. Final Report | 0% |

# SustainableProduction_Adams



| | Task Name | |
|---|---|---|
| 1 | SM-SP-3. Biomass Modeling and Assessment | 41% |
| 2 | Task SM-SP-3.1. Develop Preliminary Biomass Model and Supply Curves for OR, WA, ID, MT | 65% |
| 3 | Spatial model of biomass volumes/weights based on harvest projections | 0% |
| 4 | Expanded model of fuel treatments on OR/WA rural communities that includes a wider range of biomass supply and the entire NARA region | 0% |
| 5 | Biomass supply curves for alternative locations based on integrated spatial models of biomass and transportation | 0% |
| 6 | Extend existing models to include biomass | 75% |
| 7 | Spatial model of biomass volume/weights based on FIA inventory | 0% |
| 8 | Market model of fixed-price revenue and price-flexible demand relations for alternative regions/plant locations | 0% |
| 9 | Develop transportation model | 30% |
| 10 | Spatial model of alternative avenues for biomass transport for the NARA region | 0% |
| 11 | Integrate model with biomass projections | 0% |
| 12 | Develop harvest projections | 60% |
| 13 | Expand existing model of OR, WA timber markets to ID, MT | 0% |
| 14 | Model of forest inventory for public lands in NARA region | 0% |
| 15 | Coordinate with silviculture, soil productivity and logistics groups on model inputs | 35% |
| 16 | Establish economics of biomass harvest, removal and transport and potential plant locations from logistics group for transportation model inputs | 0% |
| 17 | Confirm biomass harvest projections with silvicultural group | 0% |
| 18 | Task SM-SP-3.2. Second iteration regional biomass supply curves as improved estimates of biomass availability and costs become available. | 0% |
| 19 | Revise and iterate the Task 1 models in response to information from other groups (including log sites and silviculture groups) | 0% |
| 20 | Task SM-SP-3.3. Model alternative plant locations and capacities | 0% |
| 21 | Generate projections of resource supplies and costs under alternative assumptions of biomass processing locations and biomass supply | 0% |
| 22 | Task SM-SP-3.4. Final Report | 0% |
| 23 | Summary of harvest projections, transportation model, alternative plant location/capacities, and biomass/supply curve mode | 0% |

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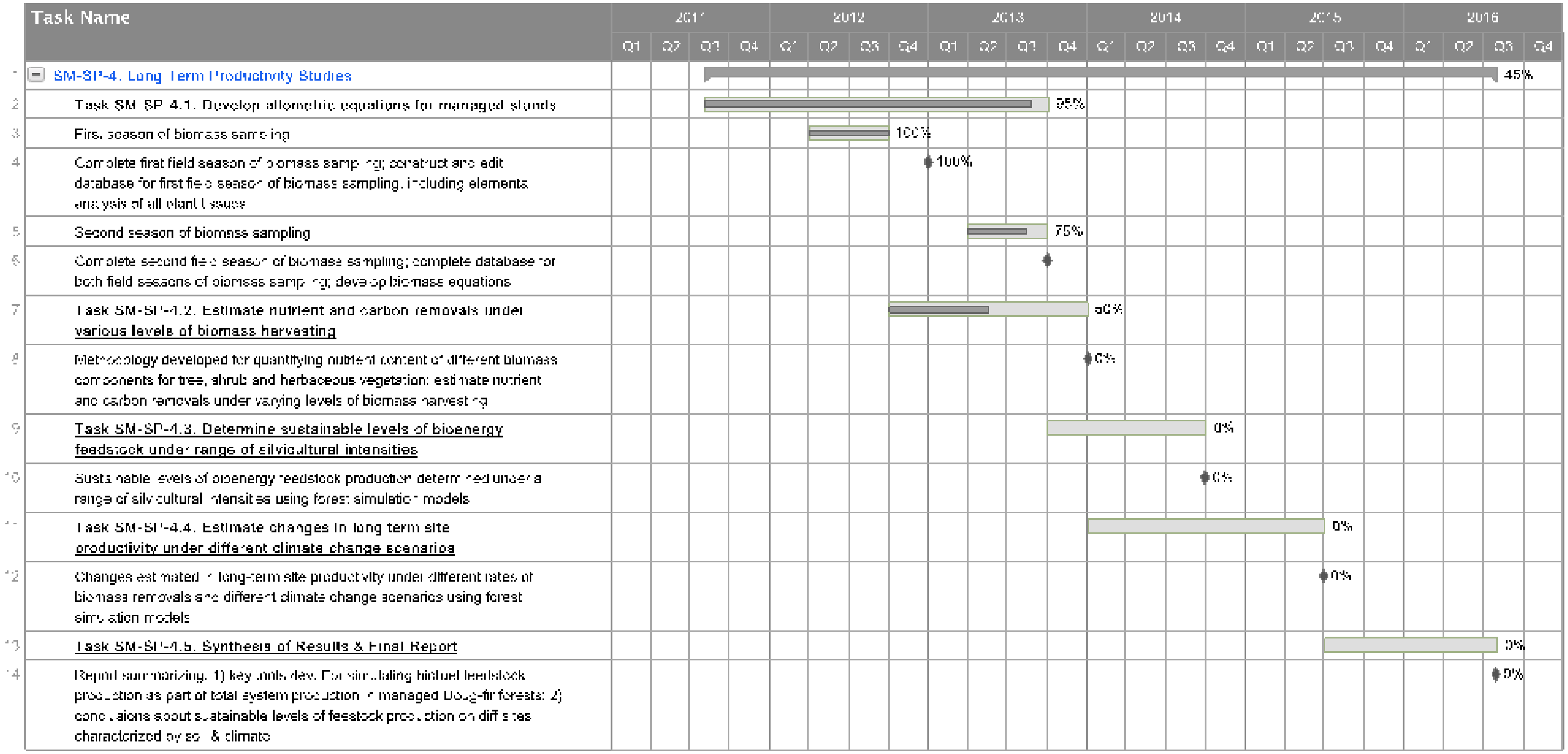
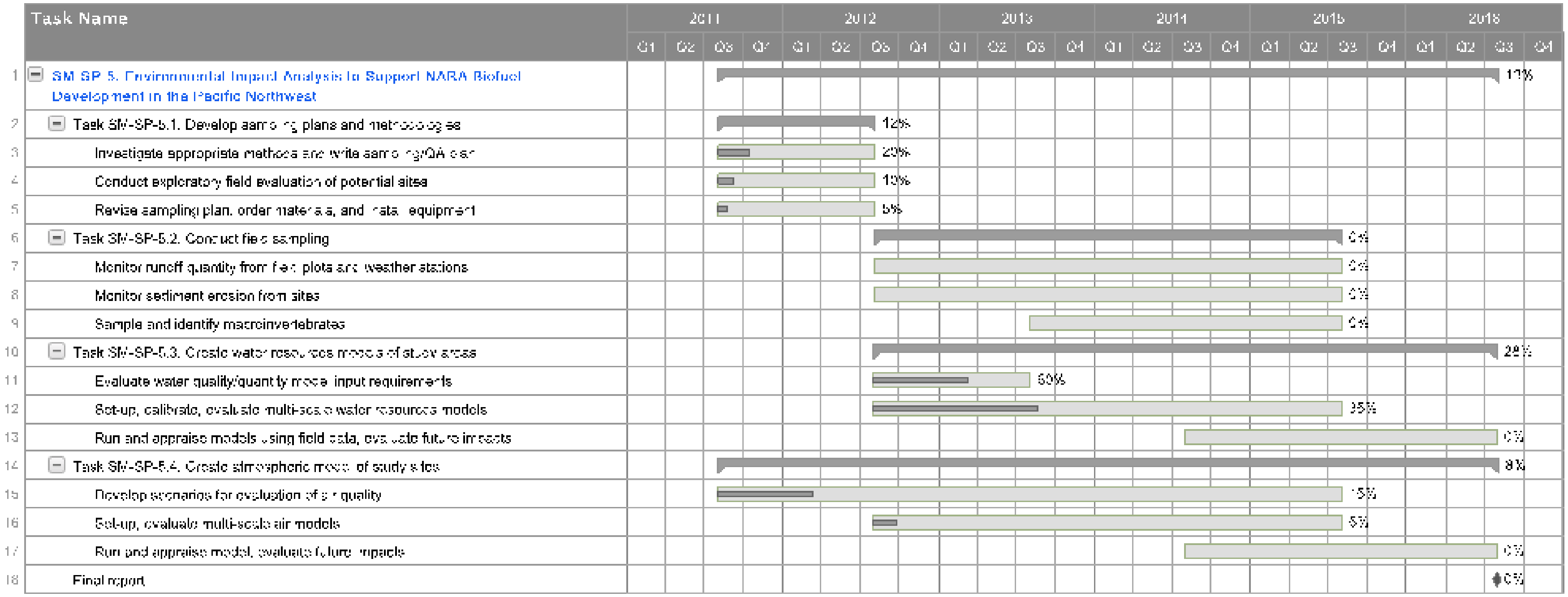
# SustainableProduction_Maguire



| | Task Name |
|---|---|
| 1 | SM-SP-4. Long Term Productivity Studies |
| 2 | Task SM-SP 4.1. Develop allometric equations for managed stands |
| 3 | First season of biomass sampling |
| 4 | Complete first field season of biomass sampling; construct and edit database for first field season of biomass sampling, including elements analysis of all plant tissues |
| 5 | Second season of biomass sampling |
| 6 | Complete second field season of biomass sampling; complete database for both field seasons of biomass sampling; develop biomass equations |
| 7 | Task SM-SP-4.2. Estimate nutrient and carbon removals under various levels of biomass harvesting |
| 8 | Methodology developed for quantifying nutrient content of different biomass components for tree, shrub and herbaceous vegetation; estimate nutrient and carbon removals under varying levels of biomass harvesting |
| 9 | Task SM-SP-4.3. Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities |
| 10 | Sustainable levels of bioenergy feedstock production determined under a range of silvicultural intensities using forest simulation models |
| 11 | Task SM-SP-4.4. Estimate changes in long term site productivity under different climate change scenarios |
| 12 | Changes estimated in long-term site productivity under different rates of biomass removals and different climate change scenarios using forest simulation models |
| 13 | Task SM-SP-4.5. Synthesis of Results & Final Report |
| 14 | Report summarizing: 1) key tools dev. For simulating biofuel feedstock production as part of total system production in managed Doug-fir forests; 2) conclusions about sustainable levels of feedstock production on diff sites characterized by soil & climate |

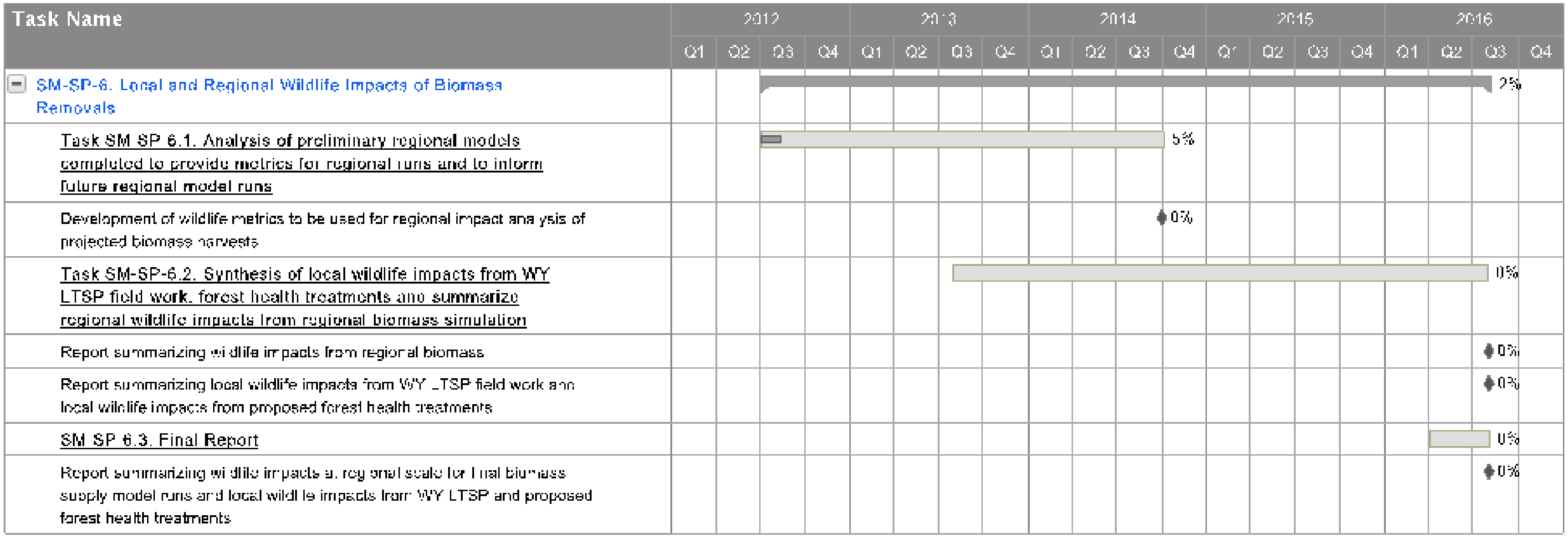
# SustainableProduction_Barber_Lamb



| | Task Name | |
|---|---|---|
| 1 | SM SP 5. Environmental Impact Analysis to Support NARA Biofuel Development in the Pacific Northwest | 11% |
| 2 | Task SM-SP-5.1. Develop sampling plans and methodologies | 12% |
| 3 | Investigate appropriate methods and write sampling/QA plan | 20% |
| 4 | Conduct exploratory field evaluation of potential sites | 10% |
| 5 | Revise sampling plan, order materials, and data equipment | 5% |
| 6 | Task SM-SP-5.2. Conduct field sampling | 0% |
| 7 | Monitor runoff quantity from field plots and weather stations | 0% |
| 8 | Monitor sediment erosion from sites | 0% |
| 9 | Sample and identify macroinvertebrates | 0% |
| 10 | Task SM-SP-5.3. Create water resources models of study areas | 29% |
| 11 | Evaluate water quality/quantity model input requirements | 60% |
| 12 | Set-up, calibrate, evaluate multi-scale water resources models | 35% |
| 13 | Run and appraise models using field data, evaluate future impacts | 0% |
| 14 | Task SM-SP-5.4. Create atmospheric model of study sites | 8% |
| 15 | Develop scenarios for evaluation of air quality | 15% |
| 16 | Set-up, evaluate multi-scale air models | 5% |
| 17 | Run and appraise model, evaluate future impacts | 0% |
| 18 | Final report | 0% |

# SustainableProduction_Betts

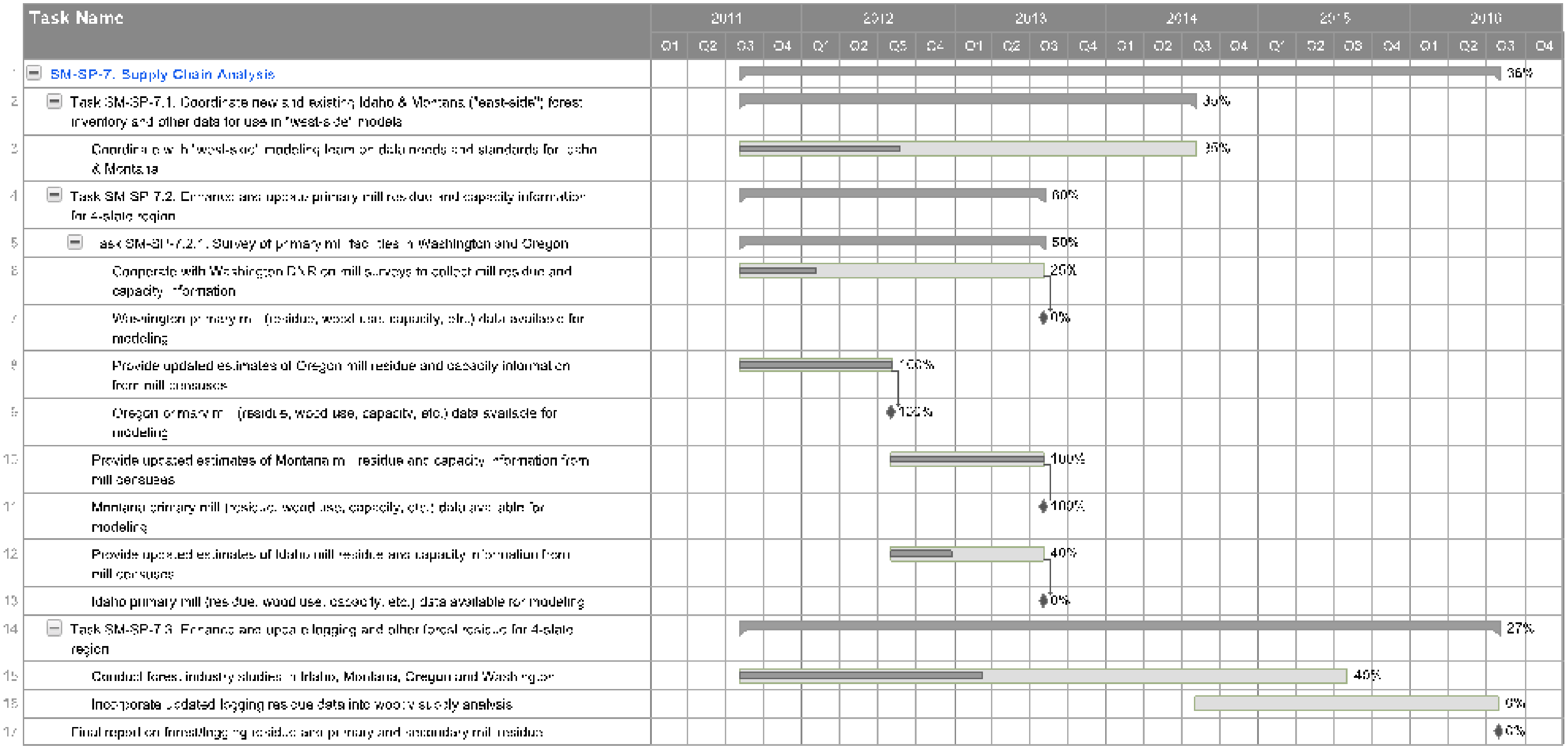
NARA



| | Task Name |
|---|---|
| 1 | SM-SP-6. Local and Regional Wildlife Impacts of Biomass Removals |
| 2 | Task SM SP 6.1. Analysis of preliminary regional models completed to provide metrics for regional runs and to inform future regional model runs |
| 3 | Development of wildlife metrics to be used for regional impact analysis of projected biomass harvests |
| 4 | Task SM-SP-6.2. Synthesis of local wildlife impacts from WY LTSP field work, forest health treatments and summarize regional wildlife impacts from regional biomass simulation |
| 5 | Report summarizing wildlife impacts from regional biomass |
| 6 | Report summarizing local wildlife impacts from WY LTSP field work and local wildlife impacts from proposed forest health treatments |
| 7 | SM SP 6.3. Final Report |
| 8 | Report summarizing wildlife impacts at regional scale for final biomass supply model runs and local wildlife impacts from WY LTSP and proposed forest health treatments |

# SustainableProduction_Morgan

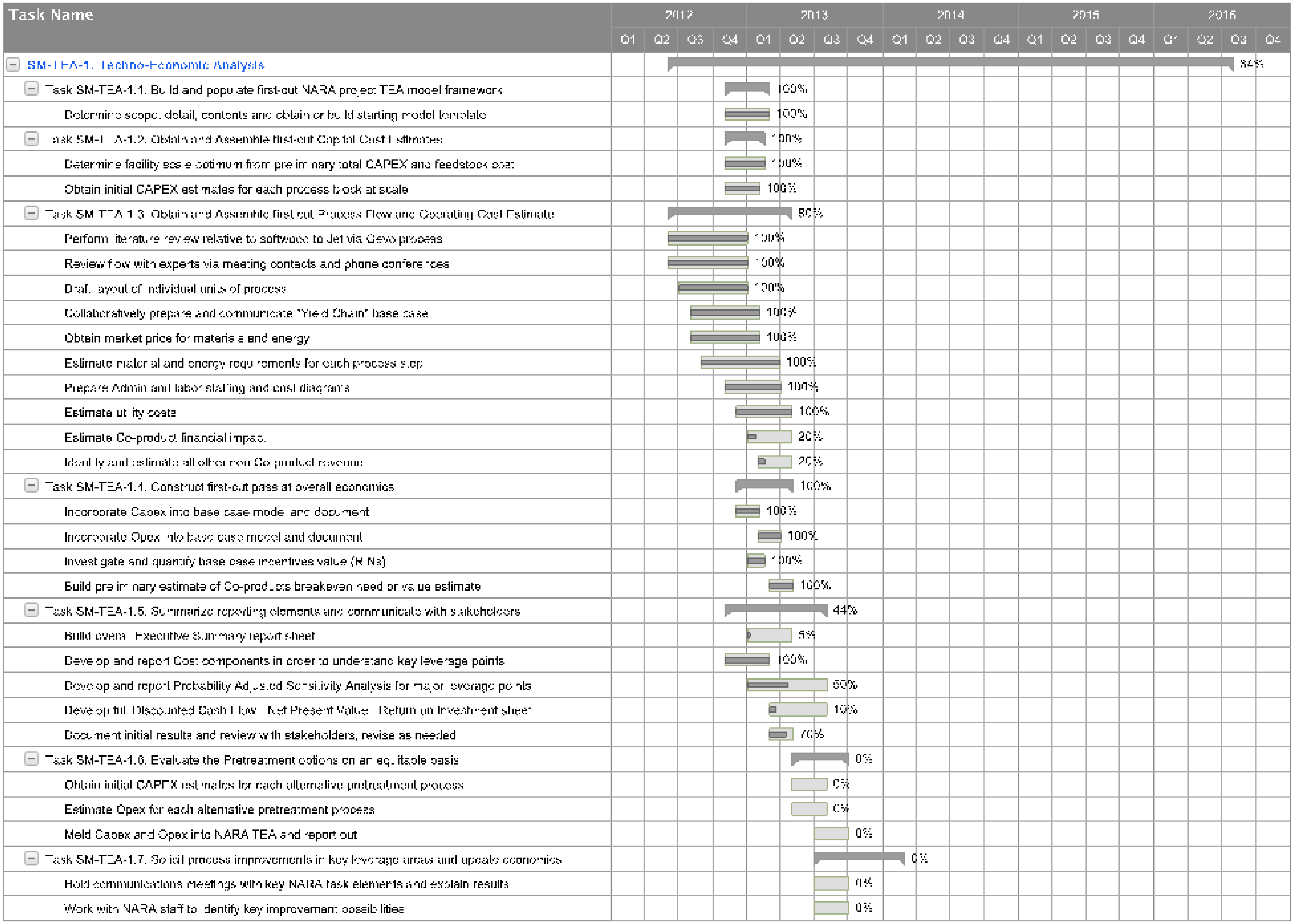
NARA



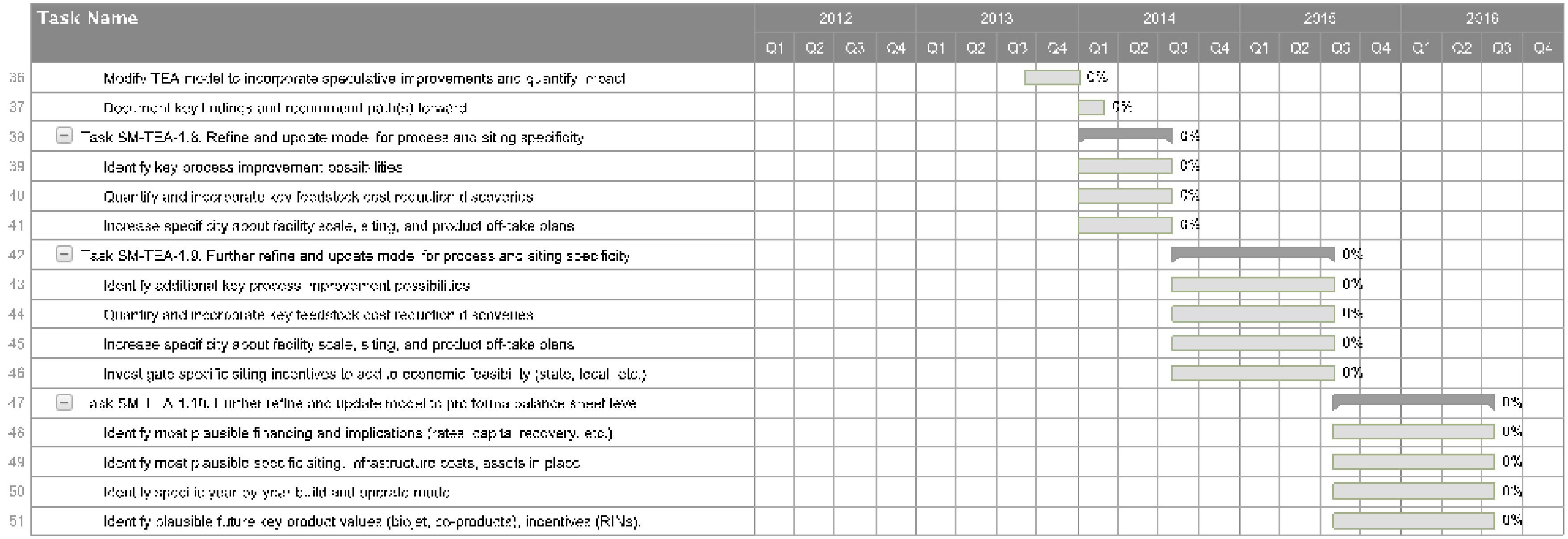
| | Task Name | |
|---|---|---|
| 1 | SM-SP-7. Supply Chain Analysis | 36% |
| 2 | Task SM-SP-7.1. Coordinate new and existing Idaho & Montana ("east-side") forest inventory and other data for use in "west-side" models | 30% |
| 3 | Coordinate with "west-side" modeling team on data needs and standards for Idaho & Montana | 35% |
| 4 | Task SM-SP-7.2. Enhance and update primary mill residue and capacity information for 4-state region | 60% |
| 5 | Task SM-SP-7.2.1. Survey of primary mill facilities in Washington and Oregon | 50% |
| 6 | Cooperate with Washington DNR on mill surveys to collect mill residue and capacity information | 25% |
| 7 | Washington primary mill (residue, wood use, capacity, etc.) data available for modeling | 0% |
| 8 | Provide updated estimates of Oregon mill residue and capacity information from mill censuses | 100% |
| 9 | Oregon primary mill (residue, wood use, capacity, etc.) data available for modeling | 100% |
| 10 | Provide updated estimates of Montana mill residue and capacity information from mill censuses | 100% |
| 11 | Montana primary mill (residue, wood use, capacity, etc.) data available for modeling | 100% |
| 12 | Provide updated estimates of Idaho mill residue and capacity information from mill censuses | 40% |
| 13 | Idaho primary mill (residue, wood use, capacity, etc.) data available for modeling | 0% |
| 14 | Task SM-SP-7.3. Enhance and update logging and other forest residue for 4-state region | 27% |
| 15 | Conduct forest industry studies in Idaho, Montana, Oregon and Washington | 40% |
| 16 | Incorporate updated logging residue data into woody supply analysis | 0% |
| 17 | Final report on forest/logging residue and primary and secondary mill residue | 0% |

# SystemsMetrics_TEA

NARA



| | Task Name | |
|---|---|---|
| 1 | SM-TEA-1. Techno-Economic Analysis | 84% |
| 2 | Task SM-TEA-1.1. Build and populate first-cut NARA project TEA model framework | 100% |
| 3 | Determine scope, detail, contents and obtain or build starting model template | 100% |
| 4 | Task SM-TEA-1.2. Obtain and Assemble first-cut Capital Cost Estimates | 100% |
| 5 | Determine facility scale optimum from preliminary total CAPEX and feedstock cost | 100% |
| 6 | Obtain initial CAPEX estimates for each process block at scale | 100% |
| 7 | Task SM-TEA-1.3. Obtain and Assemble first cut Process Flow and Operating Cost Estimate | 80% |
| 8 | Perform literature review relative to softwood to Jet via Gevo process | 100% |
| 9 | Review flow with experts via meeting contacts and phone conferences | 100% |
| 10 | Draft layout of individual units of process | 100% |
| 11 | Collaboratively prepare and communicate "Yield Chain" base case | 100% |
| 12 | Obtain market price for materials and energy | 100% |
| 13 | Estimate material and energy requirements for each process step | 100% |
| 14 | Prepare Admin and labor staffing and cost diagrams | 100% |
| 15 | Estimate utility costs | 100% |
| 16 | Estimate Co-product financial impact | 20% |
| 17 | Identify and estimate all other non Co-product revenue | 20% |
| 18 | Task SM-TEA-1.4. Construct first-cut pass at overall economics | 100% |
| 19 | Incorporate Capex into base case model and document | 100% |
| 20 | Incorporate Opex into base case model and document | 100% |
| 21 | Investigate and quantify base case incentives value (RINs) | 100% |
| 22 | Build preliminary estimate of Co-products breakeven need or value estimate | 100% |
| 23 | Task SM-TEA-1.5. Summarize reporting elements and communicate with stakeholders | 44% |
| 24 | Build overall Executive Summary report sheet | 5% |
| 25 | Develop and report Cost components in order to understand key leverage points | 100% |
| 26 | Develop and report Probability Adjusted Sensitivity Analysis for major leverage points | 60% |
| 27 | Develop full Discounted Cash Flow - Net Present Value - Return on Investment sheet | 10% |
| 28 | Document initial results and review with stakeholders, revise as needed | 70% |
| 29 | Task SM-TEA-1.6. Evaluate the Pretreatment options on an equitable basis | 0% |
| 30 | Obtain initial CAPEX estimates for each alternative pretreatment process | 0% |
| 31 | Estimate Opex for each alternative pretreatment process | 0% |
| 32 | Meld Capex and Opex into NARA TEA and report out | 0% |
| 33 | Task SM-TEA-1.7. Solicit process improvements in key leverage areas and update economics | 0% |
| 34 | Hold communications meetings with key NARA task elements and explain results | 0% |
| 35 | Work with NARA staff to identify key improvement possibilities | 0% |



| | Task Name | |
|---|---|---|
| 36 | Modify TEA model to incorporate speculative improvements and quantify impact | 0% |
| 37 | Document key findings and recommend path(s) forward | 0% |
| 38 | Task SM-TEA-1.8. Refine and update model for process and siting specificity | 0% |
| 39 | Identify key process improvement possibilities | 0% |
| 40 | Quantify and incorporate key feedstock cost reduction discoveries | 0% |
| 41 | Increase specificity about facility scale, siting, and product off-take plans | 0% |
| 42 | Task SM-TEA-1.9. Further refine and update model for process and siting specificity | 0% |
| 43 | Identify additional key process improvement possibilities | 0% |
| 44 | Quantify and incorporate key feedstock cost reduction discoveries | 0% |
| 45 | Increase specificity about facility scale, siting, and product off-take plans | 0% |
| 46 | Investigate specific siting incentives to add to economic feasibility (state, local, etc.) | 0% |
| 47 | Task SM-TEA-1.10. Further refine and update model to pro forma balance sheet level | 0% |
| 48 | Identify most plausible financing and implications (rates, capital recovery, etc.) | 0% |
| 49 | Identify most plausible specific siting, infrastructure costs, assets in place | 0% |
| 50 | Identify specific year by year build and operate mode | 0% |
| 51 | Identify plausible future key product values (biojet, co-products), incentives (RINs). | 0% |

# NARA | GOAL FOUR

August 2011 - March 2013 Cumulative Report

SUPPLY CHAIN COALITIONS

Northwest Advance Renewables Alliance

# Goal Four: 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. We are using the Outreach and Education Teams 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 biofuels 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 biofuels 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

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 biofuels industry. This effort engages stakeholders ranging from landowners and economic development specialists to forest products industry and environmental NGOs.

The Outreach Team assisted in developing surveys and identified over 300 stakeholders to participate in a stakeholder survey coordinated by the NARA EPP Team (Goal 3; Task SM-EPP-1). Additional surveys to assess stakeholder and youth understanding of biofuels were developed and distributed by the University of Idaho Extension (Figures 1-5; Task O-5; each task progress is detailed in progress reports following this summary).

Ruckelshaus Center/DGSS staff interviewed stakeholders to obtain their input on the formation and management of a NARA Advisory Board (Task O-7).

NARA Outreach team members developed a list of 24 communities/bioregions to be considered as a “NARA Community” and collaborated with the NARA EPP and Education Teams to develop a methodology for pilot supply chain selection. The Outreach Team played a significant role in identifying and coordinating stakeholders within the Western Montana Corridor (WMC) to participate in supply chain development. With the supply chain analysis in the WMC maturing, efforts to organize stakeholders on the west side of the Cascades in Oregon and Washington have come into focus (Task O-4).

**To envision regional supply chain assets for providing recommendations and strategies** on their utility, the Education Team assists the outreach efforts by forming collaborations between students, NARA mentors and stakeholders to provide the analysis. NARA researchers and university students participate in a year long integrated design course called Bioregional Integrated Design Experience (IDX). In this collaborative course, multidisciplinary student teams analyze biofuels supply chain scenarios in partnership with regional stakeholders. This group developed two regional atlases, one that focused on the Clearwater Basin in Idaho and another that focused on the WMC. Each atlas consists of two parts: a profile that outlines regional assets (natural, physical, human, economic, policy and incentives) and an analysis that provides recommendations for capitalizing on existing infrastructure, site, and natural resources. In developing the atlases, extensive participation and review was provided by members of the NARA Outreach Team, particularly by the Bureau of Business and Economic Research (BBER) at the University of Montana, as well as regional stakeholders. For the WMC, the Forest Products Retention Roundtable of the Montana Forest Restoration Committee served as the focal stakeholder group interacting with NARA (Task E-3, O-3).

A similar collaboration of students, NARA mentors, and stakeholders is employed with the regional tribal stakeholders. NARA is working with tribal foresters on biomass and cost of transport assessments that integrate with landscape management goals for the Confederated Salish and Kootenai Tribe (CSKT) reservation (Task E-1; report is listed under goal 5).

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). A preliminary assessment was performed that provides available wood waste quantities and identifies MSW and municipal recycling facilities (MRFs) for each state in the NARA region. A more detailed assessment is provided for the WMC. To determine quantities in regions where solid waste sites and inventory are not recorded, a model approach has been developed (Task E-7).

To communicate the researched-based strategies to stakeholders and facilitate business development where feasible, the Outreach Team played a significant role in orchestrating the NARA annual meeting held in Fall 2012 that attracted over 50 stakeholders and provided a forum for NARA members to exchange information. The Outreach Team maintains a database of regional stakeholders used to disseminate relevant NARA information verbally and electronically (Task O-5). Originally GreenWood Resources was tasked to work with stakeholders to develop hardwood resources, but that project was redirected to explore softwood plantation development (Task O-8).

Significant internal outputs to date for this team are listed below. Additional outputs are listed at the end of each progress report.

- NARA Outreach team members developed a list of 24 communities/bioregions to be considered as a “NARA Community” and collaborated with the NARA EPP and Education Teams to develop a methodology for pilot supply chain selection (Task O-1).

- Key regional stakeholders have been identified and are in communication with NARA (Task O-1).

- The two regional atlases serve as a tangible reference and roadmap for NARA members and stakeholders (Task E-3).

- Quantitative data on construction and demolition wood waste have been obtained and fill a critical gap in understanding the regional supply of woody biomass available as feedstock. A sum of 647,000 tons of recycled wood waste has been accounted for by MRFs within the NARA region to date (Task E-7).

## Outcomes/Impacts:

Events that cause a change of knowledge, actions of conditions for stakeholders and society.

- Establishing the WMC supply chain motivated stakeholders within the region to organize and promote development of supply chain infrastructure for a wood residue to biojet industry. The WMC Atlas provides stakeholders with biofuels supply chain scenarios that will enable the region to identify potential economic development opportunities. The WMC Atlas is an important resource to increase stakeholder's energy literacy, specifically related to using woody biomass to create liquid biofuels (Task O-1, E-3).

## Training

| Name | Affiliation | Role | Contribution |
|---|---|---|---|
| Peter Gray | WSU, Economic Sciences | PhD Student | Applying economic modeling and methods to supply chain optimization. |
| Jinxue Jiang | WSU, Materials Science & Engr. | PhD Student | Developing depot methods for conversion of biomass to feedstock and eventually sugars. Depot sizing and unit operations have resulted from their work. |
| Yalan Liu | WSU, Materials Science & Engr. | PhD Student | |
| Natalie Martinkus | WSU, Civil Engr. | PhD Student | Providing the raw GIS data for students to use in their supply chain analyses and GIS technical support for the IDX students. |
| Nannan Tian | WSU, Materials Science & Engr. | PhD Student | No longer on the project |

| | | | |
|---|---|---|---|
| Daniel Johnson | UI, Bioregional Planning & Community Design Program (BIOP) | MS Student | Leading multi-disciplinary teams to develop regional biofuels atlases and planning documents. Presenting IDX role in pilot supply chain development at conferences. |
| Kyle Merslich | UI, BIOP | MS Student | |
| Jill Moroney | UI, BIOP | MS Student | |
| Lanier Nabahe | UI, BIOP | MS Student | |
| Geoff Nielsen | UI, Architecture/BIOP Certificate | MS Student | |
| Navin Risal | UI, BIOP | MS Student | |
| John Staldine | UI, Masters of Natural Resources /BIOP Certificate | MS Student | |
| Cade Sterling | UI, Landscape Architecture/BIOP Certificate | MS Student | |
| Eric Anderson | UI, Law/BIOP | JD/MS | Leading multi-disciplinary teams to develop regional biofuels atlases and planning documents. Presenting IDX role in pilot supply chain development at conferences. |
| Seth Cool | UI, BIOP | MS Student | |
| Ryan Hutten | UI, Accounting/BIOP Certificate | MS Student | |
| Ethan Mansfield | UI, BIOP | MS Student | |
| Matthew McAnulty | UI, Architecture/BIOP Certificate | MS Student | |
| Donna Mills | UI, Agricultural Education/BIOP Certificate | MS Student | |
| Lisa Nichols | UI, BIOP | MS Student | |
| Christine Schuette | UI, BIOP | MS Student | |
| Tess Wolfenson | UI, BIOP | MS Student | |
| Eric Brandon | WSU, Civil Engineering | Undergraduate | Internal Communications Fellow -Manage Google Apps logistics, Document standard operating procedures for class, improving classroom infrastructure, assist in analysis and development of an IDX restructure plan |

|  |  |  |  |
|---|---|---|---|
| Nick Linton | WSU, Architecture | Undergraduate | External Communications Fellow -working on IDX branding, developing IDX communications plan, improving classroom infrastructure, working on IDX recruitment, designing new studio layout |
| Charlie Misner | WSU, | Undergraduate | Technology Fellow - providing software tutorials, presenting software tutorial sessions to class, manage computer lab |
| Andrea Charette-Bluff | WSU, | Undergraduate | Atlas Fellow – assisting with the development of the WMC Atlas |
| Gerald Schneider | WSU, Civil Engr. | MS Student | 100% |
| Jillian Moroney | University of Idaho | Ph.D. Student | Assess regional norms about bioimass |

# Resource Leveraging

| **Resource Type** | **Resource Citation** | **Amount** | **Relationship or Importance to NARA** |
|---|---|---|---|
| Scholarship | China Scholarship Council (CSC) |  | Support for Yalan Liu and Jinxue Jiang |
| RA Funding | WSU, Provost Office |  | Support for Peter Gray and Natalie Martinkus |
| Resource Type | Resource Citation | Amount | Relationship or Importance to NARA |
| Grant | Farm Bureau Youth Advisory Board | $100,000 | Unfunded |
|  | USFS Woody BUG (Biomass Utilization Grant) for Boiler System for Idaho State Prison | Undetermined |  |
| International Wood Composites and NARA Joint Symposium | IWCS generated budget | $1,500 | Dissemination of findings and engaging stakeholders at Joint Symposium with the International Wood Composite Symposium |

# EDUCATION

## Education Team

### Task E-3: Bioregional Integrated Design Experience (IDX)

| Key Personnel | Affiliation |
|---|---|
| Tamara Laninga | University of Idaho |
| Michael Wolcott | Washington State University |
| Todd Beyreuther | Washington State University |
| Karl Olsen | Washington State University |

#### Task Description

IDX is an integrated design studio experience for graduate students in engineering, design (architecture, landscape architecture, etc.), natural resources, and land use planning disciplines, focusing on technical assistance to communities interested in participating in the emerging biofuel economy. IDX involves a year-long integrated design course delivered jointly through the University of Idaho and Washington State University. The course is a trans-disciplinary planning and design studio that addresses planning and infrastructure needs of communities exploring their role in the biofuel supply chain. Aimed at upper-level BS and MS students, the course is organized around service-learning experiences that link teams of students with communities. Graduate students from NARA with special expertise in required areas will act as consultants to the design teams, improving the level of analysis and providing interdisciplinary experiences to the students.

Five different pilot supply chain regions will be served, one during each year of the project, with a focus on identifying regional supply chain assets, optimizing sub regional biofuels supply chains, and designing interventions at specific locations within the supply chain (e.g., depot sites, conversion facilities, multi-modal transportation hubs, etc.). The goals for this studio are:

- That every student that completes the program exits with strong collaborative research, questioning, and design methods to utilize in their academic and professional work.
- To provide technical analyses to communities interested in participating in the emerging biofuels economy. We will assist these communities in beginning the process of transformation necessary for them to be engaged in the biofuels supply chain.

## Activities and Results

Between 2011 and 2013, the UI and WSU jointly delivered their studio courses. Through this collaborative effort, multidisciplinary student teams applied skills and knowledge to understanding and analyzing biofuels supply chain scenarios.

In the IDX studio, students develop, analyze, and optimize regional supply chains during two semesters. A community capitals framework (Emery, Fey and Flora 2006) is used to organize supply chain assets: natural (e.g., biomass feedstock), physical (road; rail networks; existing, idle, decommissioned mill sites), civic (workforce, education, collaboratives), financial (cost of doing business, loans and grant opportunities) and policy (laws and landownership). In the fall, students collect and analyze assets, and identify sub-regional supply chains and potential depot and conversion sites. In the spring, students design interventions for key aspects of the supply chain, including site master plans, architectural and engineering designs for depot and conversion facilities, and transportation options.

### 2011/2012: Clearwater Basin, Idaho Pilot Biofuels Supply Chain

IDX worked in the Clearwater Basin of North Central Idaho during 2011/2012 (Figure 1). First, students identified supply chain assets and analyzed the region’s resources (biomass availability), key nodes (depot and conversion sites), and primary linkages (highways, railroads, and ports) (Figure 2). At the conclusion of fall semester, students had identified a depot site at the former Jaype Plywood Mill near Pierce, ID; a conversion facility at the Lewiston paper mill; and a transportation hub at the Port of Wilma in Whitman County, WA. Second, multidisciplinary teams conducted site assessments, developed schematic site designs and proposed interventions. They developed a chipping and pellet facility at the Jaype site; an addition to or retrofit of the Lewiston paper mill as a conversion facility; and a reorganization of the Port of Wilma site as a multi-modal transportation hub.

### 2012/2013: Western Montana Corridor Biofuels Supply Chain

IDX worked in the Western Montana Corridor (WMC) during 2012/2013 (Figure 3). During the Fall semester, WSU students identified natural and physical supply chain assets, while UI students focused on the civic, financial, and policy assets. WSU students also identified sub-regional supply chains within the WMC, examining potential conversion facility locations at Libby, Flathead, and Frenchtown, MT. Students presented posters at an Open House hosted by the NARA Outreach and Education/IDeX teams on January 17 in Missoula, MT. IDX received suggestions from the Montana Forest Products Retention Roundtable to drop the Flathead location and focus on conversion sites in in Libby and Frenchtown. The supply chain team identified several depot sites in the WMC to supply feedstock to both potential conversion facilities (Figure 4). The depot sites were classified into: working mills with a co-located depot; idle mills with infrastructure; and decommissioned mills with little or no infrastructure. These were further classified into brown and grey fields as well as by location within or outside of city boundaries, and proximity to conversion sites. During Spring semester, students were divided into seven teams to conduct site assessments, identify site opportunities and constraints, and develop site programming maps for conversion plants in Libby and Frenchtown, and four depot sites located near Colville, WA (working/greyfield); Bonners Ferry, ID (idle/greyfield); Thompson Falls, MT (decommissioned/greyfield); and Pablo, MT (idle/brownfield).

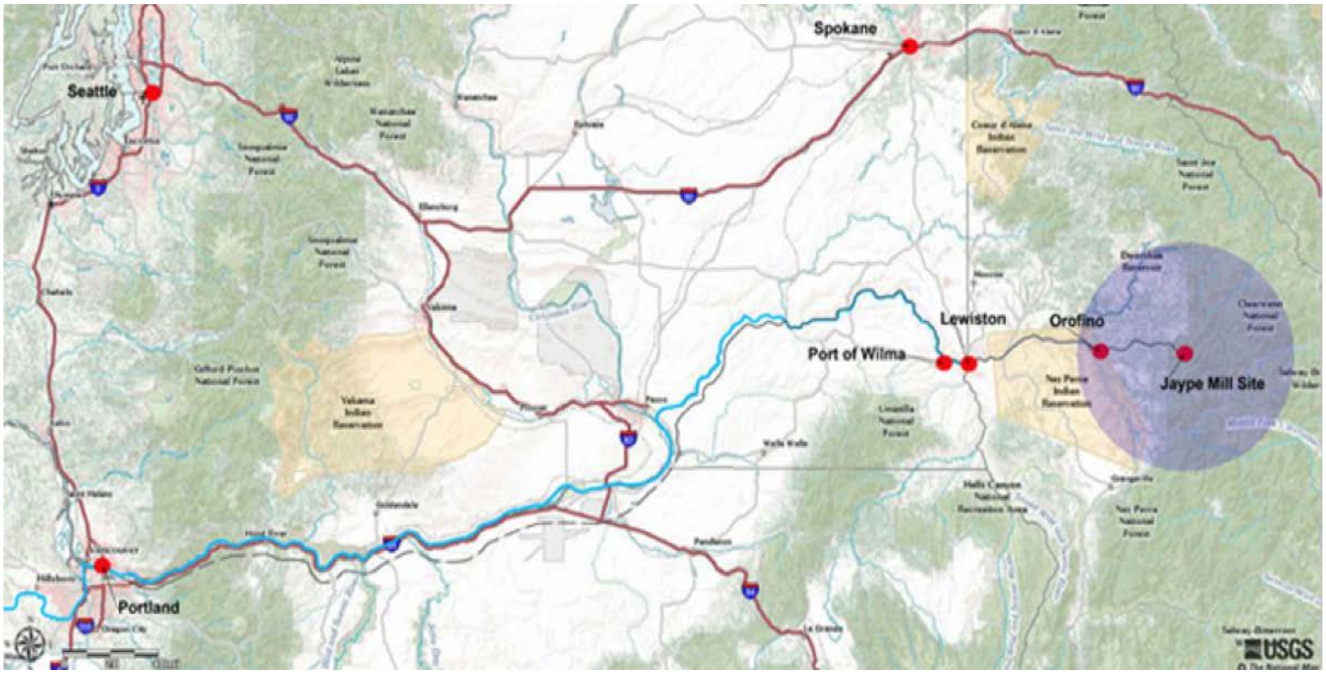


Figure 1. Clearwater Basin, Id: IDX analysis and design focused on Jaype Mill site (depot), Clearwater Paper Mill (conversion) and Port of Wilma (multi-modal transportation hub).

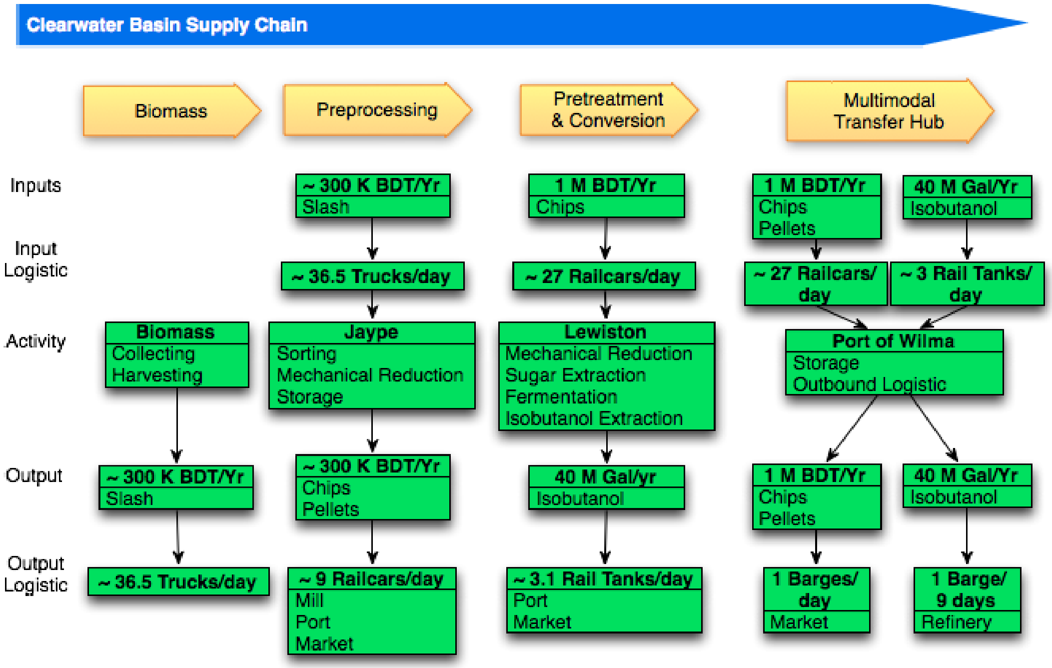


Figure 2. Clearwater Basin Supply Chain Diagram

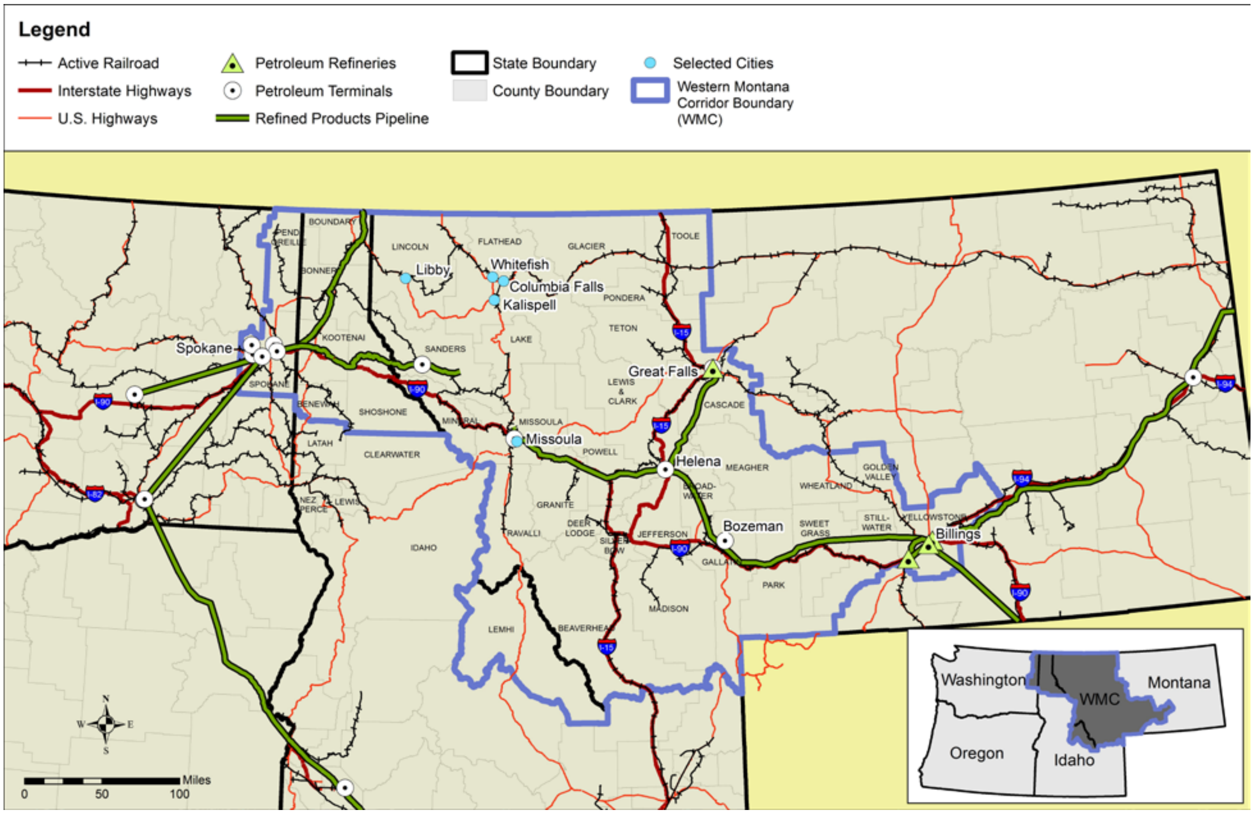


Figure 3. Western Montana Corridor (Northeast Washington, Northern Idaho and Western Montana)

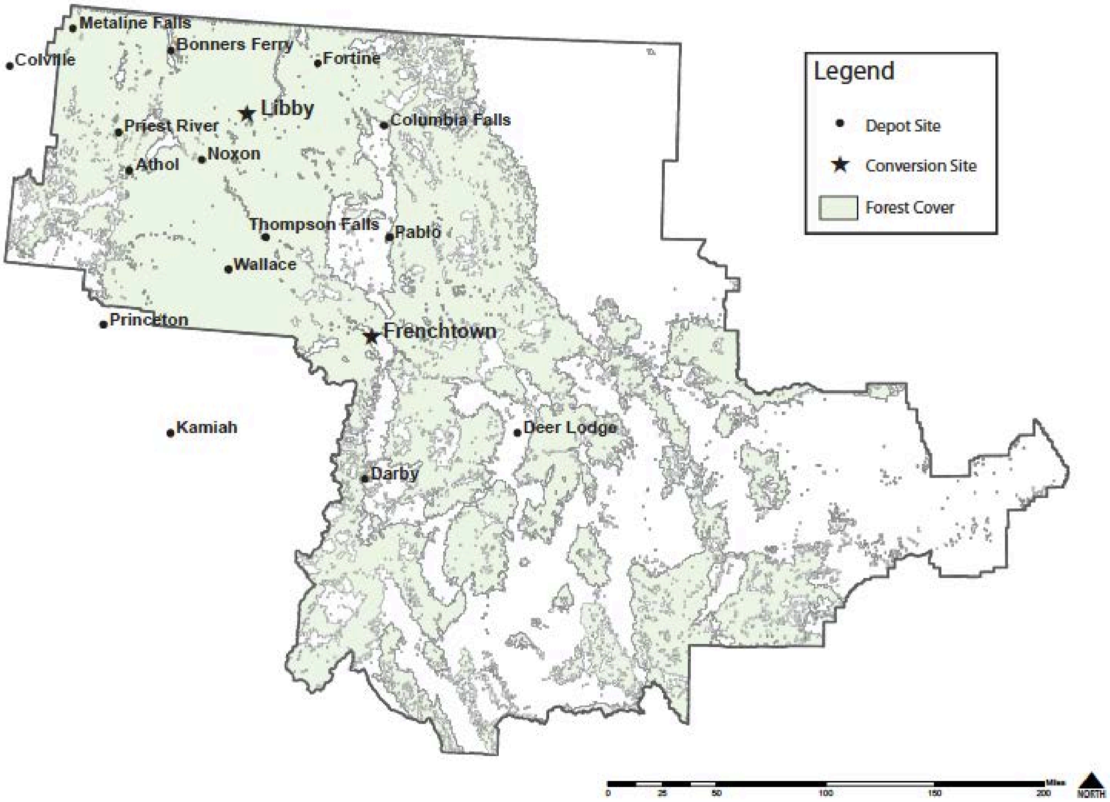


Figure 4. Western Montana Corridor Conversion and Depot Sites

Emery, M., S. Fey and C. Flora. 2006. Using Community Capitals to Develop Assets for Positive Community Change. Community Development Practice. 13: 1-19. http://www.comm-dev.org/commdev/collection/2006%2013.pdf.

## Recommendations/Conclusions

### Supply Chain Recommendations

IDX is working to develop a pilot supply chain that will provide each hypothetical conversion facility with a supply of 300,000 to 1 million BDT/year. Based on this quantity range, the IDX team developed several recommendations.

*Satellite Depot Sites and Conversion Facilities*

First, for a conversion facility to operate efficiently, satellite depot sites are necessary. Included at each conversion plant would be its own local depot for handling biomass within economic trucking range for unprocessed or lightly processed biomass. The team has developed a conversion/depot model, which recognizes that to ensure an economically and environmentally sustainable supply of feedstock, a conversion facility must rely on several depot sites to collect, store, sort, and densify feedstock for shipment to the conversion facility in a continuous stream.

### *Supply Chain Costs Analysis incorporating Geographic and Market Scenarios*

Second, supply chain cost analysis requires geographic as well as market scenarios. The team, working with P. Gray, a PhD student funded on the project, is conducting cost analyses based on geographic combined with market scenarios. The team settled on three geographic scenarios: one plant at Frenchtown, one at Libby, and a third scenario with plants at both proposed sites. For each geographic scenario, the three market scenarios are represented by prices ($40, $80, and $120 per BDT of chips or pellets) at the conversion plant gate. These prices should span the range of current market prices for such biomass, as well as higher prices that could arise from future market and/or policy changes. This model results in nine illustrative scenarios, each with a proposed selection of depot sites and transport networks, and each with a biomass and biofuel output estimate. The model should serve as a platform for more refined results based on improved future understanding of conversion plant economies of scale. It can also be used for developing more accurate cost functions and more sophisticated depot selection methods. Figure 5 shows an analysis that examines available biomass in the WMC that is within a two-hour drive time of proposed depot and conversion sites.

### *Multi-Modal Transportation System*

Finally, a multi-modal transportation system that relies on a combination of highway, rail, barge, and pipeline transport is important for cost effectiveness. Transportation analyses in the Clearwater Basin and the WMC suggested that using highway trucks might be the most effective transportation mode up to a distance threshold of 100-150 miles (Figure 6). Subsequent analyses have indicated that the truck/rail break-even distance could be less than 100 miles. The teams also found that, in the Clearwater Basin, access to port and barge transportation represents a significant cost savings for transporting chips or liquid. In the WMC, the main transport modes are off-highway truck, highway truck, rail, and pipeline. The team analyzed pipeline costs for transporting isobutanol from each potential conversion plant to a refinery in Great Falls, and found that pipeline transport costs would be a very small contributor to total per-gallon cost. However, there are some indications from biofuel industry partners that transforming isobutanol to biojet at the conversion plant might be an even more efficient method. In that scenario, a dedicated pipeline to an oil refinery would be unnecessary, and the final product could go more directly to market.

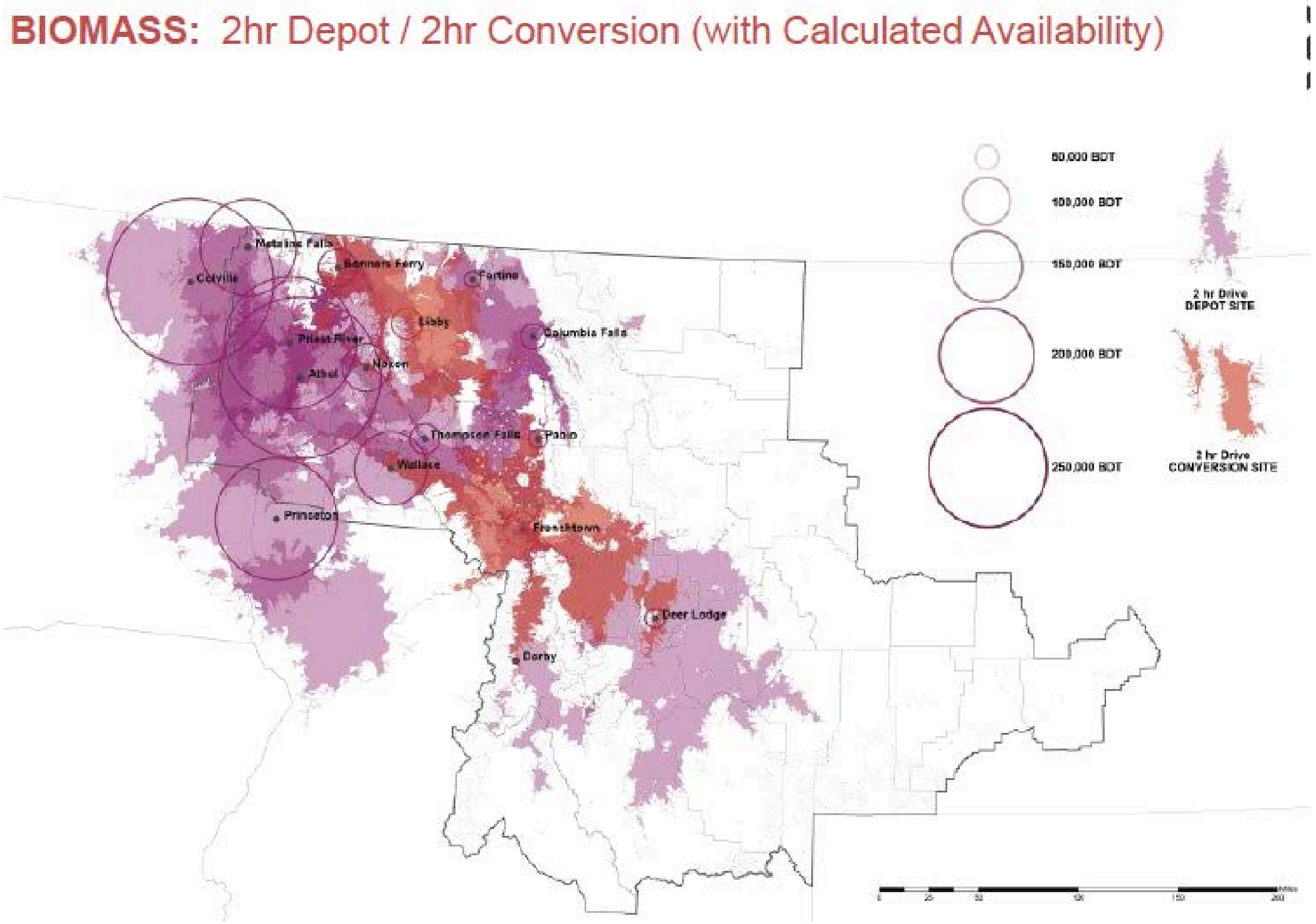


Figure 5. Biomass availability in the Western Montana Corridor within two-hour drive of proposed depot and conversion sites.

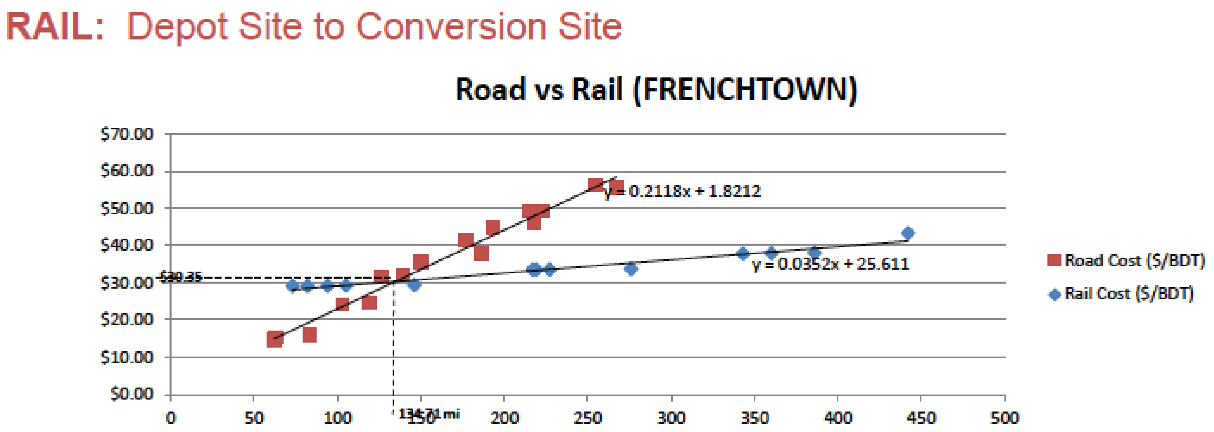


Figure 6. Road vs. Rail Costs from Depots to Conversion Facility at Frenchtown Mill Site.

## Collaboration Recommendations

For a successful collaboratory, a distributed research effort that can include multiple physical sites and disciplines (see: http://en.wikipedia.org/wiki/Collaboratory), requires time and commitment from faculty. The IDX collaboration consists of 7 faculty and 3 PhD students. IDX is organized through a virtual infrastructure that allows for collaboration among faculty, students, other NARA team members, and supply chain partners. IDX is using the Google Apps platform, relying on Google Drive to share and jointly work on documents; using Google Hangout for meetings (e.g., weekly faculty meetings); Google Sites for posting syllabi, assignments, and class resources; and Google Community for posting items of interest to the group.

After working together for two years, IDX is streamlining and articulating its goals for each region. The main IDX output is a regional atlas consisting of three parts:

1. Profile (outlines regional supply chain assets)
2. Analysis (optimization of the supply chain and identification of depot and conversion facility locations)
3. Design (interventions and case studies at specific locations)

IDX has also gone outside of the original two courses, ENGR 420 and BIOP 520, to bring in allied courses with added expertise including architecture and landscape architecture. We are identifying additional allied expertise in forest operations and supply chain management in the coming year.

Finally, an important outcome from the IDX collaboratory is the collection of data that can be used for extending research into various aspects of the supply chain by faculty and students. Furthermore, faculty and PhD students are able to use the research findings from IDX to apply in other contexts. For example, P. Gray could present on supply chain modeling and results from WMC that can be applied elsewhere, T. Laninga on refined understanding of capitals, community/stakeholder assets, N. Martinkus on GIS, and T. Beyreuther on integrated design on post-industrial sites.

## Physical and Intellectual Outputs

### Research Presentations

IDX. 2011. *Clearwater Basin Biomass Atlas*. Final Review. University of Idaho. Moscow, ID. December 14.

Beyreuther, T.  2012. *Design Programming for Post-Industrial Site Reus*e.  Plenary Speaker. Brownfields and Land Revitalization Conference. Spokane, WA. June 21-22.

Beyreuther, T.  2012.  *Crafting an Integrated Model for Architectural Education*.  AIA Western Mountain Region / Northwest and Pacific Region Joint Conference. Tucson, AZ. October 10-13.

Beyreuther, T.  2012.  *Sustainable Community Design*.  Center for Environmental Research, Education, and Outreach (CEREO) Advisory Board Annual Meeting. Washington State University: Pullman, WA. October 14.

IDX. 2012. *Clearwater Basin Bioenergy Assessment Project*. Final Review. University of Idaho: Moscow, ID. April 30.

IDX. 2012. *Western Montana Corridor Atlas*. Final Review. University of Idaho: Moscow, ID. December 7.

Poor, C., and T. Beyreuther. 2012. *Integrate Site Redevelopment*. Panel Presentation at NARA Annual Meeting. Missoula, MT. September 14.

Gray, P. 2012. S*upply Chain Economics: A Modeling and Research Plan*. Panel Presentation at NARA Annual Meeting. Missoula, MT. September 14.

Laninga, T., and M. Vachon.  2012.  *Pilot Supply Chain Coalitions: The Role of Asset Mapping and Community Capitals Framework*. Panel Presentation at NARA Annual Meeting. Missoula, MT. September 14.

Laninga, T., and M Vachon. 2012. *From Wood to Wing: Wood-based Energy Options*. Idaho Chapter, American Planning Association Annual Conference. Boise, ID. October 10-12.

Laninga, T., J. Moroney, and M. Vachon. 2012. *Clearwater Basin Pilot Biofuels Supply Chain Project*. Clearwater County Economic Development Board Meeting. Orofino, ID. October 17.

Laninga, T. 2012. *Life-Place Planning: Fostering Vibrant Communities throughout the Pacific Northwest*. University of Idaho Geography Department Research Seminar. Moscow, ID. November 6.

Martinkus, N.  2012.  *GIS as a Decision Support Tool for Supply Chain Analysis in the Western Montana Corridor*. Panel Presentation at NARA Annual Meeting. Missoula, MT. September 14.

Olsen, K., T. Beyreuther, C. Poor, T. Laninga, and M. Wolcott.  2012.  *IDeX Studio Design*. Panel Presentation at NARA Annual Meeting. Missoula, MT. September 14.

Beyreuther, T.  2013.  *Northwest Advanced Renewables Alliance (NARA): Resource Assessment & Supply Chain Analysis*. Panel Presentation at the Small Log Conference. Coeur d’Alene, ID. March 14. http://nararenewables.org/templates/hubbasic/docs/small-log/beyreuther.pdf

Martinkus, N. 2013. *GIS as a Decision Support Tool for Supply Chain Analysis in the Western Montana Corridor.* Panel Presentation at the Small Logs Conference. Coeur d'Alene, ID. March 14. http://nararenewables.org/templates/hubbasic/docs/small-log/martinkus.pdf

Wolcott, M., and T. Laninga. *Western Montana Corridor Atlas Overview*. 2013. Montana Wood Products Retention Roundtable. Missoula, MT. January 18.

## Research Posters

Gray, P. 2012. *Economics of an isobutanol supply chain – research plan*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Jiang, J., J. Wang and M. Wolcott. 2012. *Preconversion of sodium sulfite treated wood with taguchi method*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13..

Johnson, D. 2012. *Clearwater Basin Biomass Atlas*. Poster presentation at International Wood Composite Symposium. Seattle, WA. April 11-13.

Johnson, D., K. Merslich, J.M. Moroney, and L. Nabahe. 2012. *Clearwater Basin Biomass Supply Chain Challenges and Opportunities*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Johnson, D., K. Merslich, J.M. Moroney, and L. Nabahe. 2012. *Clearwater Basin Biomass Atlas*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Liu, Y., J. Wang and M. Wolcott. 2012. *Factors affecting wood pellet densification*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Martinkus, N., T. Morgan, and M. Wolcott. 2012. *GIS as a Decision Support Tool for Supply Chain Analysis in the Western Montana Corridor*. Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Merslich, K., and L. Nabahe. 2012. Clearwater Basin Biomass Supply Chain Challenges and Opportunities. Poster presentation at International Wood Composite Symposium. Seattle, WA. April 11-13.

Moroney, J.M., and D. Johnson. 2012. *Clearwater Basin Bioenergy Survey*. Poster presentation at International Wood Composite Symposium. Seattle, WA. April 11-13.

Moroney, J.M. and D. Johnson. 2012. *Clearwater Basin Bioenergy Survey.* Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Olsen, K., and C. Poor. 2012. *Bioregional Mapping Analysis using ArcGIS.* Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

Poor, C., T. Beyreuther, K. Olsen, and M. Wolcott. 2012. *Integrated design pedagogy in higher education.* Poster presentation at NARA 2012 Annual Meeting. Missoula, MT. September 13.

IDX. 2013. *Western Montana Corridor Atlas*. NARA Open House and Student Poster Session (50 Posters). Rocky Mountain Elk Foundation. Missoula, MT.

## Other Publications

IDX. 2011. *Clearwater Basin Community Profile*. University of Idaho: Moscow, ID.

IDX. 2011. *Clearwater Basin Biomass Atlas*. Washington State University and University of Idaho: Pullman, WA.

IDX. 2012. *Clearwater Basin Bioenergy Assessment Project*. Washington State University and University of Idaho: Pullman, WA.

IDX. 2012. *Western Montana Corridor Community Profile*. University of Idaho: Moscow, ID.

IDX. 2012. *Western Montana Corridor Bioregional Atlas*. Washington State University and University of Idaho: Pullman, WA. http://goo.gl/OmLSc

# Task E-7: Feedstock Supply Chain Analysis – MSW

| Key Personnel | Affiliation |
|---|---|
| Karl England | Washington State University |

## Task Description

Our task is to inventory and assess the biomass within the municipal solid waste (MSW) and construction and demolition (C&D) supply chain throughout the NARA region. Research focus will be placed upon developing an overall inventory of the woody construction debris biomass in the Northwest (especially NARA communities), developing strategies to increase the recovery this material, establishing QC/product specifications, and identifying where these materials fit within the wood utilization supply chain.

## Activities and Results

### Task E-7.1: Develop MSW/C&D woody biomass inventory in NARA region

A preliminary MSW and wood waste assessment was performed to determine quantities for each state within the NARA region, which is presented in Table 1. US waste information was acquired through an EPA report accessed online. Montana, Oregon, and Washington waste information was obtained through state databases provided online or by state employees (references included in figures). Idaho information was acquired at the county level, but not all counties have yet been contacted. Figure 1 illustrates MSW distribution by county and by landfill within the NARA region. MSW includes all household and commercial waste that is not hazardous in nature. Depending on the landfill or transfer station, recyclable items such as plastic, metal, glass, and wood are sorted and separated from non-recyclable MSW.

Wood waste can be disposed of in MSW landfills or reused/recycled at MRFs and be used to create products such as reclaimed timber, composites, compost, or hogged fuel for energy recovery. A preliminary list of MRFs was originally created using state databases and internet searches regarding wood recycling. In all, a list of 53 MRFs that recycle C&D wood waste was compiled for the NARA region. Quick-fact information regarding the MRFs is represented in Table 2. Wood waste quantities collected from MRFs were obtained in units such as board foot, C&D ton, cubic yard of loose scrap wood, and cubic yard of shredded wood; conversion factors can be viewed in Table 3. A list of MRFs and their pertinent data is represented in Table 4, and recycled wood waste distribution per county and MRF can be viewed in Figure 2. In total thus far, a sum of **646,729 tons** of recycled wood waste has been accounted for by MRFs within the NARA region.

To ascertain a more accurate description of where the wood is located within the C&D waste streams, a model approach is being implemented. To develop the model, ideal communities that have a very complete inventory of wood in their C&D waste streams will be identified and used as baseline data. These communities will cover the population spectrum from large cities to small communities and tribal lands. Based upon the wood waste numbers in these target communities, a model that maps wood wastes to translate to other similar communities will be used. Development of this model will be iterative and supported with actual inventories. By identifying characteristics of the communities, i.e. housing starts, retail sales, industry framework, etc. that will influence the amount of wood in the C&D waste streams, the model can be refined and become more accurate. Databases within the US Census website can be used to identify the metrics to define the communities throughout the NARA region.

## Task E-7.2: Inventory of NARA Communities (NC)

***Task E-7.2.1 WMC:*** The Western Montana Corridor (WMC) was the primary focus of work to date. As a review, our research has indicated that separated landfill wood waste data within the WMC is predominately categorized into three categories: inert waste, C&D waste, and wood waste (a phrase that usually refers to clean wood). Ascertaining wood waste quantities within inert waste totals is difficult and no modeling technique has currently been determined. Wood waste derived from C&D waste on average can be quantified as 31% of total C&D waste, and 34% within C&D wood waste is untreated, unpainted, or comes from pallets. Table 1 indicates MSW, C&D, and wood waste totals from counties within the WMC. There are currently five known counties within the WMC that quantify clean wood waste, and there are four known counties that quantify C&D waste. In summary, 8,456 tons of usable C&D wood waste and 15,413 tons of clean wood waste were collected by participating counties within the WMC, creating a total of **24,639.5 tons** of estimated wood waste a year. Figure 4 is an updated map representing known landfills that separate wood within the WMC. Further maps will indicate MSW, C&D, and wood waste quantities per county.

Figure 3 is a map that represents MRFs within the WMC. Wood waste and C&D wood waste have been identified with two separate shades of green to show the known wood quantities from the estimated wood quantities (C&D). MRF research within the WMC is nearly complete; further information regarding two MRFs within the WMC is still anticipated. There are currently eleven known MRFs within the WMC, which include building salvage stores, reclaimed timber mills, wood grinding service companies, and general wood recyclers. Specific years for collected data may vary. Reclaimed timber mills collected a total of 2,824 tons of wood a year. Wood recyclers collected 6,477 tons of wood a year. Building salvage stores compiled 5,375 of C&D wood waste. In total, WMC MRFs compiled **15,413 tons** of wood waste a year. This total, however, may include wood that is utilized in other markets.

***Task E-7.2.2 Western NARA Region:*** Although a NARA community has not yet been established in the western NARA region, our research indicates that the majority of C&D wood waste accrues in areas of higher population densities, most notably Seattle, WA and Portland, OR. Figure 4 represents the distribution of wood waste per county and MRF within the western NARA region. Of the 53 MRFs in the NARA region, 41 MRFs are located east of the Cascade Mountains. Out of the 646,729 total tons of the MRF recycled wood waste quantified thus far, **546,832 tons (83%)** derive from the western NARA region. Recycled wood waste in this region is primarily used for energy cogeneration in the form of hogged fuel; other uses include composites, compost, and pulp.

## Task E-7.3: Identify recovery strategies of woody biomass from MSW and C&D streams

A Supply Chain Management (SCM) network was established and is essential for determining the viability of wood waste as a biofuel feedstock. SCM includes four aspects: Sourcing, Logistics, Operations, and Marketing. Sources of wood waste include MSW, industrial waste, construction and demolition (C&D) waste, and land clearing debris. Wood waste is often collected and separated at MRFs, landfills, and transfer stations; transportation methods include municipal self-haul, residential/commercial route trucks, and commercial drop-boxes. Although landfills are known for burying waste, there are many landfills that separate recyclable materials in order to prolong the lifespan of the landfill. Recyclable materials, such as wood waste, are often subcontracted or sold to MRFs for further recycling. MRFs recycle wood waste and produce products such as reclaimed timber, engineered wood, compost, paper pulp, soil amendment, and hogged fuel for energy recovery. Figure 5 represents a supply chain flow chart of the wood waste supply chain.

*Table 1: MSW and Wood Waste quantities per State within NARA region. Generated waste is equal to the sum of recycled and disposed wastes.*

| | Generated Municipal Solid Waste | | Generated Wood Waste | |
|---|---|---|---|---|
| | Tons/Year | LBS/Person/Day | Tons/Year | LBS/Person/Day |
| United States [1] | 249,860,000 | 4.43 | 15,880,000 | 0.28 |
| Idaho [2] | Not yet determined | | | |
| Montana [3] | 1,323,343 | 7.26 | Not yet determined | |
| Oregon [4] | 4,740,561 | 6.71 | 376,798 | 0.53 |
| Washington [5] | 8,860,856 | 7.17 | 1,203,074 | 0.98 |

Sources

[1] Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Tables and Figures for 2010. *U.S. Environmental Protection Agency. Office of Resource Conservation and Recovery.* December 2011. www.epa.gov Accessed 8/15/12.

[2] Henderson, Mary. MT_LF-tonnage-req.xcl. *State of Montana Department of Environmental Quality.* File received via email: 8/14/12

[3] Solid Waste in Washington State: 20th Annual Status Report. *Waste 2 Resources Program*. December 2011. Publication #11-07-039. www.ecy.wa.gov Accessed 8/6/12

[4] WasteComp200910StateWide .xcl *State of Washington Department of Ecology*. http://www.deq.state.or.us Accessed 2/10/12

[5] Standard Volume-to-Weight Conversion Factors. EPA. http://www.epa.gov/smm/wastewise/pubs/conversions.pdf Accessed 8/22/12

*Table 2: Quick facts regarding MRF research within the NARA region.*

| MRF DATA PER STATE | | | | | |
|---|---|---|---|---|---|
| State | Total Known MRFs | Total MRFS with Data Unknown | Total MRFs with Volume Data Unknown | Estimated MRF Wood Quantities (tons/year) | Recycled Wood Majority Market |
| Idaho | 4 | 0 | 0 | 44,979 | Reclaim Timber |
| Montana | 7 | 1 | 2 | 6,812 | Reclaim Timber |
| Oregon | 18 | 3 | 6 | 100,280 | Hog Fuel |
| Washington | 24 | 2 | 8 | 494,658 | Hog Fuel |
| Total | 53 | 6 | 16 | 646,729 | Hog Fuel |

*Table 3: Table of conversion factors that were used during the wood waste assessment.*

| WOOD VOLUME CONVERSION FACTORS | | |
|---|---|---|
| Volume Type | Conversion | Source |
| Board Feet [BF] | BF * [0.008 Ton/1 BF] | Cunningham, Kyle. *Converting Board Feet to Tons*. University of Arkansas Division of Agriculture. http://www.arnatural.org/News/Timber_Report/Converting_Weight_Board_Feet.pdf Accessed 4/11/2013 |
| Clean Wood within C/D Waste | C/D Tons * [0.115 Clean Wood/CD ton] | 2007 Massachusetts Construction and Demolition Debris Industry Study, Final Report. *DSM Environmental Services, Inc.*, 5/16/2008. www.mass.gov/dep/recycle/reduce/07cdstdy.pdf Accessed 01/04/2013 |
| Cubic Yard [CY]: Shredded Wood Chips | CY * [500 lbs/1 CY] * [1 ton/2000 lbs] | *Standard Volume-to-Weight Conversion Factors*. U.S. Environmental Protection Agency. http://www.epa.gov/smm/wastewise/pubs/conversions.pdf Accessed 8/22/2012 |
| Cubic Yard [CY]: Wood Scrap, Loose | CY * [329.5 lbs/1 CY] * [1 ton/2000 lbs] | *Standard Volume-to-Weight Conversion Factors*. U.S. Environmental Protection Agency. http://www.epa.gov/smm/wastewise/pubs/conversions.pdf Accessed 8/22/2012 |

*Table 4: List of MRFs within NARA region listed by state.*

| IDAHO | | | | | |
|---|---|---|---|---|---|
| MRF | Location | Volume | Reach | Tipping Fees | Market |
| Building Material Thrift Store | Hailey, ID | 25,000 tons Building Materials per year | No Data | No Data | Timber/Lumber Reuse |
| Cannon Hill Industries | Post Falls, ID<br>Spokane, WA | ID: 32,000 green tons<br>WA: 15,000 green tons | 100 miles | No Data | Hog Fuel sent to Clearwater Paper Corporation |
| Ross Lumber | Shoshone, ID | 600 tons/year | Supply: Through U.S.<br>Distribution: Pacific Northwest | No Data | Timber/Lumber Reuse |
| Trestlewood | Blackfoot, ID | 9504 tons/year | Supply: Western U.S.<br>Distribution: Throughout U.S. | Bid Based | Reclaim Timber |
| MONTANA | | | | | |
| MRF | Location | Volume | Reach | Tipping Fees | Market |
| Big Timberworks | Gallatin Way, MT | 35 tons/year of wood waste residue | Throughout U.S. | Bid Based | Reclaim Timber |
| Eko Compost | Missoula, MT | No Data | Supply: Bonner, ID<br>No Distribution | $1/bag<br>$7/pickup or small trailer<br>$15/ large trailer<br>$50/semi load<br>No charge for pre-chipped | Compost<br>Firewood |

| | | | | | |
|---|---|---|---|---|---|
| Heritage Timber | Bonner, MT | 2800 tons stored | Supply: 250 miles<br>Distribution: Pacific Northwest | No Data | Reclaim Timber |
| Home ReSource | Missoula, MT | 1977 tons/year through | Eastern Montana and Idaho | All is donated<br>Tax Class 501C3 | Mostly Reuse<br>Small Pieces sent to Eko Compost |
| Johnson Brothers Recycle | Missoula, MT | No Data | No Data | No Data | No Data |
| Montana Reclaimed Lumber Company | Gallatin Gateway, MT | 16,000 tons stored | No Data | Bid Based | Reclaim Timber |
| Resource Site Services | Bozeman, MT | 2000 tons/year | 100 miles service reach, no distribution | Bid based | Mobile Wood and Construction Material Grinding |
| OREGON | | | | | |
| MRF | Location | Volume | Reach | Tipping Fees | Market |
| Allwood Recyclers | Fairview, OR | No Data | No Data | $7/yard<br>$12 minimum | Hog Fuel |
| Bar 7 Trucking Wood Recycling | Redmond, OR | 1,685.62 BDT/year | 50 mile service reach, no distribution | $2/cubic yard | Hog Fuel |
| Best Buy in Town | Hillsboro, OR | No Data | No Data | No Data | No Data |
| Biomass One | White City, OR | 252,000 BDT/year Total<br>2,500 BDT/year clean C/D | Supply: 30 miles<br>Distribution: Oregon | No Fees | Hog Fuel<br>Energy |
| Clackamas Compost Products | Clackamas, OR | No Data | 10-20 miles | $10/cubic yard | Urban Wood: Hog Fuel<br>Land Clearing: Compost |
| Clayton Ward | Salem, OR | No Data | Supply: 50 miles | 3 cents/pound | Hog Fuel |
| Environmentally Conscious Recycling | Portland, OR | No Data | No Data | No Data | No Data |
| Greenway Recycling | Portland, OR | 16,200 tons/year | 15 miles most of time, but will reach to 75 miles | $81/ton commingled<br>$35/ton clean wood | Hog Fuel |
| Hilton Landscape Supply | Central Point, OR | Average 8,000-10,000 tons/year | Supply: 40 miles | No charge for dumping.<br>Drop Boxes are bid based. | Hog Fuel<br>Compost |
| JB Wood Recyclers | Monmouth, OR | 300 ton/year | Supply: 35 miles | $6/yard | Hog Fuel |
| KB Recycling | Clackamas, OR | No Data | Supply: 5 miles | $25/ton | Hog Fuel |
| McFarlane's Bark | Milwaukie, OR<br>Vancouver, WA | 5,120 tons 2012 | 30 miles | $10/yard retail<br>$9/yard commercial | Hog Fuel |

| | | | | | |
|---|---|---|---|---|---|
| Northwest Wood and Fiber Recovery | Portland, OR | 19,500 tons/year | Supply: 5 miles<br>Distribution: 40-50 miles | $5/cubic yard non-commercial<br>$1/cubic yard commercial | Hog Fuel to paper company for energy co-generation |
| Northwest Environmental and Recycling | Cornelius, OR | No Data | No Data | No Data | No Data |
| Recology | Portland, OR<br>West Linn, OR | 40,000 ton/year everything<br>20,000 tons/year urban wood waste | Supply: 15 miles | $45/ton | Hog Fuel |
| SH Landscape Supplies and Recycling | Tualatin, OR<br>Hillsboro, OR | Tualatin: 12,750 tons/year<br>Hillsboro: 2,250 tons/year | Supply: 20 miles<br>Distribution: Oregon | $7/cubic yard for clean urban wood waste | Hog Fuel |
| Trails End Recovery | Warrenton, OR | 3,600 tons urban wood waste 2012 | Supply: 25-30 miles | $82.50/ton mixed<br>$45.90/ton clean wood | Hog Fuel |
| Wood Waste Management | Portland, OR | 7373.75 tons 2012 | Supply: 50 miles | $26/yard first two yards<br>$13/yard after that | Hog Fuel |
| WASHINGTON | | | | | |
| MRF | Location | Volume | Reach | Tipping Fees | Market |
| All Wood Recycling | Redmond, WA | "Hundreds of thousands of mixed—clean wood and inert wood"<br>NOTE: Recording as 100,000 tons/year | Supply: 50 miles | $30/ton clean wood | Hog Fuel |
| Allen Shearer Trucking & Landscape Supply | Belfair, WA | "A couple hundred tons per year" | Supply: 200 miles | $30/ton | Hog Fuel |
| Bobby Wolford Trucking and Demolition | Woodinville, WA | 14,879 tons 2012 | Supply: 50 miles | Bid Based | Hog Fuel |
| Busy Bee Wood Recycling | Spokane, WA | No Data | Spokane County | $8/cubic yard | Hog Fuel |
| CDL Recycle | Seattle, WA | 32,760 tons/year average | Supply: Pierce and King Counties<br>Distribution: 110 miles | $20/ton clean<br>$55/ton mixed wood<br>$95/ton commingled C/D | Hog Fuel, Mulch, "a little of everything" |
| Cedar Grove Composting | Maple Valley, WA | No Data | Supply: 75 mile | $10/ton urban wood waste | Compost |
| City Bark LLC | Vancouver, WA | 4708.75 tons 2012 | Supply: 50 miles | $11/yard | Hog Fuel |
| Diversified Wood Recycling | Spokane, WA | 260 tons/year | No Data | $6/cubic yard | Lumber Reuse<br>Hog Fuel |

| | | | | | |
|---|---|---|---|---|---|
| Eastside Wood Recycling | Moses Lake, WA | 8,000 tons urban wood waste per year | Supply:  150 miles | Bid Based | Hog Fuel |
| Gillardi Logging and Construction | Elbe, WA | No Data | Supply 75 miles | $8/cubic yard drop off<br>Pick-up fees vary | Hog Fuel |
| Glacier Recycle<br>[Waste Management] | Auburn, WA | 88,440 tons/year<br>NOTE:  Volume given by Veneer Chip Transport | No Data | No Data | No Data |
| H&H Wood Recyclers | Vancouver, WA | 28,000 tons/ year | Supply:  50-75 miles | $7/cubic yard clean lumber<br>$3.5/cubic yard pallets | Hog Fuel<br>Compost |
| Lautenbach Industries | Mount Vernon, WA | 19,500 tons/year | Supply:  30 miles | $55/ton | Hog Fuel for Port Townsend Paper Mill |
| Mason County Wood Recyclers | Shelton, WA | No Data | Supply:  150 miles | $10/pick-up load | Hog Fuel |
| Pacific Northwest Timbers | Port Townsend | No Data | No Data | No Data | Reclaim Timber |
| Pacific Topsoils | Everett, WA | No Data | Assuming 100 miles | $22-44/cubic yard depending on location | Hog Fuel for various purposes |
| Pallet Services | Mount Vernon, WA<br>Pasco, WA<br>Tacoma, WA | Wood Waste Residue:<br>Pasco:  2,600 tons/year<br>Tacoma:  15,600 tons/year | Supply:  355 miles | No data | Good Wood: Pallet construction<br>Residue:  Hog Fuel sent to Port Townsend Paper |
| Sunshine Recycling | Spokane Valley, WA | No Data | Spokane County | $45/ton<br>C/D Bid Based | Hog Fuel<br>Compost |
| Rainier Wood Recycling | Fall City, WA<br>Covington, WA | Fall City:  49,600 tons<br>Covington:  74,400 tons | Supply:  200 miles | $7.50/cubic yard, although may vary | Hog Fuel<br>Mulch<br>Composites<br>Pulp<br>Bedding |
| Recovery 1 | Tacoma, WA | 2012 Report:<br>27,968.22 tons commingled const.<br>3,214 tons commingled demo.<br>7033.63 tons bright mixed (lumber, ply, particle board, etc.)<br>2,065.64 tons land-clearing | 125 miles | $65/ton commingled C/D<br>$15/ton Bright-Mixed<br>$20/ton Land-clearing | Hog Fuel<br>Mulch<br>Composites |
| Resource Woodworks | Tacoma, WA | No Data | No Data | No Data | No Data |

| | | | | | |
|---|---|---|---|---|---|
| RW Rhine | Tacoma, WA | 21,600 tons stored | Supply: 2500 miles | C/D Bid Based | Reclaim Timber |
| Veneer Chip Transport | Tacoma, WA | Under Pallet Services and Glacier Recycle | No Data | No Data | Transport |
| West Van Material Recovery Center | Vancouver, WA | 5800 tons | 30 miles | $62.57-60.66/ton clean urban wood waste | Hog Fuel |

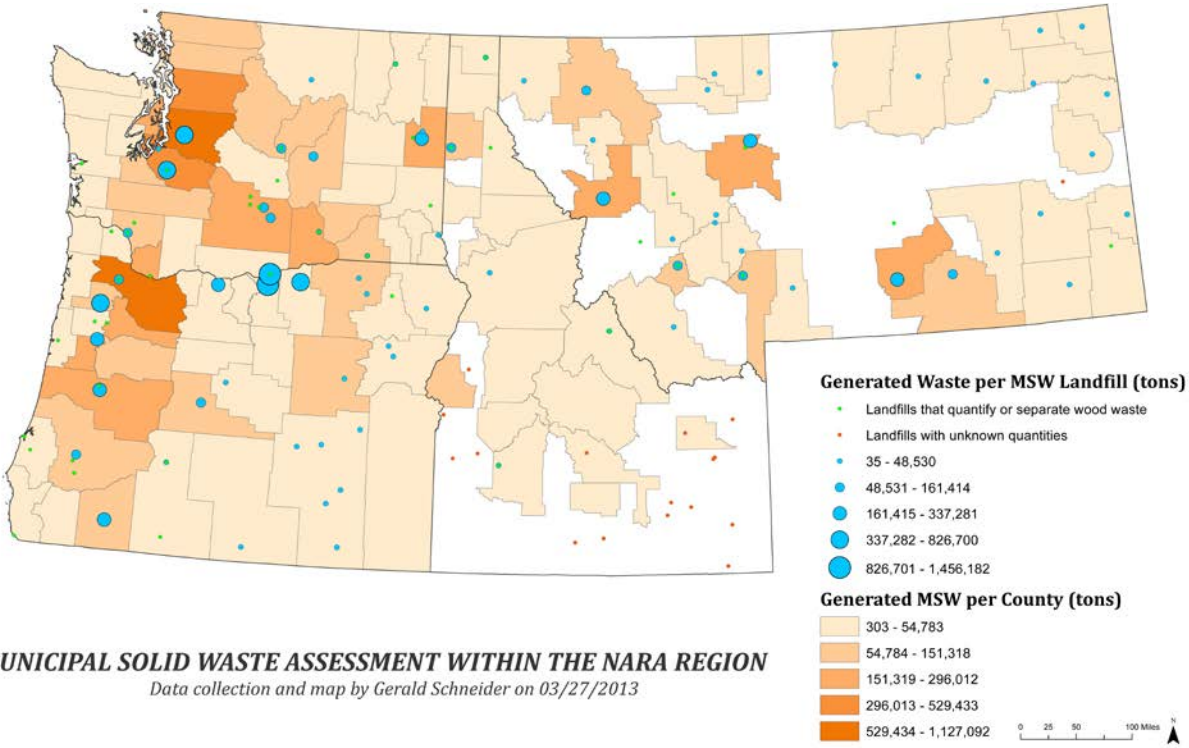


*Figure 1: MSW distribution by county and landfill within the NARA region.*

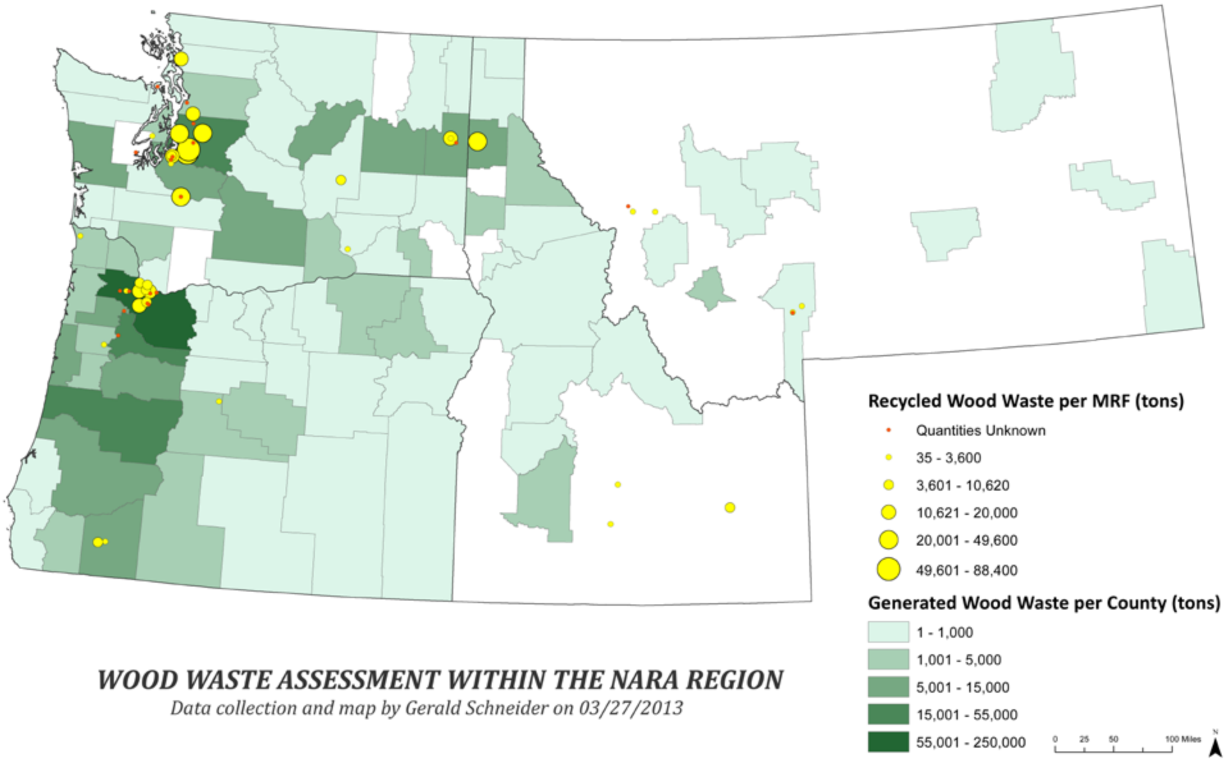


*Figure 2: Wood waste distribution by county and MRF within the NARA region.*

*Table 5: Wood waste and C&D clean wood waste totals for counties within the WMC.*

| State | County | Population (2011) | MSW (tons) | C&D (tons) | C&D Wood* (tons) | Wood (tons) |
|---|---|---|---|---|---|---|
| ID | Bonner[1] | 40,808 | 33,330 | 0 | 0 | 2,500 |
| | Boundary[2] | 10,804 | 4,500 | 0 | 0 | 318 |
| | Kootenai[3] | 141,132 | 121,171 | 0 | 0 | 10,899 |
| | Lemhi[4] | 7,967 | 9,048 | 644 | 74.06 | 0 |
| | Shoshone[5] | 12,672 | 5,691 | 0 | 0 | 1,390 |
| MT | Gallatin[6] | 91,377 | 108,647.37** | 6,807.3 | 782.84 | 306 |

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[1] *Bonner County Solid Waste Department*. Received via telephone questionnaire: 8/22/12

[2] *Boundary County Solid Waste Department*. Received via telephone questionnaire: 8/22/12

[3] 2011 Solid Waste Analysis. *Kootenai County Solid Waste Department*. Coeur D'Alene, ID. Provided by Kootenai County Solid Waste Department: 8/22/12

[4] *Lemhi County Solid Waste Management*. Received via telephone questionnaire: 8/22/12

[5] *Shoshone County Solid Waste Department.* Received via telephone questionnaire: 8/22/12

[6] Gallatin Solid Waste Management District. Fiscal Year 2010—2011 Annual. Provided by Gallatin Solid Waste Management District: 8/02/12

| | | | | | | |
|---|---|---|---|---|---|---|
| | Silver Bow[7] | 34,383 | 75,679** | 13,060 | 1,501.90 | 0 |
| WA | Spokane[8] | 473,761 | 314,355.91 | 59,719.12 | 6,867.70 | 0 |
| | | | | | *9,226.50* | *15,413* |
| | | *TOTAL* | | | | |
| | | | | | *24,639.50* | |

**Clean C&D Wood figured as11.5% of C&D total.*

***MSW quantities provided by State of Montana*[9]

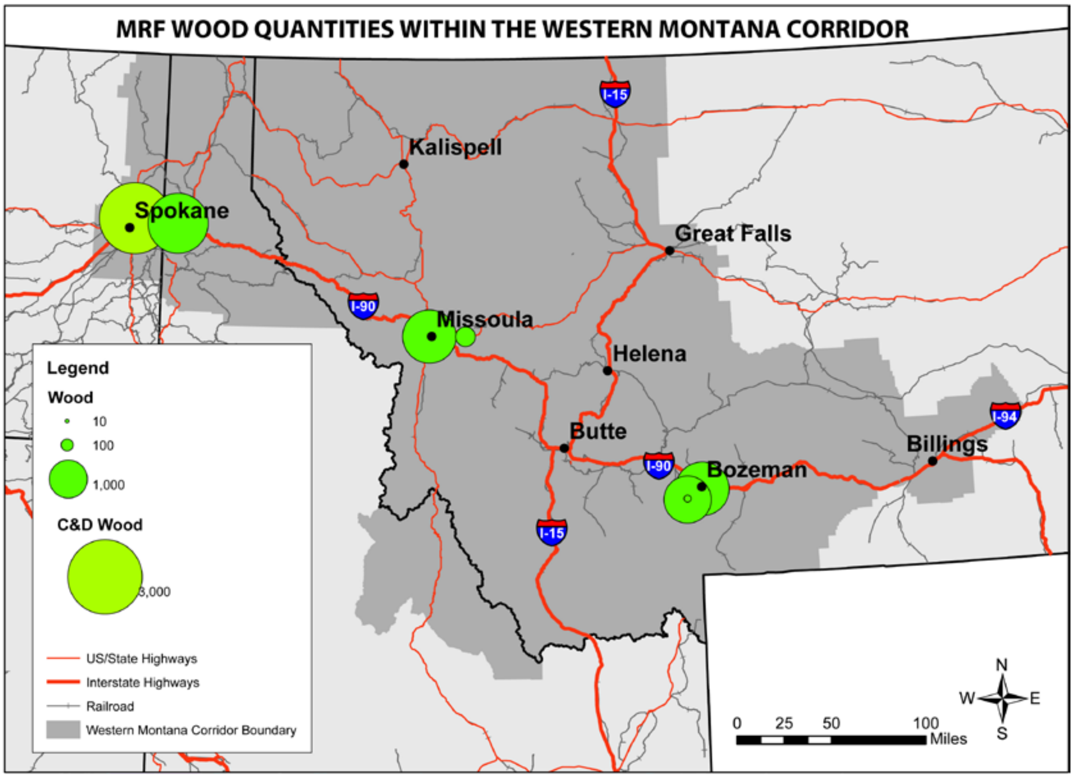

*Figure 3: Wood waste distribution per MRF within Western Montana Corridor.*

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[7] *Butte Silver Bow Rocker Landfill*. Received via telephone questionnaire: 8/02/12

[8] CountyTotals11.xcl. State of Washington Department of Ecology. http://www.ecy.wa.gov/programs/swfa/solidwastedata/ Accessed 1/07/13

[9] MT—LF-tonnage-reg.xcl. *State of Montana Department of Environmental Quality*. Received 8/14/12

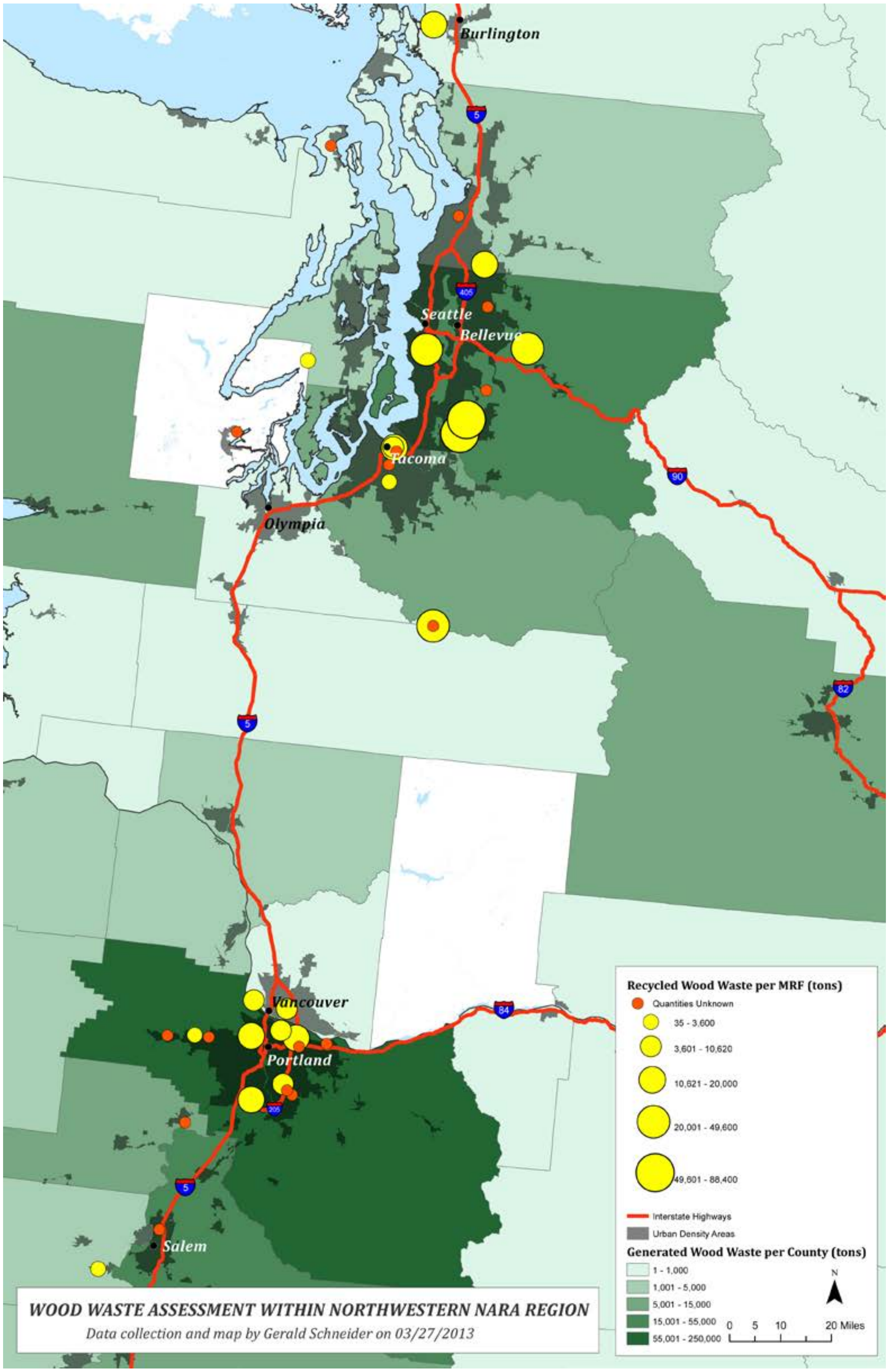

*Figure 4: Wood waste distribution near urban density areas within western NARA region.*

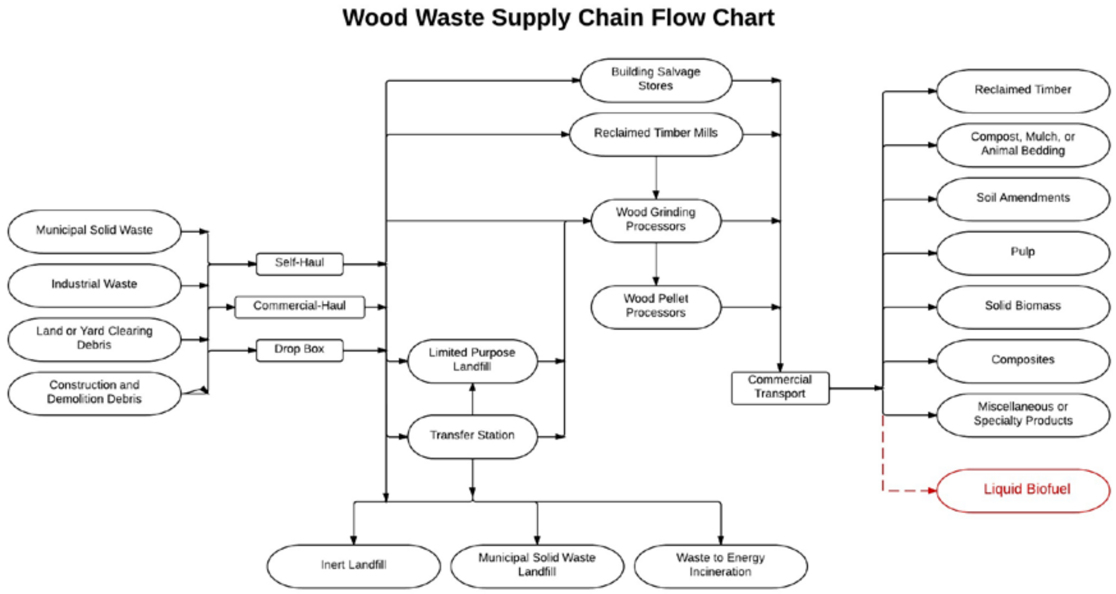

*Figure 5: Illustrated flow chart of the wood waste supply chain.*

## Recommendations/Conclusions

Wood inventories within the C&D and MSW streams continue to be compiled between the states and communities of the NARA region. ArcGIS is being used to map the wood waste locations and databases are being develop that can be incorporated into the NC assessment study. Efforts are being made to develop empirical models to predict the waste wood inventories in communities that do not have sufficient data.

## Physical and Intellectual Outputs

### Oral Presentation

*Englund, KR. 2013. Waste Wood and Plastics: Where does/can it all go? UI President's Sustainability Symposium. North Idaho College - Coeur d'Alene, ID March 20.

## Poster Presentation

Schnieder, G.A. and K. Englund. 2013. Wood Waste Assessment within the Construction and Demolition Industry. Poster presented at 2013 International Wood Symposium hosted by Washington State University, Seattle, WA, April 3-4.

# OUTREACH

## Outreach Team

### Task O-1: Washington State University NARA Extension Initiatives

| Key Personnel | Affiliation |
|---|---|
| Vikram Yadama | Washington State University |
| Karl Englund | Washington State University |

#### Task Description

NARA teams, along with research, extension and industry members, will act as partners and facilitators with the ultimate goal of empowering the stakeholders to plan and implement the changes needed to build, develop, and sustain a biorefinery infrastructure. The goal of the outreach team is to promote stakeholder bioenergy literacy and build regional supply chain coalitions for development of a framework of biofuel and co-products production from woody biomass. End outcomes of this goal are sustainable production of biojet fuel, co-products and rural economic development. Following are the objectives of the outreach team to reach this goal:

> **Task O-1.1 Bioenergy Literacy,** where we: a) disseminate the research-based information on technology and markets to our industrial stakeholders and understand the technical challenges regarding implementation at industrial scale (industry-focus); b) relate the feedstock development and logistics information to our resource-based stakeholders (local communities, forest landowners, forest managers) and hear their concerns regarding the type of information that will assist them in keeping their costs low and marketable value high (resource-focus); and c) engage the organizations and partnerships in connecting with public-interest groups and policymakers (public-focus). These activities will be carried out via a variety of communication mechanisms, including social media, newsletters, briefing papers, extension publications, workshops/seminars, conferences, field trips, and stakeholder meetings. Bioenergy literacy to professionals will be achieved through the following tasks:
>
> 1) Develop a bioenergy literacy platform for flow of information and knowledge between NARA research teams and the stakeholders
> 2) Implement targeted outreach activities for engaging stakeholders and advancing bioenergy literacy to professionals
> 3) Catalog activity outcomes and benchmark reports and studies
>
> **Task O-1.2 Build Supply Chain Coalitions** (logistical support and stakeholder development and engagement). We will form working groups with stakeholders at community and bioregion levels to

involve them through collaboration across the supply chain: forestland owners and managers, environmental NGOs, businesses, regulatory facilitators, and community infrastructure working groups to interact with and inform policymakers at regional, state, and federal levels. These stakeholders will be internal and external focused around the NARA communities (NCs) selected in the four-state region. This process will rely on support from other teams, such as Education and EPP, and consider physical and social assets along with practical aspects in narrowing down the list to a manageable number of communities with the four-state region. A long list will be shortened through surveying community-based stakeholders in the PNW and intermountain region to strategically choose several NCs for studying the viability of a biofuel-based infrastructure. Once communities are identified, focus group meetings involving a wide variety of stakeholders will be held at each community to discuss feedstock specifications and logistics, technology adoptions within the existing infrastructure, and viable strategies practical and beneficial for the communities. This process will involve industrial stakeholders and NARA industry partners as well. Establishing a meaningful dialogue about what local experts perceive to be the barriers and opportunities for establishing a biorefinery infrastructure in their community is critical. Building supply chain logistics consists of three major tasks:

1) Defining stakeholders and articulating stakeholder communication mechanism
2) Establishing NARA pilot supply chain (PSC) study regions and stakeholder development to engage in compiling supply chain assets, analyzing potential regional supply chain structure, and forming regional alliances
3) Assisting EPP with PSC selection process and support index study to develop a decision support tool

## Activities and Results

### Task O-1.1. Bioenergy Literacy

*Task 1:* A comprehensive stakeholder communication plan utilizing conventional channels, as well as social media for a two-way interaction between NARA stakeholders and NARA team members has been implemented (Figure 1).

A web-based mechanism was also established on the NARA web site for stakeholder engagement, self-identification, and categorization. Through this engagement platform, unbiased and vetted NARA-related information and activities are communicated to our stakeholders. NARA affiliates also include NARA activities on their websites. Other NARA social media communications include:

- Twitter (https://twitter.com/NARA_Renewables/)
- Facebook (http://www.facebook.com/pages/NARA/232111166837523), and
- YouTube (http://www.youtube.com/nararenewables).

The state extension personnel from each of the four states, USFS personnel, Forest Business Network (FBN, an industry association partner), and the Ruckelshaus Center engage stakeholders in communicating project scope, findings, and activities as well as hearing their concerns and input. Four NARA newsletters have been distributed to 231 subscribers. The newsletter is now on a monthly distribution schedule. Thirty-four independent news events (newspaper articles, web articles, television news) featuring NARA were generated. The NARA project has been featured on a display at the Future of

Flight Aviation Center and Boeing Tour and at the 2012 Smithsonian Folklife Festival at the Washington Mall.

NARA has co-hosted and participated in three symposia/conferences in 2011 and 2012. NARA was also represented at several other conferences, workshops, and meetings. 35 news articles, a video news story and an E-newsletter were presented to the general public. Eight “NARA one-pagers” or fact sheets have been generated and distributed.

A Knowledge Base repository was established and linked to the NARA website. Proceedings of the symposia/conferences that NARA has co-hosted have been catalogued in this repository.

### Task O-1.2. Build Supply Chain Coalitions

NARA’s stakeholders have been identified along with ways to communicate with them (Figure 2).

The Outreach team worked with Integrated Design Experience (IDX) in developing a biomass atlas for the Clearwater Basin, Idaho, during the first year. In the second year, NARA’s first official pilot supply chain study (PSC) region (Western Montana Corridor**)** was established where the outreach team is facilitating IDX and EPP team with engaging stakeholders and conducting supply chain analysis. We are in the process of establishing a second PSC study region in western Oregon and Washington.

Simultaneous to working in defined PSC study regions, the outreach team collaborated with the EPP and Education teams to develop a scientific method for PSC selection processes. As per established methodology, a survey of the NARA Outreach team members was conducted to develop a long list of potential NCs. A total of 24 communities/bioregions have been nominated.

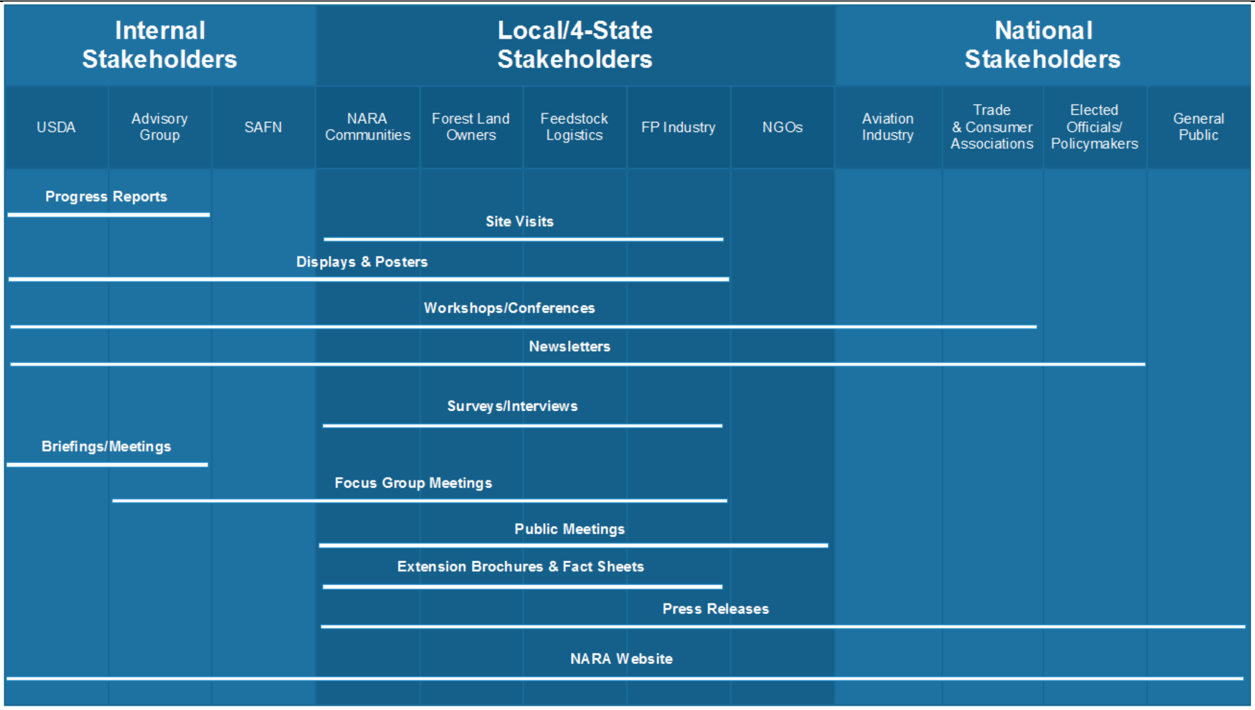

Figure 1. NARA’s communication platform with stakeholders at different interaction levels.

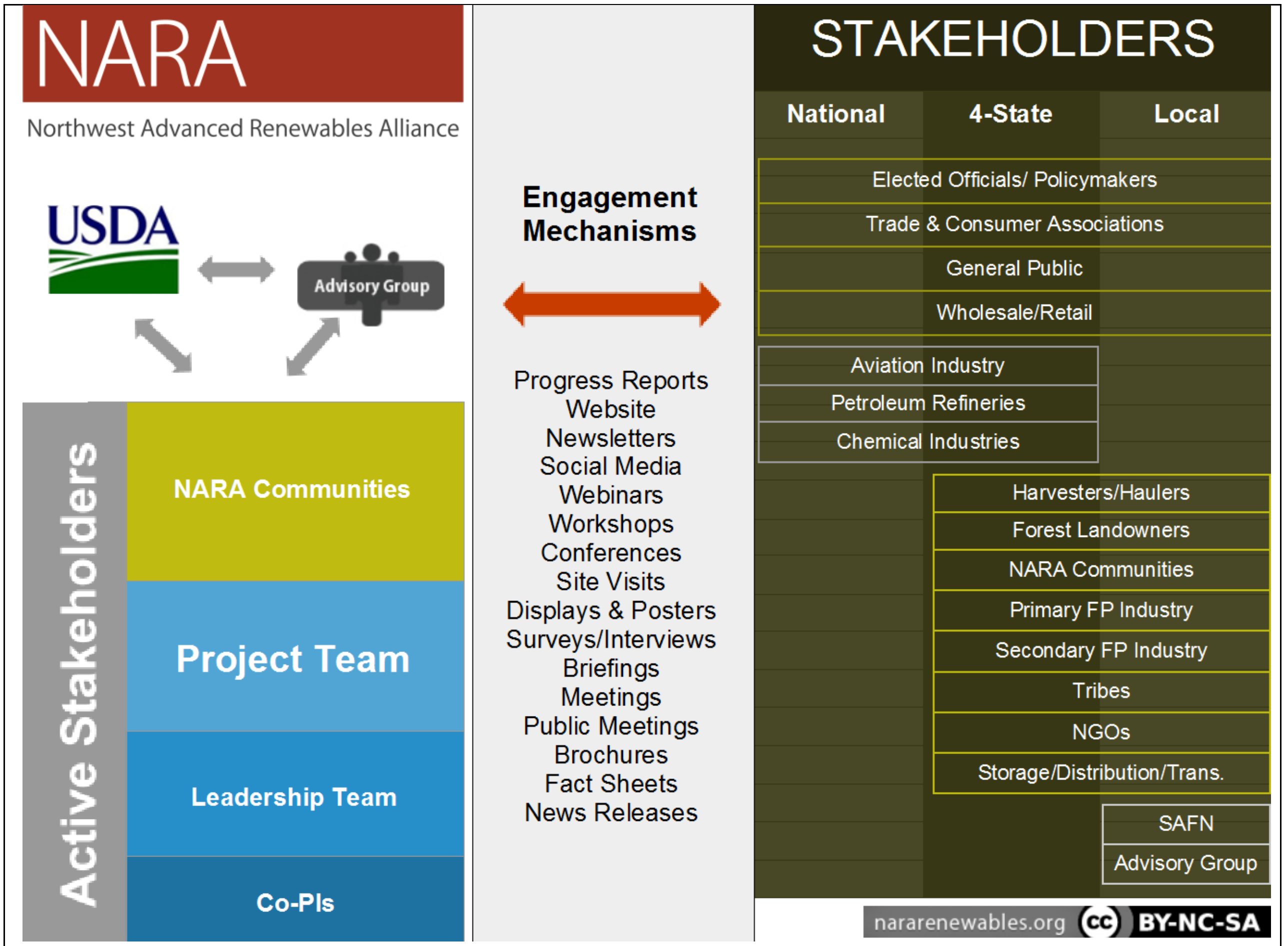

Figure 2. NARA stakeholders and defined levels of interaction with them.

## Recommendations/Conclusions

Based on the interactions with stakeholders, the outreach team has learned the following:

1. It is critical to communicate to the stakeholders the description of NARA's feedstock.
2. Forestland owners and managers are very much in favor of finding value-added options for excess post-harvest biomass from the forest floors. Based on anecdotal evidence, there is plenty of underutilized forest residuals, but it is scattered and needs a cost-effective solution to transport.
3. It is critical to communicate that NARA is developing pathways to convert forest residuals and C&D waste into biofuels and not bioenergy (wood pellets).

4. Stakeholders are enthusiastic and eager to help when they realize that NARA's efforts involve development of value added co-products (such as lignin co-products) besides biojet fuel.

5. Feedstock stakeholders are concerned about biomass transportation costs.

6. It is essential to involve and engage ENGOs for the project to succeed.

7. Resource-based communities are ready to find alternative uses for forest residuals and C&D wood waste; however, many communities are also eager to find value-added options for small diameter timber from forest thinning operations (as these have no profitable markets currently).

8. Forest industry is mostly favorable to finding value-added markets for underutilized residuals as long as the supply to current industry is not affected.

9. There is a need to communicate the option of examining sugars from wood as a potential market.
10. The conversion process of wood into biojet fuel has to be articulated better to the stakeholders.

11. There is a general appreciation for supply chain analysis as one of the essential elements for stimulating biofuel development from woody biomass.

12. Many resource-based and economic development organizations have begun to take inventory of supply chain assets and understand the need to develop programs that help existing sites to retool for renewable industries based on woody biomass.

13. Pilot supply chain study regions are necessary to engage stakeholders in the process of designing, planning, and monitoring of supply chain activities.

14. Working through PSC study regions is critical to establishing credibility and access to existing datasets as well as realistic data for supply chain analysis.

In general, the Outreach tasks for Bioenergy Literacy and Building Supply Chain Coalitions goals are on schedule. We are collaborating with other teams to develop educational/outreach tools for stakeholders to communicate research findings and other relevant information. Four NARA affiliates, Montana State University, Oregon State University, the US Forest Service, Pacific Northwest Research Station, and the Forest Business Network include NARA activities on their websites. Since the inception of the NARA website, it has had 20,539 visits with 83,270 page views from all 50 states in the US and from 114 countries. The Knowledge Base repository contains unbiased information that covers all aspects related to the NARA project. It is available to the general public and to date has had a total of 1710 visits from 23 states and 10 countries. To reach professionals, NARA has co-hosted and participated in three symposia/conferences that include a track on Managing the Woody Biomass Supply Chain at the International Wood Composites Symposium, Northwest Bioenergy Research Symposium and Future Energy Conference, and Small Log Conference. Additionally, FBN (www.forestbusinessnetwork.com) posts NARA related topics and activities (such as biomass, biofuels, tax credits) at their web site and distribute their weekly newsletters to over 10,000 readers. The Outreach team will be organizing a NARA conference in Year 3 to disseminate project findings to the stakeholders and to hear their feedback.

The outreach team has taken measures to ensure that the objectives and scope of the project is conveyed to general public as well through NARA displays at the events discussed above. The Flight Museum attracts over 225,000 regional, national, and international visitors annually. An additional 75,000 people visit the facility to participate in a special event—activities surrounding delivery of Boeing aircraft, receptions, and school activities. The 2012 Smithsonian Folklife Festival at the Washington Mall attracts over one million visitors each year.

In an effort to reach regional and national stakeholders, NARA was represented at the Society of American Foresters National Convention, the Clearwater Forestry and Conservation Practices Tour, the National eXtension Conference, Montana Forest Council, local Society of American Forester chapters, the Spokane Tribe, Forest Owners Field Days, Montana and Idaho Loggers Associations, the Council on Forest Engineering, and at monthly Montana Forest Restoration Committee meetings.

We are also working with the Decon 13 conference to look at waste products from municipal solid waste streams for recycled products and energy production. Various commercial forest operations that generate residue feedstock were videotaped to develop educational vignettes used to convey NARA's objectives, scope, and findings to our stakeholders, who include students, community leaders, public, and forest products industry. Vignettes and targeted one-page fact sheets are in production. The Ruckelshaus Center has distributed two quarterly briefing papers designed to inform over 1,200 local, regional, and national policy-makers about the project's progress. This has included simultaneously distributing quarterly briefing papers for the Advanced Hardwoods Biofuels Northwest (AHB) project, to avoid stakeholder confusion surrounding these two complementary projects.

As for developing a PSC selection process with EPP team, follow-up assessments of the communities that have been nominated will be carried out with assistance of the EPP and Education teams to narrow the list down to selected NCs with which to work closely during the remainder of the project. The selection methodology will be validated with the work being conducted in the pilot supply chain study regions. In the PSC study regions, the outreach teams in working closely with the IDX and EPP teams in compiling regional supply chain assets, analyzing feedstock supply scenarios, conducting LCA, performing conversion site analysis and community impact analysis for developing a framework of competitive infrastructure.

What is needed now is interaction with other NARA teams and industry partners to draft future outreach activities in different research areas. In addition, we need to aggressively pursue setting up an effective blog to have two-way communications with our stakeholders.

## Physical and Intellectual Outputs

### Physical

- Four NARA newsletters have been distributed to 231 subscribers. The newsletter is now operating on a monthly distribution schedule. (https://nararenewables.org/news/newsletter)

- The NARA website, www.nararenewables.org, had 20,539 visits with 83,270 page views. Viewership came from all 50 states and from 114 countries.

- The Ruckelshaus Center has distributed two quarterly briefing papers designed to inform policy-makers to over 843 regional and national policymakers.

- The Knowledge Base repository contains unbiased information that covers all aspects related to the NARA project. It is available to the general public and to date has had a total of 1710 visits from 23 states and 10 countries. (https://nararenewables.org/knowledgebase)

## Conference Proceedings and Abstracts from Professional Meetings

Tichy, R., Yadama, V., Englund, K., Lowell, E., Leavengood, S., and Rawlings, C. 2012. *Managing Woody Biomass Supply Chain.* Proceedings of the International Wood Composites and NARA Joint symposium, Seattle, WA, April 11-12 (http://www.nararenewables.org/2012-iwcs)

WA Department of Commerce. 2012. *Northwest Bioenergy Research Symposium.* Proceedings of 2012 Northwest Bioenergy Research Symposium, Seattle, WA, November 13 (http://pacificbiomass.org/BioenergyResearchSymposiums/BioenergyResearchSymposium2012.aspx)

Forest Business Network. 2013. *Small Log Conference.* Proceedings of the 2013 Small Log Conference, Coeur d'Alene, Idaho, March 13-15 (http://www.forestbusinessnetwork.com/our-events/slc/proceedings/)

## Research Presentations

Wolcott, M.P. 2012. *The Northwest Advanced Renewables Alliance: A supply chain to aviation biofuels and environmentally preferred products*. Invited Speaker. Pacific West Biomass Conference & Trade Show, San Francisco, CA, January 17.

Yadama, V. 2012. *Scope of the outreach activities within NARA*. Montana Stakeholder Meeting, Missoula, MT, March 21.

NARA Outreach Brochure 1: *Northwest Advanced Renewables Alliance*. 20 June 2012.

Yadama, V. and Englund, K. 2012. *Conversion of woody biomass to biofuels and co-products*. Oral Presentation, Spokane Tribe, Wellpinit, WA, August 24.

Yadama, V. 2012. *Bioenergy Literacy to Professionals*. 1st NARA Annual Meeting, Missoula, MT, September 13.

Gaffney, M., Englund, K., Kern, M., Leavengood, S., Arno, M., Moulton, P., Lowell, E., Kolb, P., Perez-Garcia, and Yadama, V. 2012. *Rural Economic Development & Stakeholder Engagement*. 1st NARA Annual Meeting, Missoula, MT, September 14.

Zhu, R., Yadama, V., and Englund, K. 2012. *Hot water extraction (HWE) as a pre-conversion technique for Douglas-fir wood chips.* Poster, National Convention of the Society of American Foresters, Spokane, WA, Oct. 24-28.

NARA Fact Sheet 1: *Taking Wood To New Heights.* 17 October 2012.

NARA Outreach Team. 2012. *Selection process of potential NARA Pilot Supply Chain coalitions in the Pacific Northwest Region.* Poster, NW Bioenergy Research Symposium, Seattle, WA, Nov. 13.

NARA Fact Sheet 2: *Woody Biofuels Initiative in the Pacific Northwest*. 16 November, 2012.

NARA Fact Sheet 3: *NARA Supply Chain.* January 2013.

USDA FS PNW. 2013. *Northwest Advanced Renewables Alliance (NARA): A Supply Chain to Aviation Biofuels and Environmentally Preferred Products*. Briefing Paper, March 2013.

Zhu, R. and Yadama, V. 2013. *Impact of hot water extraction (HWE) pretreatment conditions on the physiochemical characteristics of Douglas-fir (DF) wood chips*. Poster, Small Log Conference, Coeur d'Alene, Idaho, March 13-15.

## Other Publications

A press release has been sent out by Charles Burke regarding the joint symposium "Managing the Woody Biomass Supply Chain," in Seattle, WA.

Weaver, M. 2012. *Woody biomass alliance holds first meeting*. Capital Press, September 11 (http://www.capitalpress.com/newsletter/mw-Woody-biomass-meeting-091112).

Styles, G. 2012. *Jet fuel from trees (or almost anything else)*. The Energy Collective, September 13, (http://theenergycollective.com/geoffrey-styles/112611/jet-fuel-trees-or-almost-anything-else).

Baker, D.S. 2012. *What's happening in the Woody Energy Market?* Pallet Enterprise, August 1 (http://www.palletenterprise.com/articledatabase/view.asp?articleID=3716)

Dorminey, B. 2012. *Flying on woody biomass and camelina: consortium seeks biofuel answers*. Renewale Energy World.COM, August 21 (http://goo.gl/0RQCM)

Missoula Economic Partnership. 2012. *Biojet Project Takes Off in Missoula* (http://goo.gl/EpNNe)

Seale, A. 2012. *Biomass – fueling aviation*. Clean Energy (An independent supplement from MediaPlanet to the Seattle Times, September (http://goo.gl/RpZQK)

Burke, C. 2012. *Western Montana Corridor: Putting the Pieces Together*. NARA Newsletter, August (http://nararenewables.org/news/newsletter)

FBN Blog maintained by Craig Rawlings: http://www.forestbusinessnetwork.com/17751/naras-woody-biomass-biofuels-effort-hits-close-to-home-and-how-you-can-help-fuel-the-momentum/

Chaney, R. 2012. *Group looks to turn forest waste into fuel for jets*. The Missoulian, June 16. (http://missoulian.com/business/local/group-looks-to-turn-forest-waste-into-fuel-for-jets/article_e9560970-b774-11e1-8c83-0019bb2963f4.html#comments

## Videos and Webinars

Video news story on NARA's First Annual Meeting (http://goo.gl/u4NFM)

## Trainings, Education and Outreach Materials

*Managing Woody Biomass Supply Chain*. 2012. Joint symposium with International Wood Composites Symposium, Seattle, WA, April 11-12 (http://www.nararenewables.org/2012-iwcs)

Yadama, V. 2012. *WSU Biofuels Project*. Forest Owners Field Day, August 18, Maytown, WA.

Yadama, V. and Rawlings, C. 2012. *NARA: A Supply Chain to Aviation Biofuels and Lignin Co-products*. Oral Presentation, Montana Loggers Association, Lubrecht Experimental Forest Station, MT, September 15.

2012 Northwest Bioenergy Research Symposium, Seattle, WA, November 13, 2012 (http://pacificbiomass.org/BioenergyResearchSymposiums/BioenergyResearchSymposium2012.aspx)

Yadama, V. 2013. *Using Biomass to Create Jet Fuel*. 21st Annual Family Foresters Workshop, January 18, Coeur d'Alene, Idaho.

Yadama, V. 2013. *From Sticks to Jet-Stream: Using logging slash to create Jet Fuel*. Northeast Chapter Annual Winter Meeting, Washington Farm Forestry Association, February 9, Chewelah, WA.

Small Log Conference, Coeur d'Alene, Idaho, March 13-15, 2013 (http://www.forestbusinessnetwork.com/our-events/slc/proceedings/)

The NARA project, in connection with WSU, is featured on a display at the Future of Flight Aviation Center and Boeing Tour. The Museum attracts over 225,000 visitors annually. Of these guests, roughly 1/3 are from the immediate region, 1/3 from the balance of the United States, and 1/3 are international. An additional 75,000 people visit the facility to participate in a special event—activities surrounding delivery of Boeing aircraft, receptions, school activities, and so on

The NARA project, in connection with WSU, was featured at the 2012 Smithsonian Folklife Festival at the Washington Mall. This event attracts over one million visitors each year.

A NARA exhibit booth has been generated and used at the Small Wood Conference, CdA

# Task O-2: Montana State University NARA Extension Initiative

| Key Personnel | Affiliation |
|---|---|
| Peter Kolb | Montana State University |

## Task Description

Montana State University (MSU) Extension Forestry will assist with the NARA Extension Working Group by providing information about the NARA program and research updates to Montana stakeholders including industry, logging and landowner professional organizations and conferences. In addition we will produce and publish brochures, popular articles and guidelines for these groups, as well as assist with the scoping process and development of a test bed site.

### Milestones Year 1:

Meet with NARA extension group and develop guidelines for selecting test bed sites. Cooperate with NARA team to develop and launch web site. Meet with Montana interest groups including Montana biomass working group, Montana Logging Association, Montana Forest Council, Montana Tree Farm, Montana Forest Owners Association and introduce the NARA project and scoping for test bed site in Montana. Develop outline for woody biomass harvesting guidelines for forest landowners.

### Milestones Year 2:

Develop draft of woody biomass harvesting guidelines for review by multiple Montana interest groups. Meet with stakeholders in various communities for outline and discussion of possible test bed sites. Organize several field trips for field reviews of potential test bed sites. Write three articles on NARA project for statewide media outlets. Contribute towards NARA website.

## Activities and Results

Montana State Extension Forestry assisted with the development and implementation of an educational and logistical support program across Montana for the development of a forest residue-to-energy industry. Forest landowners, managers, agency, industry and multiple western Montana community representatives have learned about the process and raw material requirements for a potential industry that converts woody debris into isobutanol – a drop-in ready jet fuel alternative. Multiple articles in landowner and professional newsletters, as well as presentations at potential partner-industry board meetings, have outlined the process and requirements. This has resulted in reaching more than 3000 private forest landowners, 8 major forest products companies, major logging contractors and tribal, state and federal forestry personal representing forest inventories on more than 2 million acres of private lands, 800,000 acres tribal lands, 800,000 acres state trust lands and 12 million acres of federal lands with wood harvesting potential. Based on conference and communications feedback, most of these stakeholders are today optimistic about the potential of selling woody debris that is a current byproduct of wildfire hazard reduction, forest restoration and traditional logging operations, and are ready to assist if further conversion research shows a feasible solution. An MSU Extension web page and a biomass stakeholder list-serve inclusive of other woody biomass conversion research and entrepreneurship has been developed and is used to update western Montana constituents of any new developments regarding forest biomass markets.

## Recommendations/Conclusions

There is a surplus of woody biomass available across Montana that would benefit from an economically viable market. Such a market would increase healthy forest conservation efforts, private enterprise and rural communities. Continued research into developing a technological solution that converts forest residue into a transportable drop-in-ready liquid fuel is essential.

## Physical and Intellectual Outputs

### Physical:

100 lbs each of ground ponderosa pine needles and branches from: 1) fresh pine, 2) recently beetle killed, and 3) 6 month-old beetle killed were delivered to the WSU Bioproducts, Sciences & Engineering Laboratory for analysis of secondary metabolites.

### Other Publications

Kolb, Peter F. 2012. The future of biomass in Montana, Montana Family Forest Spring Newsletter.

Kolb, P., 2012. The Future of Forest Biomass 2012, Montana Forest Owners Spring Newsletter

Kolb, P., 2012. Is Biomass a Future Market in Montana, Northwest Woodlands Fall 2012, Volume 28. No.4.

Kolb, Peter. 2013. Managing for Forest Soil Productivity, Montana Family Forest News, Issue No. 40.

Twer, Martin. 2012. Why the Western Montana Corridor as a “Pilot NARA Community”. Misc MSU Extension Forestry publication.

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http://www.msuextension.org/forestry/nara.html
http://www.msuextension.org/forestry/nara_resources.html

Created a Montana NARA listserv

## Trainings, Education and Outreach Materials

“An overview of the NARA project and expected outcomes” presented to:

- *Montana Forest Council*
- *Montana Tree Farm Board of Directors*
- *Montana Forest Owners Association*
- *Montana Logging Association*
- *Montana Association of County Agriculture (Extension) Agents*

Participation in work meetings, including two two-day comprehensive stakeholder meetings

- NARA Open House
- Western Montana NARA Fieldtrip
- NARA Annual Conference

# Task O-3: University of Montana NARA Extension Initiative

| Key Personnel | Affiliation |
|---|---|
| Todd Morgan | University of Montana |

## Task Description

NARA units, research, extension and industry members, will act as partners and facilitators with the ultimate goal of empowering the stakeholders to plan and implement the changes needed to build, develop, and sustain a biorefinery infrastructure. The goal of the outreach team is to promote stakeholder bioenergy literacy and build regional supply chain coalitions for development of a framework of biofuel and co-products production from woodybiomass. End outcomes of this goal are sustainable production of biojet fuel and co-products and rural economic development. Following are the objectives of the outreach team to reach this goal:

1. **Bioenergy Literacy,** where we: a) disseminate the research-based information (on technology and markets) to our industrial stakeholders and understand the technical challenges regarding implementation at industrial scale (industry-focus); b) relate the feedstock development and logistics information to our resource-based stakeholders (local communities, forest landowners, forest managers) and hear their concerns regarding the type of information that will assist them in keeping their costs low and marketable value high (resource-focus); and, engage the organizations and partnerships in connecting with public-interest groups and policymakers (public-focus). These activities will be carried out via a variety of communication mechanisms, including social media, newsletters, briefing papers, extension publications, workshops/seminars, conferences, field trips, and stakeholder meetings. Bioenergy literacy to professionals will be achieved through following tasks.
    a. Develop a bioenergy literacy platform for flow of information and knowledge between NARA research teams and the stakeholders.
    b. Implement targeted outreach activities for engaging stakeholders and advancing bioenergy literacy to professionals.
    c. Catalog activity outcomes and benchmark reports and studies.

2. **Build Supply Chain Coalitions** (logistical support and stakeholder development and engagement), where we will form working groups with stakeholders at community and bioregion levels to involve them through collaboration across the supply chain: forestland owners and managers, environmental NGOs, businesses, regulatory facilitators, and community infrastructure working groups to interact with and inform policymakers at regional, state, and federal levels. These stakeholders will be internal and external focused around the NARA communities (NCs) selected in the four-state region. This process will rely on support from other teams, such as Education and EPP, and consider physical and social assets along with practical aspects in narrowing down the list to a manageable number of communities with the four-state region. A long list will be shortened through surveying community-based stakeholders in the PNW and intermountain region to strategically choose several NCs for studying the viability of a biofuel-based infrastructure. Once communities are identified, focus group meetings involving a wide variety of stakeholders will be held at each community to discuss feedstock specifications and logistics, technology adoptions within the existing infrastructure, and viable strategies practical and beneficial for the communities. This process will involve industrial stakeholders and NARA industry partners as well. Establishing a meaningful dialogue on what local experts perceive to be

the barriers and opportunities for establishing a biorefinery infrastructure in their community is critical. Building supply chain logistics consists of four major tasks.

a. Define stakeholders and articulate stakeholder communication mechanism.
b. Define and establish NARA pilot supply chain (PSC) study regions to engage stakeholders in compiling supply chain assets, analyzing potential regional supply chain structure, and forming regional alliances.
c. Stakeholder development in the four-state region and pilot supply chain study regions.
d. Assist EPP with PSC selection process and support index study to develop a decision support tool.

## Activities and Results

Over the past two years of the NARA project, BBER staff have worked with NARA Team Leaders and members and local Montana forestry and wood products associations, agencies, and individuals to help increase bioenergy literacy and build supply chain coalitions. Specifically, BBER staff have been active in Outreach activities to:

- identify appropriate selection criteria for NARA communities
- provide timber harvest, mill, and other information to MSU Extension
- select the Western Montana Corridor (WMC) as a NARA pilot community
- engage and inform local and regional stakeholders of the NARA project
- participate in the WMC planning events and annual NARA meeting held in Missoula
- communicate local (western Montana) concerns and issues to the NARA teams
- share information and progress from NARA with Montanans
- provide Montana-specific information and local contacts to members of other NARA Teams
- review drafts of the WMC Atlas produced by the NARA Education Team

BBER researchers have continued to inform individuals and groups throughout Montana and other states about NARA research since the start of the project. Todd Morgan, Steve Hayes and other BBER staff have attended the Montana Forest Restoration Committee's Forest Products Retention Roundtable monthly meetings to share information on NARA progress and hear comments from stakeholders in the WMC. The Roundtable was identified as the NARA "client" in Montana. Todd Morgan (of BBER) and Craig Rawlings (of Forest Business Network) regularly attend the Roundtable, report on NARA progress, and otherwise serve as liaisons between the Roundtable and NARA.

BBER personnel recently invested more than 100 staff hours reviewing the NARA Western Montana Corridor Atlas project. BBER personnel reviewed three separate Atlas products: posters at the January 2013 Missoula Open House, a rough draft Atlas document, and the revised Atlas draft. These oral and written reviews uncovered significant content problems, provided remedies for these shortcomings, and helped shape the final Atlas product.

## Recommendations/Conclusions

The majority of the Extension/Outreach work that BBER is doing for the NARA project consists of sharing our research results from the Feedstock/Supply Chain side of the project and maintaining contact with the various Montana stakeholders, including the MFRC Forest Products Retention Roundtable, MWPA, MLA, and others. MSU is Montana's Forestry Extension program.

BBER's Forest Industry Research Program will continue to participate in the monthly Roundtable and other meetings, despite our formal withdrawal from the NARA Outreach Team (please see comments below). BBER staff have invested much time refining the Western Montana Atlas products. We will work with the Roundtable and NARA members to ensure the final Atlas meets stakeholder expectations.

Montana loggers, mill owners, forestry agency personnel, forest landowners and others worry that the NARA project may produce only paper plans with low probability of outcomes that would directly benefit their organizations financially. We must provide our stakeholders with succinct, unvarnished updates of project progress and high-quality, professionally-prepared information.

### The Future:

In Year 3, the BBER team will cease formal Outreach activities under the NARA agreement, but will continue to share information with NARA Teams and stakeholders on an informal basis.

Given proposed budget changes (i.e., direct expenses reduced to accommodate increased indirect costs) BBER is losing approximately $9,400 in Year-3 direct funding. BBER's Year-3 Outreach efforts are estimated to have a direct cost of $8,700. The size of the direct budget cut requires a reduction in the quantity of activities and reporting that BBER is performing for NARA. Since the draft WMC Atlas was delivered to the Roundtable client in Year 2 and NARA Outreach and Education activities will be shifting to communities outside Montana in Year 3, BBER's level of Outreach activity would have otherwise decreased. In order to minimize the overall impact of the budget reduction on BBER's NARA research (System Metrics) activities and to reduce BBER's reporting burden, formal Outreach activities under NARA will cease.

We ask that the NARA Outreach Team re-organize its efforts in Montana to rely on Montana State University (MSU) Forestry Extension (under Peter Kolb) and Forest Business Network (under Craig Rawlings) for formal Outreach activities. While BBER staff will continue to participate in the MFRC Roundtable and fill information requests related to the NARA project, it will not be as a formal Outreach Team member.

We thank Outreach Team Leader Dr. Vikram Yadama for his enthusiastic leadership of NARA outreach efforts. We wish our fellow Outreach team members well and trust they will effectively engage many stakeholders in the NARA project.

## Physical and Intellectual Outputs

### Physical

- Todd Morgan, Steve Hayes, and/or other BBER staff participate in the monthly MFRC Forest Industry Retention Roundtable.
- BBER staff helped to coordinate and participated in the June 2012 WMC planning meeting, where researchers, students, and stakeholders met to discuss and plan other activities associated with the WMC Atlas project.
- BBER staff participated in the September 2012 NARA annual meeting held in Missoula, providing technical and logistic support, participating in the group capital "brainstorming" activities, and presenting information to those in attendance.

### Research Presentations

Berg, E. 2012. Western Montana Corridor: Woody biomass from logging and mill residuals. Presentation at the NARA Annual Meeting, September 12-14, 2012. Missoula, MT.

### Other Publications

The University of Montana produced a short press release (http://news.umt.edu/2011/10/100311nara.aspx ) when the NARA project was announced at SeaTac. Todd Morgan had an interview on October 5, 2011 with a local TV news (KPAX) reporter, Russ Thomas, as follow-up to the press release.

### Trainings, Education and Outreach Materials

Morgan, T. 2011. From stump to pump: wood-based biofuel research in the Northwest. Presentation/ web-cast is available online at: http://fresc.usgs.gov/spotlight/Presentations.html. The presentation introduced the NARA project in general, and provided details about the measurement of logging residues that BBER researchers are collecting. Portland State University, Portland, OR, December 15.

Morgan, T. 2012. Woody Biomass from Logging and Mill Residuals. Presentation described some of the work BBER is conducting as part of the NARA team and highlighted major trends and conditions in the Montana forest inventory, forest industry, and timber harvest. NARA meeting, Missoula, MT, June 13.

## Task O-4: Oregon State University NARA Extension Initiative

| Key Personnel | Affiliation |
|---|---|
| Scott Leavengood | Oregon State University |

### Task Description

NARA units, research, extension and industry members, will act as partners and facilitators with the ultimate goal of empowering the stakeholders to plan and implement the changes needed to build, develop, and sustain a biorefinery infrastructure. The goal of the outreach team is to promote stakeholder bioenergy literacy and build regional supply chain coalitions for development of a framework of biofuel and co-products production from woody biomass. End outcomes of this goal are sustainable production of biojet fuel and co-products and rural economic development. Following are the objectives of the outreach team to reach this goal:

1. **Bioenergy Literacy,** where we: a) disseminate the research-based information (on technology and markets) to our industrial stakeholders and understand the technical challenges regarding implementation at industrial scale (industry-focus); b) relate the feedstock development and logistics information to our resource-based stakeholders (local communities, forest landowners, forest managers) and hear their concerns regarding the type of information that will assist them in keeping their costs low and marketable value high (resource-focus); and, engage the organizations and partnerships in connecting with public-interest groups and policymakers (public-focus). These activities will be carried out via a variety of communication mechanisms, including social media, newsletters, briefing papers, extension publications, workshops/seminars, conferences, field trips, and stakeholder meetings. Bioenergy literacy to professionals will be achieved through following tasks.
    a. Develop a bioenergy literacy platform for flow of information and knowledge between NARA research teams and the stakeholders.
    b. Implement targeted outreach activities for engaging stakeholders and advancing bioenergy literacy to professionals.
    c. Catalog activity outcomes and benchmark reports and studies.

2. **Build Supply Chain Coalitions** (logistical support and stakeholder development and engagement), where we will form working groups with stakeholders at community and bioregion levels to involve them through collaboration across the supply chain: forestland owners and managers, environmental NGOs, businesses, regulatory facilitators, and community infrastructure working groups to interact with and inform policymakers at regional, state, and federal levels. These stakeholders will be internal and external focused around the NARA communities (NCs) selected in the four-state region. This process will rely on support from other teams, such as Education and EPP, and consider physical and social assets along with practical aspects in narrowing down the list to a manageable number of communities with the four-state region. A long list will be shortened through surveying community-based stakeholders in the PNW and intermountain region to strategically choose several NCs for studying the viability of a biofuel-based infrastructure. Once communities are identified, focus group meetings involving a wide variety of stakeholders will be held at each community to discuss feedstock specifications and logistics, technology adoptions within the existing infrastructure, and viable strategies practical and beneficial for the communities. This process will involve industrial stakeholders and NARA

industry partners as well. Establishing a meaningful dialogue on what local experts perceive to be the barriers and opportunities for establishing a biorefinery infrastructure in their community is critical. Building supply chain logistics consists of four major tasks.

a. Define stakeholders and articulate stakeholder communication mechanism.
b. Define and establish NARA pilot supply chain (PSC) study regions to engage stakeholders in compiling supply chain assets, analyzing potential regional supply chain structure, and forming regional alliances.
c. Stakeholder development in the four-state region and pilot supply chain study regions.
d. Assist EPP with PSC selection process and support index study to develop a decision support tool.

## Activities and Results

Leavengood's primary role with respect to this project has been to serve as the key outreach liaison for Oregon. In that regard, Leavengood has focused efforts on identifying the key stakeholders in Oregon, keeping them and others informed of the activities of the project, and working to ensure stakeholders are able to engage and participate. These efforts have included giving presentations to the Oregon Forest Biomass Working Group, organizing meetings between members of the working group and NARA team members, developing newsletter articles and web pages, and serving as host for Michael Wolcott to give a lecture on the project as part of OSU's Starker Lecture Series.

The efforts have also included providing other NARA teams with information to assist in their efforts, e.g., coordinating completion of the 'stakeholder assessments' for the EPP team.

One sign of results is that Oregon agency personnel (e.g., Matt Krumenauer with the Oregon Department of Energy and Marcus Kauffman with the Oregon Department of Forestry) with responsibilities related to forest biomass utilization have organized conference calls and meetings about the NARA project independently of my efforts or of the efforts of other NARA team members. Sue Safford with Oregon BEST (Oregon built and environmentally sustainable technologies) also asked for information about technology commercialization opportunities from the project that might come about for the state. If nothing else, this shows that outreach efforts are having their desired effect of ensuring that key stakeholders in Oregon are engaged and committed to the project's success.

## Recommendations/Conclusions

The results mentioned in the paragraph above and participation in meetings indicate that the outreach efforts are having some level of success, at least with regards to the task 2 - *Building Supply Chain Coalitions*. However, as mentioned in previous quarterly reports, stakeholders have asked for more of the details about the research efforts connected with this project, i.e., tasks related to task 1 - *Bioenergy Literacy*. Therefore, future efforts will focus on keeping stakeholders informed about progress with respect to efforts of the research teams – forest residues preparation, transportation, pretreatment, enzymatic hydrolysis, fermentation, and co-products as well as information related to life cycle assessment. Assisting with the organization of a NARA conference will be one task to achieve this goal as will working with other outreach team members to develop educational materials that can be distributed via webinars, newsletter articles, and the website.

## Physical and Intellectual Outputs

### Physical

- 15 ‘Community Surveys’ were created for specific Oregon communities related to key assets in these communities relevant for NARA; these surveys were developed to help define and establish NARA pilot supply chain (PSC) study regions
- 2 ‘Stakeholder assessments’ spreadsheets were developed - 1 for southwest and 1 for northwest Oregon; these contained contact information for key personnel in Oregon to assist the EPP team with PSC selection process.

### Other Publications

Oregon Wood Innovation Center (OWIC) Spring 2012 newsletter – article on NARA

OWIC website – page dedicated to disseminating information about the project - http://owic.oregonstate.edu/NARA

### Videos and Webinars

Wolcott, M. 2013. Wood to Wing: Envisioning and Aviation Biofuels Industry Based on Forest Residuals in the Pacific Northwest (archived video of presentation). Starker Lecture Series, Oregon State University. April 11. (I served as organizer and host for the lecture)

### Trainings, Education and Outreach Materials

Wolcott, M. 2013. Wood to Wing: Envisioning and Aviation Biofuels Industry Based on Forest Residuals in the Pacific Northwest. Starker Lecture Series, Oregon State University. April 11. (I served as organizer and host for the lecture)

Leavengood, S. 2013. Meeting of key Oregon agency personnel with interest in NARA Pilot Supply Chains. March 20. I served as organizer of an initial Pilot Supply Chain meeting of key personnel in the Oregon Forest Biomass Working Group.

Leavengood, S. 2012. Meeting of key Oregon agency personnel with interest in NARA project. October 22. I served as organizer and moderator of the meeting that included personnel from the Governor’s office (Oregon Governor’s Energy Policy Advisor), Business Oregon (economic development agency), Oregon Department of Forestry, Oregon Department of Energy, Oregon Department of Environmental Quality, Oregon BEST (Built Environment and Sustainable Technologies, a state-funded research center), Sustainable Northwest (eNGO), US Forest Service, Oregon Forest Resources Institute, US Bureau of Land Management, Oregon State University and Washington State University (Mike Wolcott in addition to Jim Funck with the Advanced Hardwoods Biofuel Network).

Leavengood, S. 2012. The Northwest Advanced Renewables Alliance (NARA): Recap of outreach team meeting in Missoula, MT. Informal presentation to the Oregon Forest Biomass Working Group. April 2.

Leavengood, S. 2011. The Northwest Advanced Renewables Alliance (NARA): An Introduction. Presentation to the Oregon Forest Biomass Working Group. October 25.

## Task O-5: University of Idaho NARA Extension Initiative

| Key Personnel | Affiliation |
|---|---|
| Randy Brooks | University of Idaho |

### Task Description

NARA units, research, extension and industry members, will act as partners and facilitators with the ultimate goal of empowering the stakeholders to plan and implement the changes needed to build, develop, and sustain a biorefinery infrastructure. The goal of the outreach team is to promote stakeholder bioenergy literacy and build regional supply chain coalitions for development of a framework of biofuel and co-products production from woodybiomass. End outcomes of this goal are sustainable production of biojet fuel and co-products and rural economic development. Following are the objectives of the outreach team to reach this goal:

1. **Bioenergy Literacy,** where we: a) disseminate the research-based information (on technology and markets) to our industrial stakeholders and understand the technical challenges regarding implementation at industrial scale (industry-focus); b) relate the feedstock development and logistics information to our resource-based stakeholders (local communities, forest landowners, forest managers) and hear their concerns regarding the type of information that will assist them in keeping their costs low and marketable value high (resource-focus); and, engage the organizations and partnerships in connecting with public-interest groups and policymakers (public-focus). These activities will be carried out via a variety of communication mechanisms, including social media, newsletters, briefing papers, extension publications, workshops/seminars, conferences, field trips, and stakeholder meetings. Bioenergy literacy to professionals will be achieved through following tasks.
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    c. Catalog activity outcomes and benchmark reports and studies.

2. **Build Supply Chain Coalitions** (logistical support and stakeholder development and engagement), where we will form working groups with stakeholders at community and bioregion levels to involve them through collaboration across the supply chain: forestland owners and managers, environmental NGOs, businesses, regulatory facilitators, and community infrastructure working groups to interact with and inform policymakers at regional, state, and federal levels. These stakeholders will be internal and external focused around the NARA communities (NCs) selected in the four-state region. This process will rely on support from other teams, such as Education and EPP, and consider physical and social assets along with practical aspects in narrowing down the list to a manageable number of communities with the four-state region. A long list will be shortened through surveying community-based stakeholders in the PNW and intermountain region to strategically choose several NCs for studying the viability of a biofuel-based infrastructure. Once communities are identified, focus group meetings involving a wide variety of stakeholders will be held at each community to discuss feedstock specifications and logistics, technology adoptions within the existing infrastructure, and viable strategies practical

and beneficial for the communities. This process will involve industrial stakeholders and NARA industry partners as well. Establishing a meaningful dialogue on what local experts perceive to be the barriers and opportunities for establishing a biorefinery infrastructure in their community is critical. Building supply chain logistics consists of four major tasks.

a. Define stakeholders and articulate stakeholder communication mechanism.
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c. Stakeholder development in the four-state region and pilot supply chain study regions.
d. Assist EPP with PSC selection process and support index study to develop a decision support tool.

## Activities and Results

Since project inception, UI Extension Forestry has delivered over 20 presentations about the NARA project and woody biomass utilization to over 1,000 stakeholders across the state of Idaho. Postcards and a one page fact sheet were developed and handed out at the above mentioned meetings and to various stakeholders. Surveys were developed to assess attitudes, and knowledge obstacles to woody biomass utilization. Many stakeholders are familiar with the basic processes (Figure 1) and a majority of stakeholders feel like utilizing woody biomass has the advantage of being sustainable (Figure 2). Overwhelmingly, stakeholders feel that lack of financial support (capital) is the major obstacle (Figure 3). Most think that their communities would benefit through jobs, economic development, healthier forests, and being associated with sustainable practices (Figure 4), while most did not see any drawbacks to utilizing woody biomass for energy production (Figure 5). As a result of a meeting held in Orofino in the spring of 2012, Brooks has been part of a smaller group that was awarded funding to build a biomass boiler system built in Orofino. Town hall meetings are being planned in the Orofino community to inform stakeholders about the potential use of biomass for bioenergy associated with the grant.

Working with graduate student Jilian Moroney, we organized and held the Clearwater County 6th Grade Forestry Tour. The 3-day, 2-night tour focused on natural resources. We introduced the NARA Project, and Jillian then made 5 presentations to the youth about thinning and utilizing biomass for biofuels. As part of Moroney's thesis research project, the youth were given a pre-test in May, and then given a post-test (consisting of the same pre-test questions) at the end of the tour. The same post-test was given two months after the tour to assess long-term knowledge retention. A survey was also given to the youth to assess their knowledge of biomass and its utilization. Findings were presented at the national eXtension annual conference held in Oklahoma City, OK. These results have been summarized and will be submitted to the Journal of Extension. We attended the NARA Annual meeting in Missoula, MT and presented four posters about our work with the NARA grant over the past year. Moroney also attended the American Planning Association Idaho Chapter annual conference in Boise, Idaho and presented three posters on her work with NARA. Overall, we have made 8 poster presentations about the project.

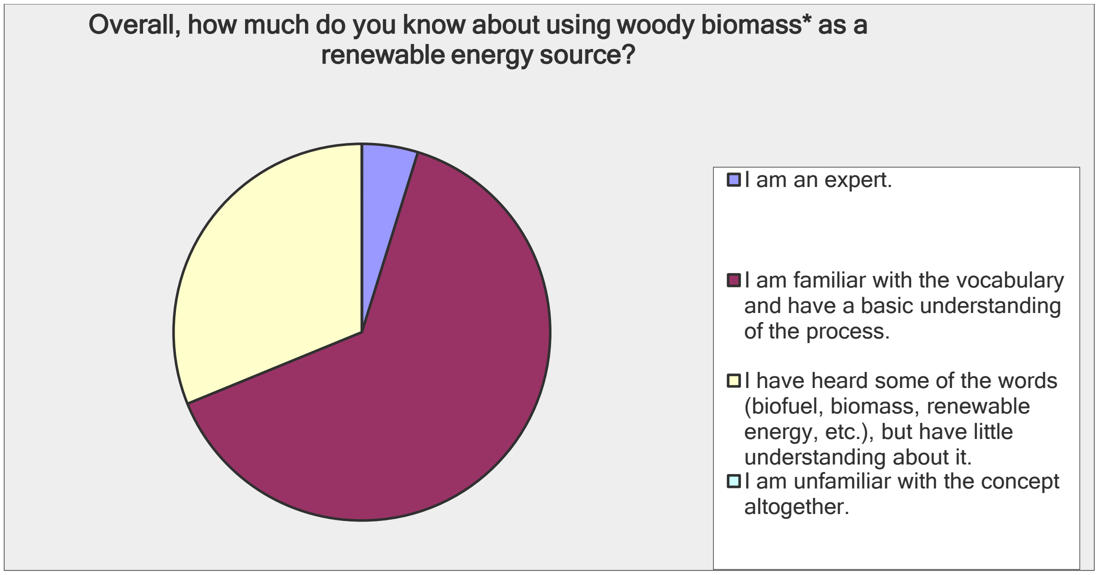


**Figure 1.** How much do stakeholders know about using woody biomass as a renewable energy source?

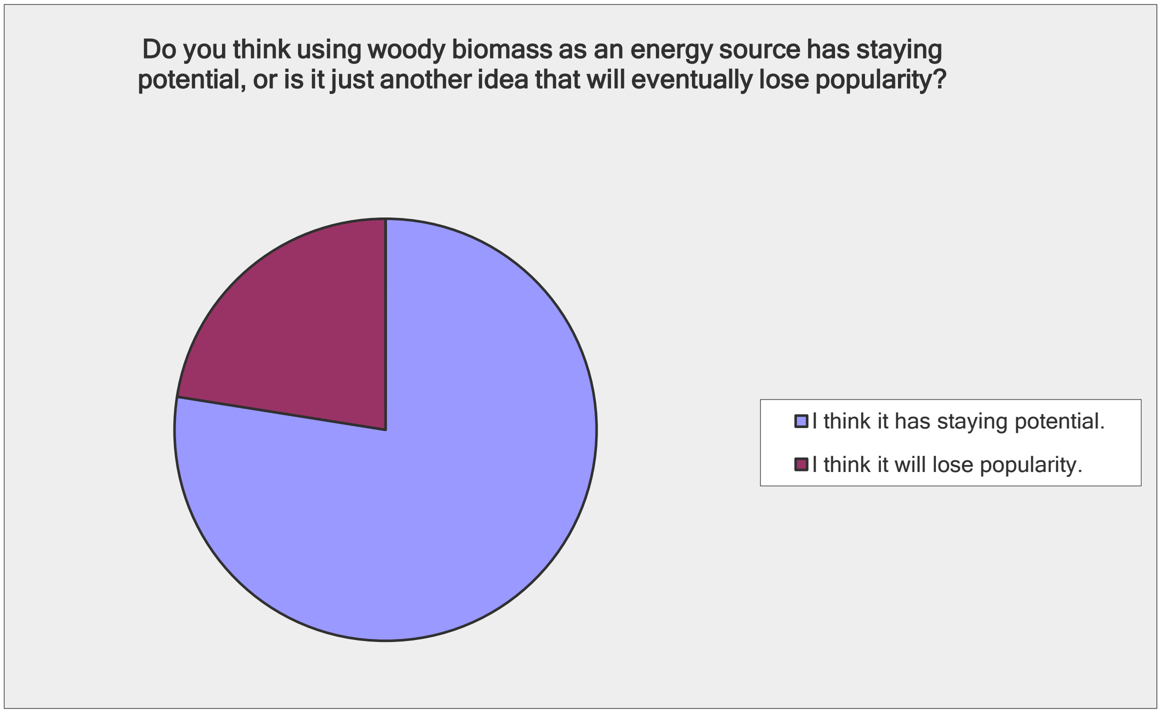


**Figure 2.** Does woody biomass have staying potential or will it lose popularity?

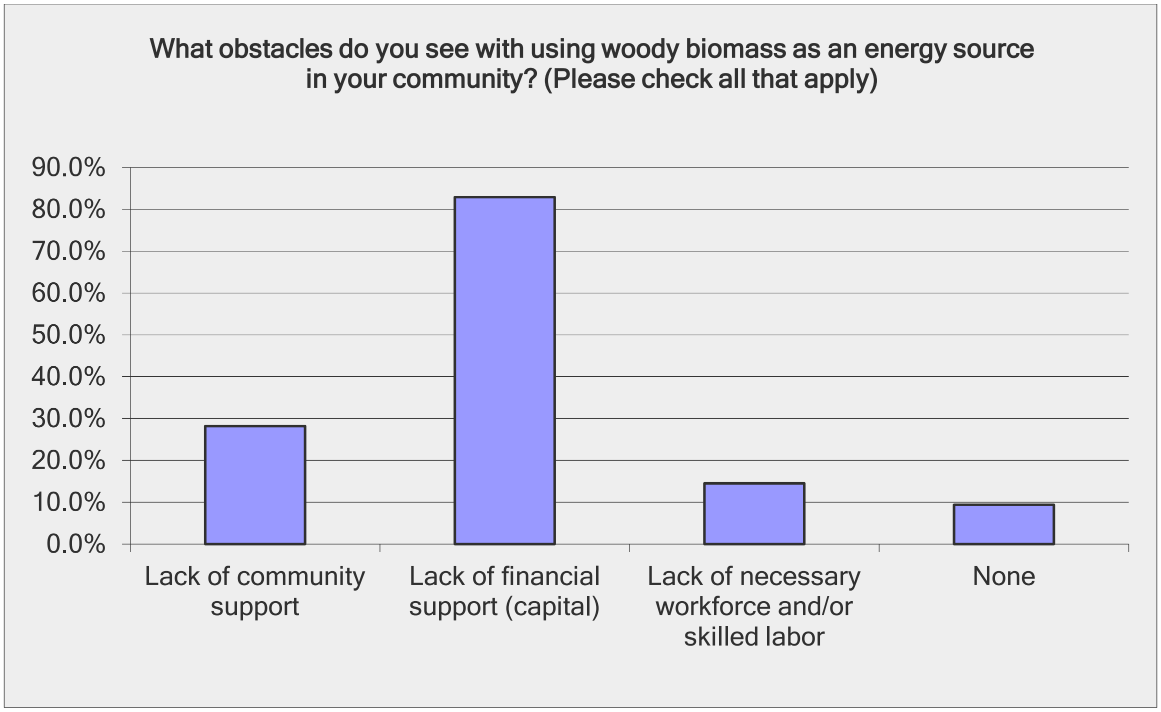


**Figure 3.** What are the obstacles to using woody biomass?

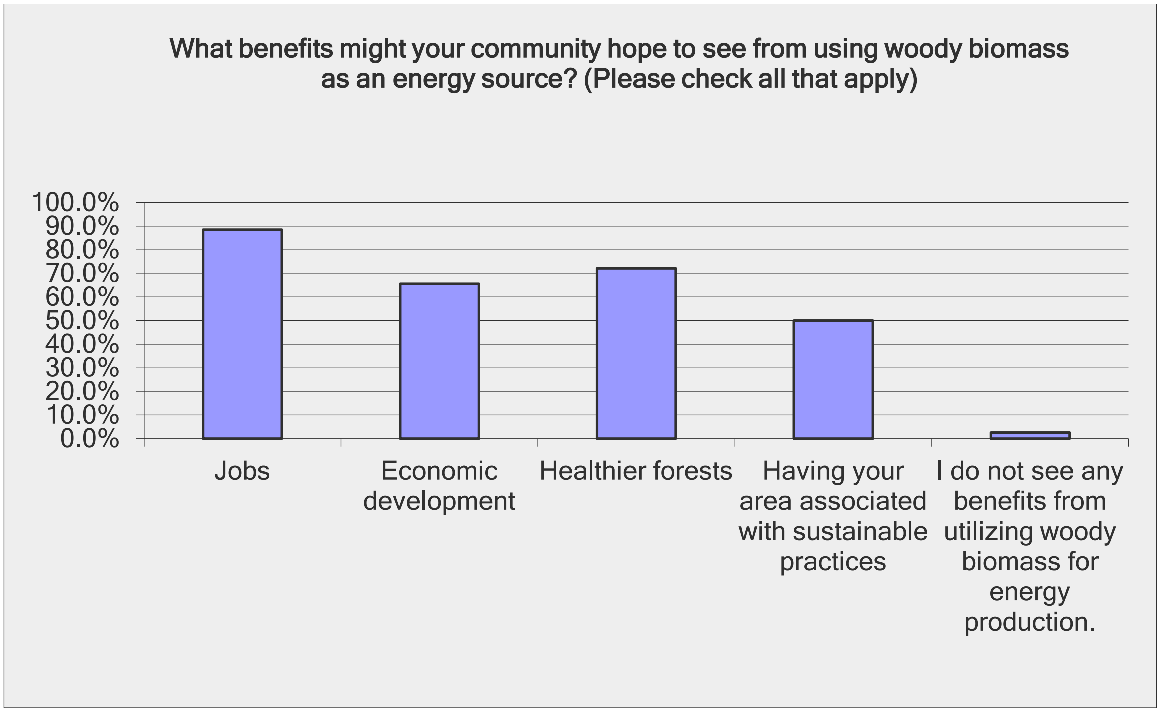


**Figure 4.** How would communities benefit from using woody biomass?

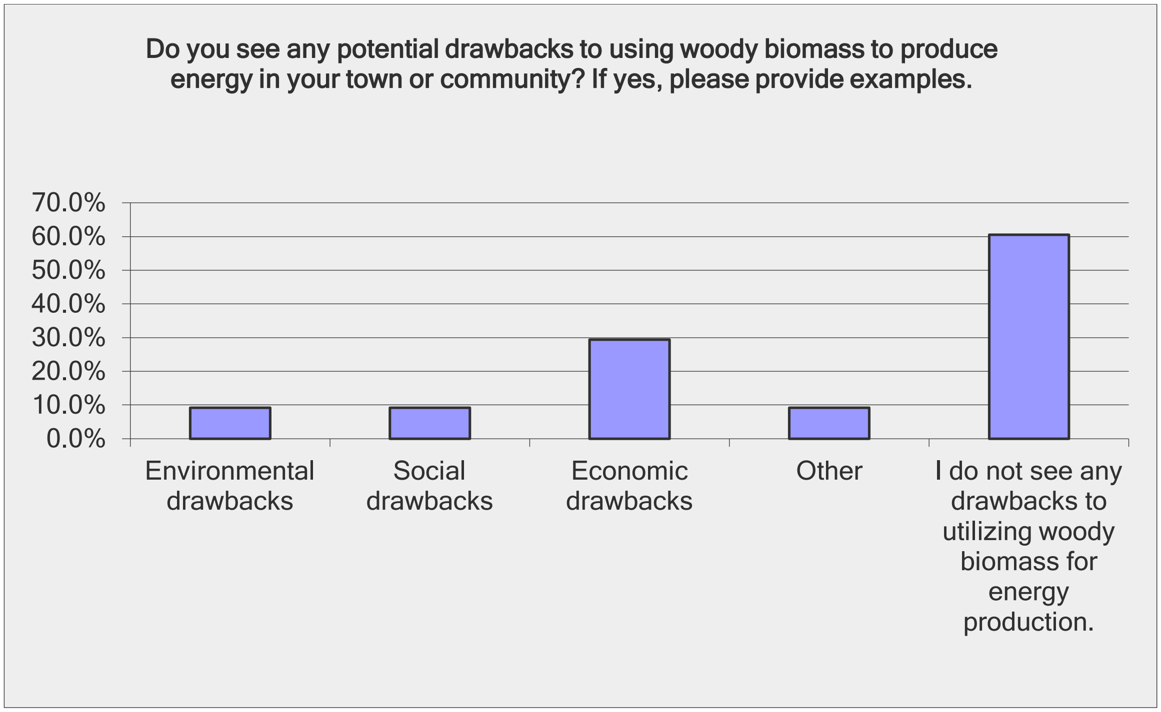


**Figure 5.** What are potential drawbacks to using woody biomass to produce energy?

## Recommendations/Conclusions

Over 400 loggers have been introduced to the NARA Project and introduced to options for biomass utilization. Logger Education post-workshop exit evaluations showed 62% of those surveyed indicated they could identify opportunities and challenges associated with forest biomass and residues, while 21% were not sure, and 17% indicated probably not. Suggestions for future training topics included biomass updates, energy & oil, what new products can be found in woody biomass, and expanding the markets.

Over 120 youth have been introduced the woody biomass and the concept of making biofuel from woody biomass. A portion of these youth were given pre-test, post-test, and a 2nd post-test two months after the workshops (to assess long-term knowledge retention).

Survey results are still being evaluated, but early indicators show that relatively few stakeholders in Idaho are using electronic means to receive communications. Therefore, efforts to educate stakeholders in Idaho need to utilize every opportunity to attend face-to-face meeting to inform them about the project.

## Physical and Intellectual Outputs

### Physical

- Survey Monkey Stakeholder Survey was developed in March, 2012 and given to community leaders.
- Survey Monkey Stakeholder Survey was developed in February, 2013 and given to 6 groups (loggers, students, teachers, mill/industry foresters, landowners, extension stakeholders)

### Refereed Publications (accepted or completed)

Brooks, R. and J. Moroney. 2013. Forestry Tour Educates Youth in North Central Idaho. Journal of Extension. Accepted, in review.

### Conference Proceedings and Abstracts from Professional Meetings

Brooks, R., and J. Moroney. 2012. Clearwater Basin Bioenergy Survey. Poster presented to Northwest Bioenergy Research Symposium. Seattle, WA. Nov. 12-14, 2012.

### Research Presentations

Brooks, R., J. Moroney, R. Keefe, and T. Laninga. 2013. Biomass Survey Assessment of Idaho Forestry Extension Stakeholders. Poster presented at The International Wood Composite Symposium. Seattle, WA. April 2-4, 2013.

Brooks, R., J. Moroney, and T. Laninga. 2012. Clearwater Basin Bioenergy Survey. Poster presented at Northwest Bioenergy Research Symposium and Future Energy Conference, Seattle, WA. Nov. 13-14, 2012

Moroney, J. 2012. Clearwater County Idaho Sixth Grade Forestry Tour Assessment: Tracking the Change in Students' Knowledge and Attitudes. Research presented at the National eXtension Conference, Oklahoma City, OK. Oct. 3, 2012.

Moroney, J, T. Laninga, and R. Brooks. 2012. Clearwater Basin Bioenergy Survey. Poster presented at Idaho Chapter of the American Planning Association Annual Conference, Boise, ID. Oct. 10-12, 2012

Brooks, R. 2012. Forestry Tour Educates Youth and Teachers. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Moroney, J.M., R. Brooks, and T. Laninga. 2012. Clearwater County Forestry Tour: A Knowledge Assessment. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Brooks, R. and J. Moroney. 2012. Clearwater Basin Bioenergy Survey: A brief assessment of regional norms and values that could have an impact on community responses to the development of woody biomass as an energy source in the Clearwater Basin. Poster presented at The International Wood Composite Symposium. Seattle, WA, April 11-13, 2012.

## Other Publications

Maroney, J.M. and R.H. Brooks. Biomass 101 for Idaho Forest Landowners. 2012. University of Idaho. In preparation.

Brooks, R. 2012. From Wood to Wing: Biofuels and the NARA Opportunity. Idaho Gem State Producer. Vol. 15:8. Pg. 25-27. Dec. 2012.

## Trainings, Education and Outreach Materials

Brooks, R. 2013. A NARA Project Update and Review. Presented at LEAP Update sessions in 5 locations across north Idaho. 290 participants. Dates: March 3 through March 29, 2013.

Brooks, R. 2013. How Tree Biology can fit in the NARA Project. Presented to Asotin County, Washington, Advanced Master Gardeners. 43 participants. March 12, 2013.

Brooks, R. 2013. Forestry and Biofuels. Presented to UI Extension “Keeping the Legacy Alive”. 15 participants. Lewiston, ID. March 13, 2013.

Brooks, R. The NARA Project: An Overview. Talk given to UI CNR Dean’s Annual Stakeholder Mtg., Moscow, ID. 9/22/12

Brooks, R. Utilizing forest biomass to make biofuels. 3 Presentations to UI Ag Resource Policy class. Camp Wittman, ID. 9/19/12

Brooks, R. Biomass opportunities associated with thinning for forest insects and diseases. UI Extension Forest Insects & Disease Field Day, Moscow, ID. 7/27/12

Brooks, R. How biomass and biofuels fits in with a thinning regime. UI Extension Forestry Thinning & Pruning Field Day, Cottonwood, ID.7/20/12

Moroney. J.  From Biomass to Biofuels: Clearwater County (ID) 6th Grade Forestry Tour. Headquarters, ID. 7/12/12

Brooks, R. and J. Moroney. Woody Biomass and the NARA Project Overview: Presented Natural Resources Youth Camp north of Sun Valley, ID at the Central Idaho 4-H Camp. **2 lectures** and **5 labs** where presented on biomass, biomass utilizations, and biofuels. Over 70 youth and 14 adults were present. June 25-29, 2012.

Moroney, J. Bioregional Planning and Community Design studio project presentations (2). These projects consisted of looking at the community attitudes towards woody biomass and the feasibility of this industry taking root in North Central Idaho. Approximately 15 stake holder and community participants. (Jillian Moroney) Mar/May, 2012.

Brooks, R. A woody biomass overview: presented at LEAP Update sessions in Council, Idaho, and at LEAP sessions in Moscow and Coeur d'Alene, Idaho. 90 participants. May, 2012.

Brooks, R. The NARA Project in Idaho: A project overview presented to the Idaho Association of Logging Contractors. 43 participants. April, 2012.

Brooks, R.  2012.  A woody biomass overview: presented at LEAP Update sessions in 5 locations across northern Idaho. 300 participants.  March, 2012.

Brooks, R.  2012.  Keeping the Forest Legacy Alive. Presented to family forest owners Craigmont, ID and Moscow, ID. 40 participants.  Feb. 24, 2012.

Brooks, R.  2012.  Biomass: Options & Opportunities: Presented to the Selkirk Chapter Society of American Forests quarterly meeting. 34 participants.  Feb. 16, 2012.

Brooks, R.  2012.  NARA Project Overview: Presented to north central Idaho Pesticide Applicators training meeting, Nezperce, ID. 21 participants.  Jan. 24, 2012.

## Thesis and Dissertations

Moroney, J. 2012. Clearwater County Sixth Grade Forestry Tour Program Evaluation: Determining Participants' Knowledge Gain and Behavioral Change. University of Idaho, Master's Thesis. 2012.

# Task O-6: Forest Service-Pacific NW Research Station

| **Key Personnel** | **Affiliation** |
|---|---|
| Eini Lowell | USDA FS PNWRS |

## Task Description

NARA units, research, extension and industry members, will act as partners and facilitators with the ultimate goal of empowering the stakeholders to plan and implement the changes needed to build, develop, and sustain a biorefinery infrastructure. The goal of the outreach team is to promote stakeholder bioenergy literacy and build regional supply chain coalitions for development of a framework of biofuel and co-products production from woody biomass. End outcomes of this goal are sustainable production of biojet fuel and co-products and rural economic development. Following are the objectives of the outreach team to reach this goal:

1. **Bioenergy Literacy,** where we: a) disseminate the research-based information (on technology and markets) to our industrial stakeholders and understand the technical challenges regarding implementation at industrial scale (industry-focus); b) relate the feedstock development and logistics information to our resource-based stakeholders (local communities, forest landowners, forest managers) and hear their concerns regarding the type of information that will assist them in keeping their costs low and marketable value high (resource-focus); and, engage the organizations and partnerships in connecting with public-interest groups and policymakers (public-focus). These activities will be carried out via a variety of communication mechanisms, including social media, newsletters, briefing papers, extension publications, workshops/seminars, conferences, field trips, and stakeholder meetings. Bioenergy literacy to professionals will be achieved through following tasks.
    a. Develop a bioenergy literacy platform for flow of information and knowledge between NARA research teams and the stakeholders.
    b. Implement targeted outreach activities for engaging stakeholders and advancing bioenergy literacy to professionals.

2. **Build Supply Chain Coalitions** (logistical support and stakeholder development and engagement), where we will form working groups with stakeholders at community and bioregion levels to involve them through collaboration across the supply chain: forestland owners and managers, environmental NGOs, businesses, regulatory facilitators, and community infrastructure working groups to interact with and inform policymakers at regional, state, and federal levels. These stakeholders will be internal and external focused around the NARA communities (NCs) selected in the four-state region. This process will rely on support from other teams, such as Education and EPP, and consider physical and social assets along with practical aspects in narrowing down the list to a manageable number of communities with the four-state region. A long list will be shortened through surveying community-based stakeholders in the PNW and intermountain region to strategically choose several NCs for studying the viability of a biofuel-based infrastructure. Once communities are identified, focus group meetings involving a wide variety of stakeholders will be held at each community to discuss feedstock specifications and logistics, technology adoptions within the existing infrastructure, and viable strategies practical and beneficial for the communities. This process will involve industrial stakeholders and NARA industry partners as well. Establishing a meaningful dialogue on what local experts perceive to be

the barriers and opportunities for establishing a biorefinery infrastructure in their community is critical. Building supply chain logistics consists of four major tasks.

a. Define stakeholders and articulate stakeholder communication mechanism.
b. Define and establish NARA pilot supply chain (PSC) study regions to engage stakeholders in compiling supply chain assets, analyzing potential regional supply chain structure, and forming regional alliances.
c. Stakeholder development in the four-state region and pilot supply chain study regions.
d. Assist EPP with PSC selection process and support index study to develop a decision support tool.

## Activities and Results

Lowell has worked within the PNW Research Station to prepare materials that inform key stakeholders, leadership, and the public about NARA. These include press releases as appropriate and congressional briefing papers for the Research Station's annual visit to Washington, DC. He continues to work with other NARA Outreach members to prepare one page updates on NARA progress that are posted on the website and distributed through other channels such as printed materials at meetings. Lowell has also advised students of the opportunities associated with Summer Undergraduate Research Experience (NARA-SURE).

The first Pilot Supply Chain (PSC) coalition has been identified in the Northern Rocky Mountain Ecoregion. Lowell actively participated in the stakeholder meetings, conference calls, and site visits. The Outreach team is now working to identify the second PSC. It was decided that western Oregon/Washington would be a likely candidate. So he has worked to identify key stakeholders from this area to invite to preliminary meetings. A concerted effort was made to engage the US Forest Service in these discussions. The initial meetings were held in March 2013; one in OR and the other in WA. A joint meeting with additional stakeholders was held in Vancouver, WA in April 2013. Identification of a different set of NARA stakeholders and clients is of relevance to several other NARA teams. Lowell have provided input to activities of other NARA teams such as The Environmentally Preferred Product group which is conducting informed Stakeholder (SH) Assessment interviews.

Lowell has also been actively leveraging NARA efforts through involvement with his research at the PNW Station. The Collaborative Forest Landscape Restoration Program (CFLRP) within the USDA Forest Service provides an opportunity to address both biomass availability issues and rural economic development. There are several projects in the Northwest that would be possible foundations for, or additions to, pilot supply chain coalitions. These projects also provide an existing partnership framework of stakeholders and clients. Another project overlaps some of NARA's goals and includes development of a Community Biomass Handbook. This is a multimedia electronic library to help community partners rapidly explore and initially evaluate a variety of bioenergy and other product options without having to invest significant time, resources, or pursue costly feasibility studies. It may enable communities to determine where they could potentially find a fit in the NARA PSC. A Research Joint Venture Agreement was entered into with David Smith (Oregon State University Wood Innovation Center) to conduct case studies describing pro forma business plans for Coos Bay, OR. The research team engages students, industry experts, OSU Extension, and community business leaders fostering bioenergy literacy. An interactive model will be developed that will allow potential investors to examine various facility capacities and product mixes to determine the optimum configuration and capabilities for a particular biomass processing center.

## Recommendations/Conclusions

Work in identifying Pilot Supply Chain coalitions is progressing and generating interest among stakeholders and clients. Forest Service personnel working in rural communities and at the wildland-urban interface are especially following NARA progress. I will continue to engage these personnel and work to integrate existing partnerships into NARA's stakeholder and client groups. I have an active role in planning and conducting workshops and work will begin on organizing the first NARA conference. The PNW Research Station will publish a proceedings from this conference. Preparation of other materials, including one page information sheets documenting progress of other NARA teams, will continue.

## Physical and Intellectual Outputs

### Physical

Preparation of one page information sheets on:

- NARA and Advance Hardwood Biofuels Northwest – a one page document was developed to illustrate the differences between the 2 projects and alleviate confusion among the public
- NARA Supply Chain
- NARA Feedstocks

Pilot Supply Chain Coalition Meetings:

- Missoula, MT (2012: March 20-22, June 12-14, Sept. 9-14)
- Salem, OR (March 20, 2013)
- Chehalis, WA (March 26, 2013)
- Vancouver, WA (April 12, 2013)

### Research Presentations

Lowell, Eini C. 2012. Video conference presentation to the Chief of the U.S. Forest Service that included describing the overall objectives and providing information on the NARA project as well as my role on the Outreach Team. "Conversation with the Chief" - June 28, 2012

Lowell, Eini C. 2012. "Bioeconomy Opportunity Zones or how do we get there from here?" An oral presentation made to the PNW Research Station Management Team, July 16, 2012.

Lowell, E.C. 2013. "The Northwest Advanced Renewables Alliance A Supply Chain to Aviation Biofuels and Environmentally Preferred Products." An oral presentation to Willamette National Forest Leadership and community leaders. Springfield, OR (1/25/2013) (will be available on-line shortly)

## Other Publications

Sands, Yasmeen. 2011. Woody biomass research grant to launch biofuel industry in the Pacific Northwest. Press release issued from Pacific Northwest Research Station/USDA Forest Service. September 28, 2011.

Petersen, L. RENEWABLE ENERGY: USDA looks to jump-start wood-to-fuel conversion in Pacific Northwest. Land Letter. E&E Publishing, LLC. Wash., D.C. October 6, 2011 (Quoted in)

PNW Research Station, Communications and Applications. A briefing paper was prepared for the PNW Research Station Director visit to Capitol Hill. April 8-12, 2013.

## Trainings, Education and Outreach Materials

Attendence at the International Wood Composites Symposium to network with other NARA members learning the of potential new technologies that could be incorporated into the pilot supply chain coalitions.

## Task O-7: William D. Ruckelshaus Center

| Key Personnel | Affiliation |
|---|---|
| Michael Kern | Ruckelshaus Center |
| Michael Gaffney | Ruckelshaus Center /DGSS |

### Task Description

The Ruckelshaus Center senior staff members will: 1). work with the Leadership Team to assist in the creation of a "Stakeholder Advisory Board,"; 2). facilitate monthly Leadership Team meetings, quarterly Advisory Board meetings, and an annual stakeholder meeting. Additionally the Center will assist in development of process protocol agreements and help engage policy makers through distribution of quarterly web-based newsletters and briefing papers from information provided by the Project Directors and Leadership Team and 3). participate in an assessment of public perceptions to "connect social and technical aspects" of the project through quantitative surveys and focus groups.

### Supplemental Research Proposal

The Division of Governmental Studies and Services (DGSS) has been engaged on the NARA project since its inception – as a subcontractor to the William D. Ruckelshaus Center. The original set of deliverables for DGSS consisted solely of an assessment process to inform the development of the project Advisory Committee. In addition to completing that deliverable, DGSS has also over time participated in stakeholder (SH) Assessment and engagement efforts as a part of the Outreach team, and has begun active participation with the EPP team on physical-social asset assessment efforts. In order to secure additional effort from DGSS on the development and administration of SH Assessment interviews, and to facilitate the ground-truthing of large national database application to potential NARA communities through the use of existing DGSS community-level survey databases, DGSS requests additional funding through year four of the project. Specific deliverables from an additional $40,000 (annual basis) include:

1. Support access to DGSS's web-survey capacity ("Remark" software) to facilitate data entry from SH Assessment telephone interviews to be conducted by EPP team.
2. Substantial data aggregation, manipulation and analyses to render data from existing DGSS community surveys into a format useful for analysis to be used in conjunction with national data and SH Assessment interview results in a triangulated approach ("Ground-truthing") for NARA Region social asset assessment
3. Continued and expanded participation by elements of DGSS on the EPP team in support of team community stakeholder Assessment efforts
4. Support and participation in preparation and submission of reports, presentations, and publications

These efforts would be in addition to, and would complement, DGSS and Ruckelshaus participation in the Outreach team and contracted project management support activities.

## Activities and Results

*Task O-7.1.* All of the Ruckelshaus Center responsibilities under this task have been completed. Ruckelshaus/DGSS worked extensively with the Outreach Team, Team Leaders and the executive team to develop a structure for categorizing and engaging diverse stakeholders. The Ruckelshaus Center/DGSS completed an interview-based assessment of informed observers and senior stakeholders, to obtain input on the formation and management of an Advisory Board for the NARA project. A summary report of that effort was presented to the project's executive committee, with recommendations regarding the interests that should be considered when selecting potential board members, along with a list of individuals who had been suggested as potential members. This report was used to inform the executive committee's selection of Advisory Board members and in the management of interactions with that board. The inquiry also addressed the more general topic of stakeholder engagement, and recommendations on that topic were passed on to the executive committee and the Outreach team.

*Task* O-7.*2.* The Ruckelshaus Center has been actively engaged in facilitation and project management support – specifically supporting the project leadership with team facilitation, agenda development and establishment of ground rules and meeting protocols. Ruckelshaus senior staff facilitated the monthly leadership team meetings since the project kick-off in 2011. The monthly leadership team meetings have focused on a number of relevant topics, including the Phase & Gate process and various discussions related to the management of NARA teams and units.

The Center assisted in the development, planning, and facilitation of the September 2011 and 2012 NARA annual meetings in Spokane, Washington and Missoula, Montana. The Center facilitated a lunch discussion at the 2012 annual meeting between NARA stakeholders and Outreach team leaders.

The Center invited interested SAFN members to attend the presentation on NARA at the 2012 International Wood Composites Symposium followed by an informal discussion with Dr. Wolcott and Ruckelshaus Center over lunch. The Ruckelshaus Center focused its spring 2012 Ruckelshaus Center Advisory Board meeting in Spokane on aviation biofuels and featured the PIs of NARA and the UW-led project on hybrid poplars.

The Center, with the NARA leadership committee, communications team and outreach team, worked closely with the Advanced Hardwood Biofuels Northwest (AHB) project to prepare a series of quarterly briefing papers aimed at jointly informing policy-makers in Washington, Oregon, Idaho, Montana and Northern California about the projects' progress. The first briefing was sent in September 2012, the second in February 2013, and the third will be sent in April 2013.

*Task O-7.3.* The Ruckelshaus Center/DGSS has been working with the NARA Environmental Preferred Products team on the assessment of potential NARA communities and targeted engagement of stakeholders in those communities, using a variety of research and outreach methods. This effort is focused on the identification and refinement of several social asset tools to better focus on these NARA communities. Included in the process of NARA community assessment will be the use of numerous existing DGSS survey data sets to validate the use of national-level data sets in the selection process.

## Recommendations/Conclusions

- Continue to facilitate the monthly Leadership Team meetings, plan and facilitate the NARA annual meetings, and potentially help facilitate team or unit discussions if mutually agreeable
- Continue to produce joint quarterly policy-maker briefings with the UW AHB project.
- Continue to work with the EPP team on NARA community assessment protocols
- Continue participation on the Outreach Team regarding stakeholder engagement

## Physical and Intellectual Outputs

- The Center invited SAFN members to attend the presentation on NARA at the 2012 International Wood Composites Symposium followed by an informal lunch discussion with Dr. Wolcott and Ruckelshaus Center.
- The Ruckelshaus Center focused its spring 2012 Ruckelshaus Center Advisory Board meeting in Spokane on aviation biofuels and featured the PIs of NARA and the UW-led project on hybrid poplars.
- The Center, with the NARA leadership committee, communications team and outreach team, worked closely with the Advanced Hardwood Biofuels Northwest (AHBN) project to prepare a series of quarterly briefing papers aimed at jointly informing 1,500+ policy-makers in Washington, Oregon, Idaho, Montana and Northern California about the projects' progress.

### Research Presentations

Kern, M. and M. Gaffney. 2012. *Engaging Policy Makers & Advisory Board Assessment.* Presentation at 2012 NARA Annual Meeting, Missoula, MT, September 13-14.

Wolcott, M. 2012. *Northwest Advanced Renewables Alliance: A New Vista for Green Fuels, Chemicals and Environmentally Preferred Products.* Presentation at The William D. Ruckelshaus Center Advisory Board Meeting, Spokane, WA, April.

Kern, M. 2011. *The William D. Ruckelshaus Center: Fostering Collaborative Public Policy.* Presentation at WSU Extension and CAHNRS all Faculty Conference, Pullman, WA, October.

### Other Publications

Kern, Michael. "Creating a 'Flight Path' for Aviation Biofuels. Ruckelshaus Center eNews Fall 2011 Nov. 2011 http://ruckelshauscenter.wsu.edu/eNewsFall2011Edition.html

# Task O-8: GreenWood Long-Term Strategic Feedstock Production Analysis and Outreach Initiative

| **Key Personnel** | **Affiliation** |
|---|---|
| Brian Stanton | GreenWood Resources, Inc. |
| Jake Eaton** | GreenWood Resources, Inc. |

## Task Description

GreenWood Resources was originally tasked with developing a strategic business plan using poplar feedstock from dedicated plantation and agro-forestry systems throughout the Pacific Northwest to supplement the broader NARA supply of logging residues. GreenWood was directed to develop a new project and statement of work in September, 2012 focused on softwood resource management. The objective was an integrated plan of blending the supply of forest residuals and purpose-grown, the latter serving as a strategic biomass reserve for bioenergy facilities.

The biomass reserve incorporated three components:

1. Energy feedstock intercropping with higher-value poplar stands managed for veneer and saw logs
2. Intercropping poplar energy feedstock with conventional agricultural crops;
3. Dedicated energy tree farm systems on marginal agricultural land

GreenWood's NARA project was designed to complement its AFRI subcontract to the University of Washington's, "*Advanced Hardwoods Biofuels Northwest"* in that its poplar focus was as a supplemental feedstock source that would be integrated with the primary feedstock supply from logging and thinning operations conducted in softwood stands (The sole focus of the *Advanced Hardwoods Biofuels Northwest* project is poplar as a standalone dedicated feedstock operation). The premise is that cyclicality in the construction market and its effect on saw log demand will introduce long-term volatility in the volume and pricing of forest residuals and thinnings. Accordingly, sole reliance on logging residuals and thinnings for NARA refineries will be attended by too much risk. Thus, GreenWood's approach was to assess the potential value of a second approach that combines residuals with a strategic component of plantations grown specifically for energy markets (i.e. purpose-grown trees or the reserve). GreenWood's premise is that feedstock supply portfolios that include purpose-grown energy plantations as an indispensable addition to forest residuals will better position NARA bio-refineries to secure their requisite financing.

Key project goals and deliverables were as follows:

1. **Strategic Planning** – We prepared a report identifying regional opportunities where poplar biomass makes economic sense as an adjunct to forest and agricultural residues either as dedicated energy tree farms or integrated agroforestry systems. We developed a business and

execution plan that considers multiple revenue sources including environmental credits. GreenWood was to have formulated a financing and investment plan to acquire investment from capital markets to build out Phase II full commercialization.

2. **Landowner and Community Development** – We worked with extension teams to develop an outreach program for farming and forestry communities that present poplar production opportunities. GreenWood is to work with the NARA extension initiative to identify key stakeholders and assist them in implementation of the plan.

## Activities and Results

GreenWood initiated its project during the reporting period for the NARA Western Montana Corridor. An assessment was begun for dedicated poplar plantations as a biomass resource that could be converted into simple sugars for Rivertop Renewables. Rivertop Renewables is a chemistry company based in Missoula, MT that manufactures biodegradable and non-toxic chemicals and bio-products derived from renewable plant sugars. GreenWood met with Rivertop Renewables and learned about a Midwestern facility and its willingness to consider a similar one for Missoula, if a sugar source were readily available. GreenWood proposed a concept to Rivertop Renewables with annual demand at 60 million pounds of sugar. GreenWood's project design was to supply one-third of this demand – 20 million pounds – on an annual basis. Yield projections, plantation design features, growing costs, and varietal selections required by the project were based upon GreenWood's 2009 poplar field trial conducted in collaboration with Flathead Valley Community College in Kalispell, Montana. Parameters are listed below under B.2. The project plan was also to include partnering with Hybrid Energy Group on poplar feedstock production. GreenWood met with Hybrid Energy Group. They have been working with the City of Missoula to acquire and develop potential wastewater land application sites adjacent to the City's municipal treatment facility utilizing poplar plantations. Approximately 5% of Missoula's wastewater effluent could be used to grow poplar plantations during an initial demonstration phase after which GreenWood would expand the program through the NARA Outreach program.

## Recommendations/Conclusions

GreenWood recommended a dedicated plantation to supply biomass to provide one-third of Rivertop Renewables' sugar demand. The essential parameters for management of a network of poplar plantations are detailed in the following table.

| Model Parameter | Definition and Units |
|---:|---|
| 3 | Biomass growth rate in bone dry tons-per-acre-per-year |
| 5 | Coppice rotation length in years |
| 15 | Per acre yield of biomass in bone dry tons at rotation |
| 6 | Per acre yield of sugar in bone dry tons |
| 12,000 | Per acre yield of sugar in dry pounds at rotation |
| 60,000,000 | Annual demand of sugar in pounds |
| 33 | Percentage of annual sugar demand to be supplied from poplar plantation managed in a combined strategy of refinery reserves and farmer based partnerships. |
| 19,800,000 | Annual demand of sugar to be met with poplar in pounds |
| 1,650 | Annual cut of poplar in acres |
| 8,250 | Total project size in acres |

## Physical and Intellectual Outputs

### Conference Proceedings and Abstracts from Professional Meetings

Summers, B. 2012. Managing Woody-Biomass Supply-chain. Abstract for International Wood Composite Symposium, Seattle, WA, April 11-13, 2012.

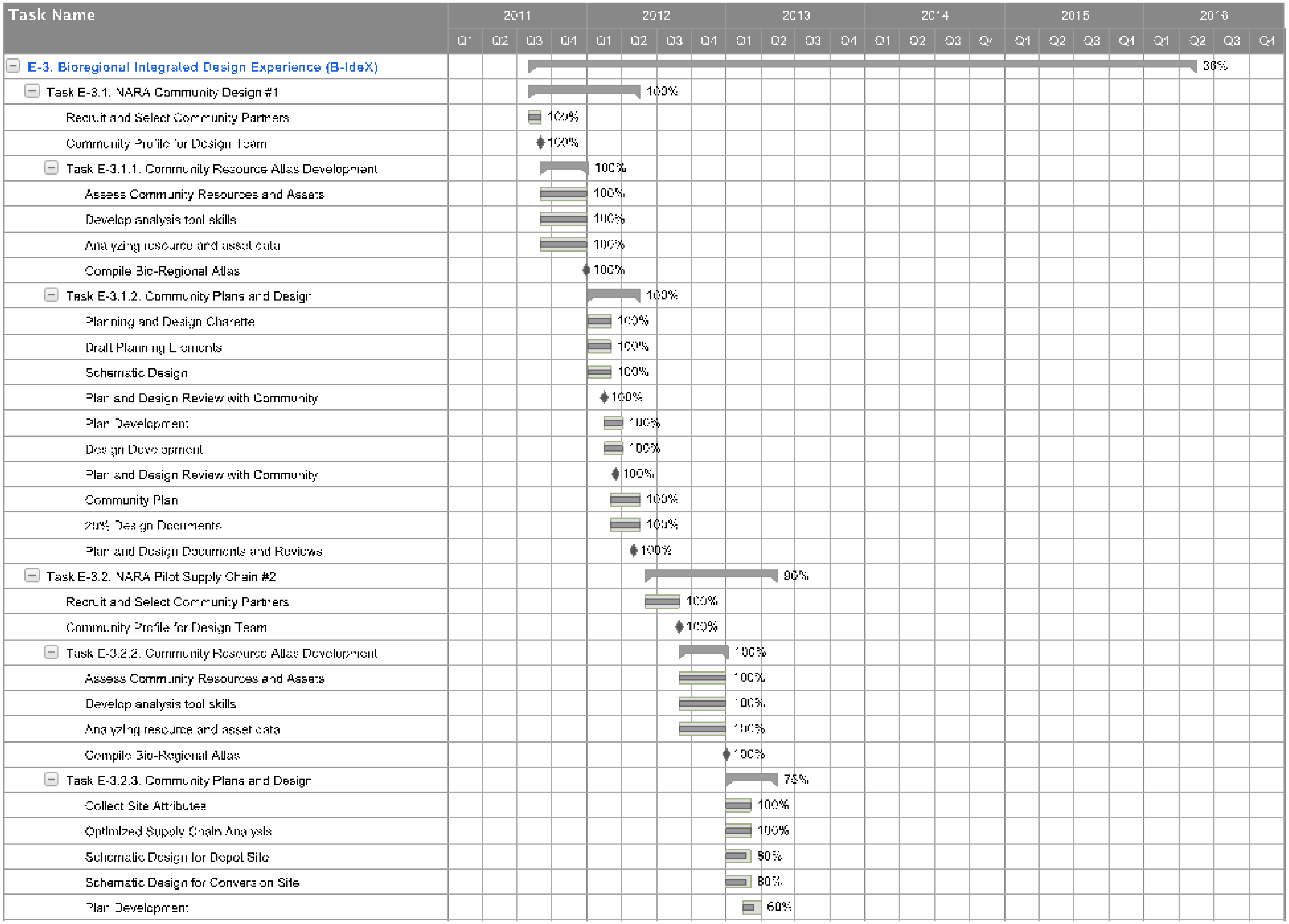
### Research Presentations

Summers, B. 2012. Managing Woody-Biomass Supply-chain. Presentation at International Wood Composite Symposium, Seattle, WA, April 11-13, 2012.

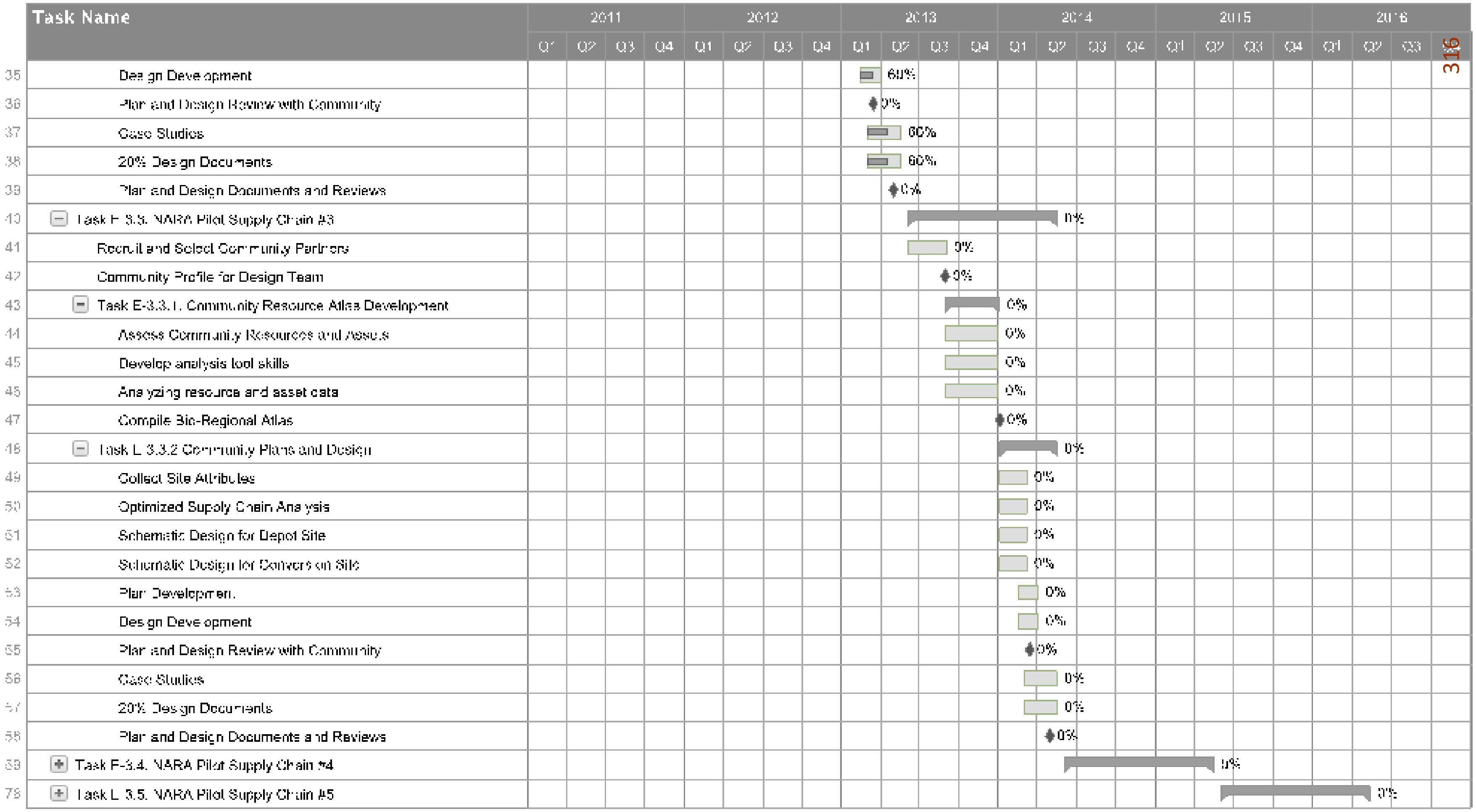
Smithhart, X., B. Stanton, and H. Brown. 2012. Strategic positioning of softwood plantations as a secondary feedstock resource for NARA bio-refineries. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

# Education_Wolcott_Laninga

NARA

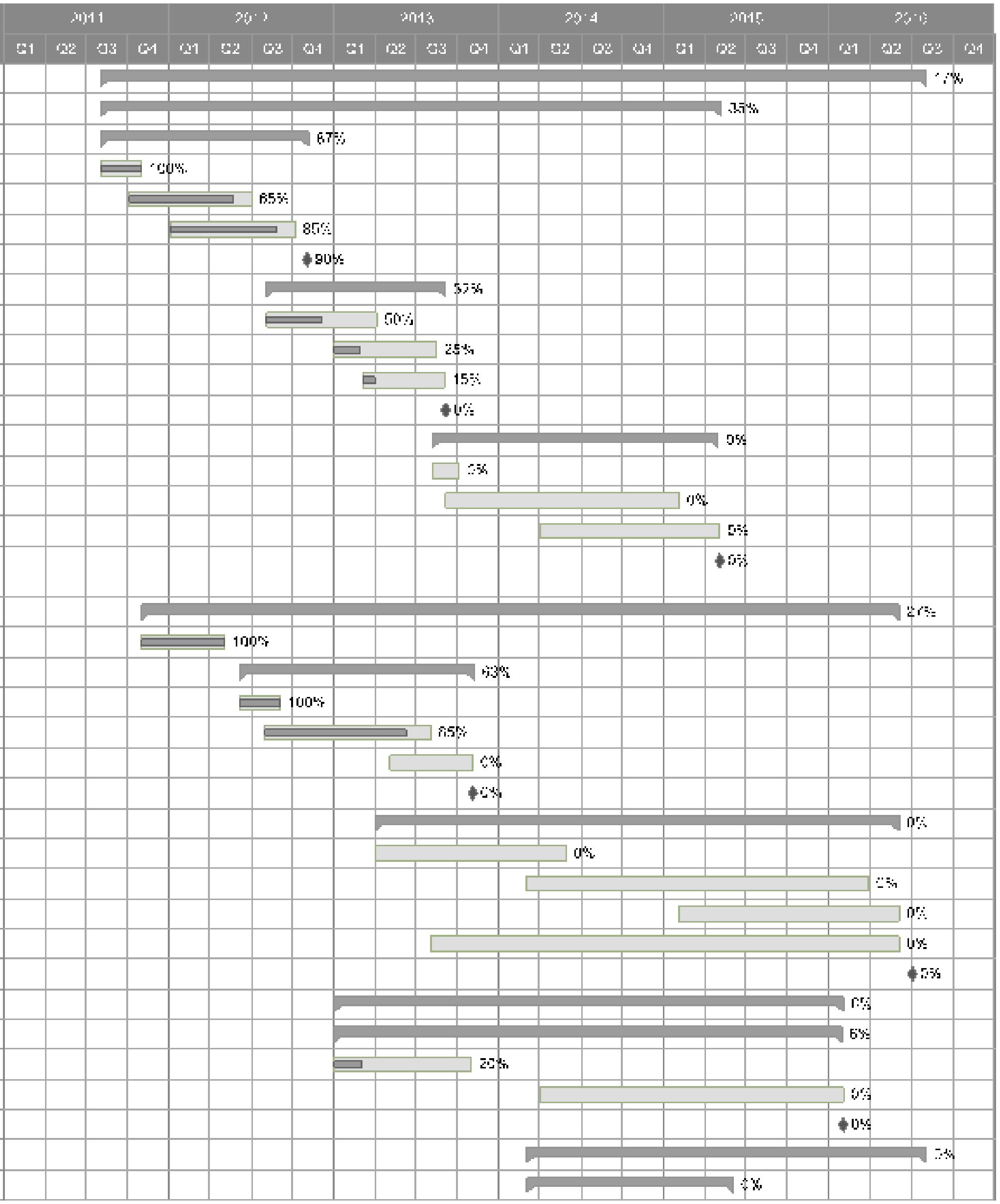


| | Task Name | |
|---|---|---|
| 1 | E-3. Bioregional Integrated Design Experience (B-IdeX) | 30% |
| 2 | Task E-3.1. NARA Community Design #1 | 100% |
| 3 | Recruit and Select Community Partners | 100% |
| 4 | Community Profile for Design Team | 100% |
| 5 | Task E-3.1.1. Community Resource Atlas Development | 100% |
| 6 | Assess Community Resources and Assets | 100% |
| 7 | Develop analysis tool skills | 100% |
| 8 | Analyzing resource and asset data | 100% |
| 9 | Compile Bio-Regional Atlas | 100% |
| 10 | Task E-3.1.2. Community Plans and Design | 100% |
| 11 | Planning and Design Charette | 100% |
| 12 | Draft Planning Elements | 100% |
| 13 | Schematic Design | 100% |
| 14 | Plan and Design Review with Community | 100% |
| 15 | Plan Development | 100% |
| 16 | Design Development | 100% |
| 17 | Plan and Design Review with Community | 100% |
| 18 | Community Plan | 100% |
| 19 | 20% Design Documents | 100% |
| 20 | Plan and Design Documents and Reviews | 100% |
| 21 | Task E-3.2. NARA Pilot Supply Chain #2 | 90% |
| 22 | Recruit and Select Community Partners | 100% |
| 23 | Community Profile for Design Team | 100% |
| 24 | Task E-3.2.2. Community Resource Atlas Development | 100% |
| 25 | Assess Community Resources and Assets | 100% |
| 26 | Develop analysis tool skills | 100% |
| 27 | Analyzing resource and asset data | 100% |
| 28 | Compile Bio-Regional Atlas | 100% |
| 29 | Task E-3.2.3. Community Plans and Design | 75% |
| 30 | Collect Site Attributes | 100% |
| 31 | Optimized Supply Chain Analysis | 100% |
| 32 | Schematic Design for Depot Site | 80% |
| 33 | Schematic Design for Conversion Site | 80% |
| 34 | Plan Development | 60% |


Task Name
2011
2012
2013
2014
2015
2016
Q1
Q2
Q3
Q4
35 Design Development 60%
36 Plan and Design Review with Community 0%
37 Case Studies 60%
38 20% Design Documents 60%
39 Plan and Design Documents and Reviews 0%
40 Task E-3.3. NARA Pilot Supply Chain #3 0%
41 Recruit and Select Community Partners 0%
42 Community Profile for Design Team 0%
43 Task E-3.3.1. Community Resource Atlas Development 0%
44 Assess Community Resources and Assets 0%
45 Develop analysis tool skills 0%
46 Analyzing resource and asset data 0%
47 Compile Bio-Regional Atlas 0%
48 Task E-3.3.2 Community Plans and Design 0%
49 Collect Site Attributes 0%
50 Optimized Supply Chain Analysis 0%
51 Schematic Design for Depot Site 0%
52 Schematic Design for Conversion Site 0%
53 Plan Development 0%
54 Design Development 0%
55 Plan and Design Review with Community 0%
56 Case Studies 0%
57 20% Design Documents 0%
58 Plan and Design Documents and Reviews 0%
59 Task E-3.4. NARA Pilot Supply Chain #4 0%
78 Task E-3.5. NARA Pilot Supply Chain #5 0%

# Education_Englund

|  | Task Name |
|---|---|
| 1 | E-7. Feedstock Supply Chain Analysis - MSW |
| 2 | Task E-7.1. Develop MSW/C&D woody biomass inventory in NARA region |
| 3 | Task E-7.1.1. Identify and collect existing MSW and C&D data - by states |
| 4 | Establish contacts for inventory info |
| 5 | Collect all existing inventory data |
| 6 | Normalize data to collate and compare |
| 7 | Create inventory of existing data |
| 8 | Task E-7.1.2. Establish model for woody biomass inventory in NARA regions |
| 9 | Identify potential models for inventory assessment |
| 10 | Identify model communities for wood inventory |
| 11 | Establish modeling procedure for NARA region |
| 12 | Inventory model completed |
| 13 | Task E-7.1.3. Validate model with surveys and on-site inventories |
| 14 | Identify applicable test sites for inventory |
| 15 | Collect data via on-site or compiled info |
| 16 | Validate model from data collection |
| 17 | Develop inventory of wood waste in MSW throughout NARA region based on existing data and model results |
| 18 | Task E-7.2. Inventory of NARA Communities (NC) |
| 19 | Work with Extension team to develop NC criteria |
| 20 | Task E-7.2.1. Develop extensive inventory for 1st NC |
| 21 | Identify geographical range |
| 22 | Identify all sources of MSW and C&D |
| 23 | Collect data and normalize for summation |
| 24 | Finalized data entered into GIS database |
| 25 | Task E-7.2.2. Inventory analysis of remaining NCs |
| 26 | Identify geographical range |
| 27 | Identify all sources of MSW and C&D |
| 28 | Collect data and normalize for summation |
| 29 | Finalized data entered into GIS database |
| 30 | Final inventory assessment of NCs |
| 31 | Task E-7.3. Identify recovery strategies of woody biomass from MSW and C&D streams |
| 32 | Task E-7.3.1. Identify removal, separation, and cleaning techniques and equipment |
| 33 | Overview of existing recovery strategies |
| 34 | Access performance and efficiencies of recovery methods |
| 35 | Final report on MSW and C & D wood recovery strategies |
| 36 | Task E-7.4. Establishing QC/product specifications for final biofuel use |
| 37 | Task E-7.4.1. Identify potential hurdles with contaminates |

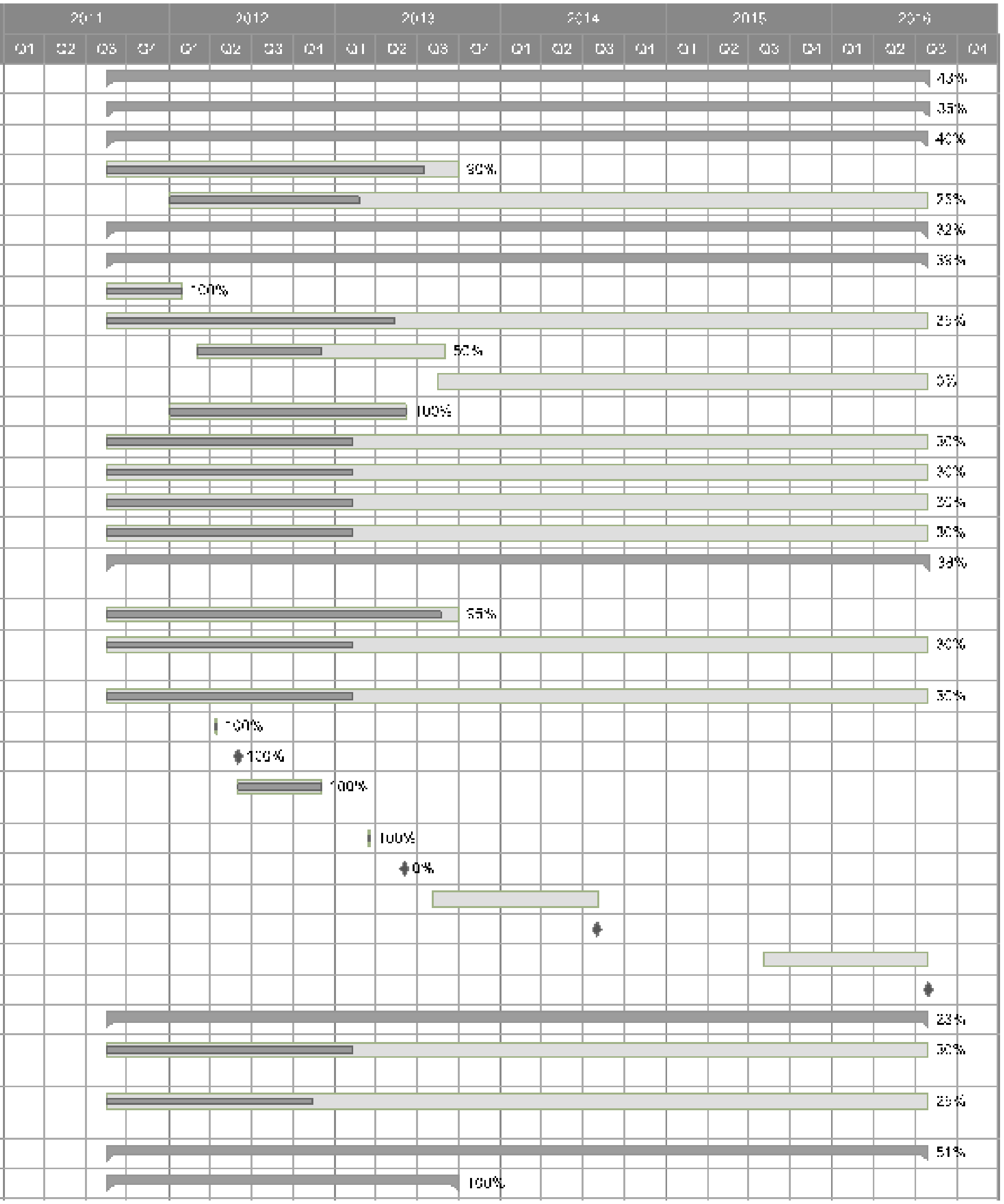


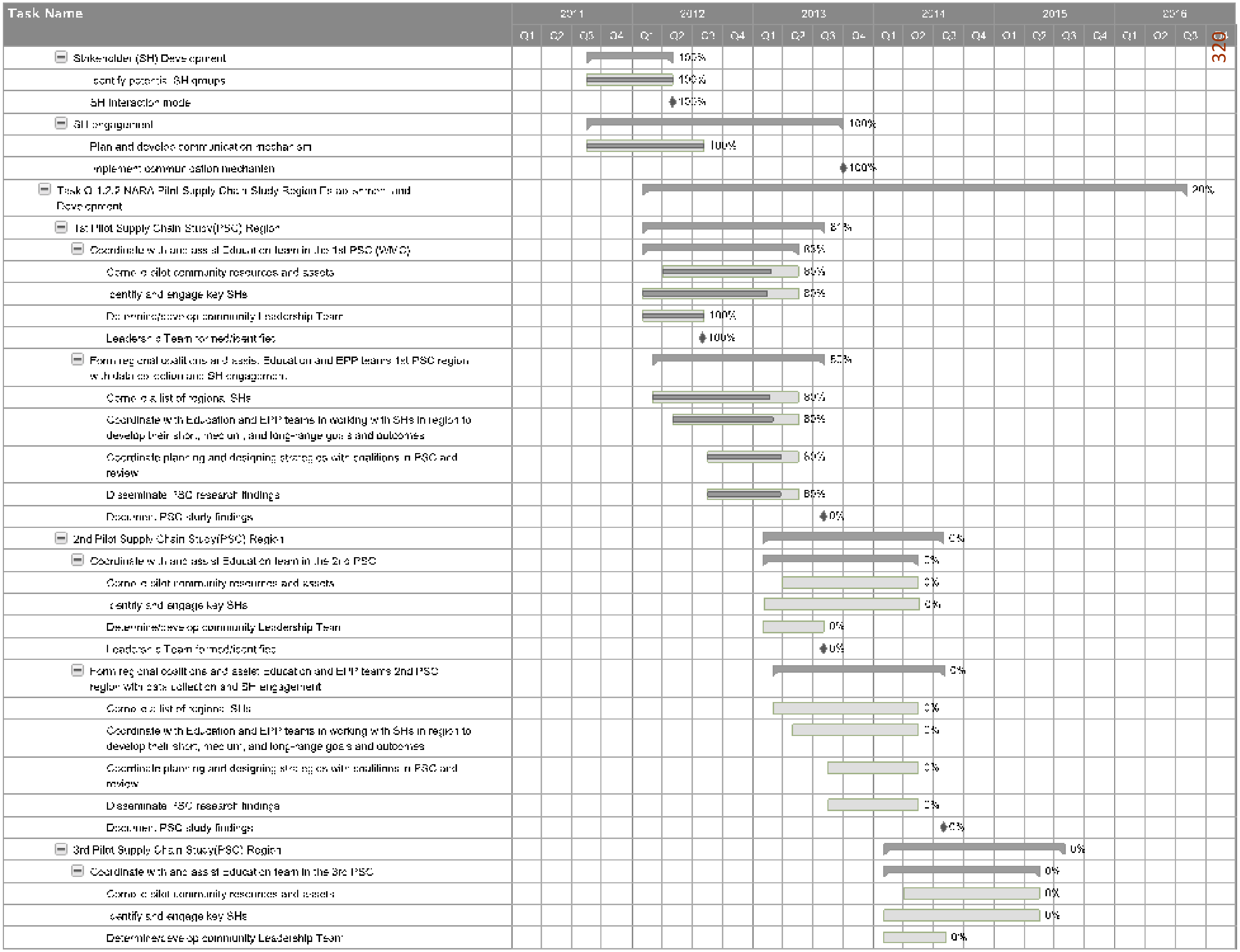
| | Task Name |
|---|---|
| 38 | Identify and categorize major contaminants for fuel production |
| 39 | Determine contaminant levels in wood wastes |
| 40 | Task E-7.4.2. Develop specifications for "allowable materials" for biofuel usage |
| 41 | Task E-7.4.3. Develop supply chain logistics model to efficiently utilize recovered material for ideal end use |
| 42 | ⊟ Task E-7.5. Develop wood composition model |
| 43 | Collect initial data/info on wood materials in MSW |
| 44 | Address historical data on wood materials in building construction |
| 45 | Model wood material types in the C&D stream |
| 46 | Final report on quality control and specifications for using MSW and C&D wood as biofuel |

# Outreach_Yadama_Englund

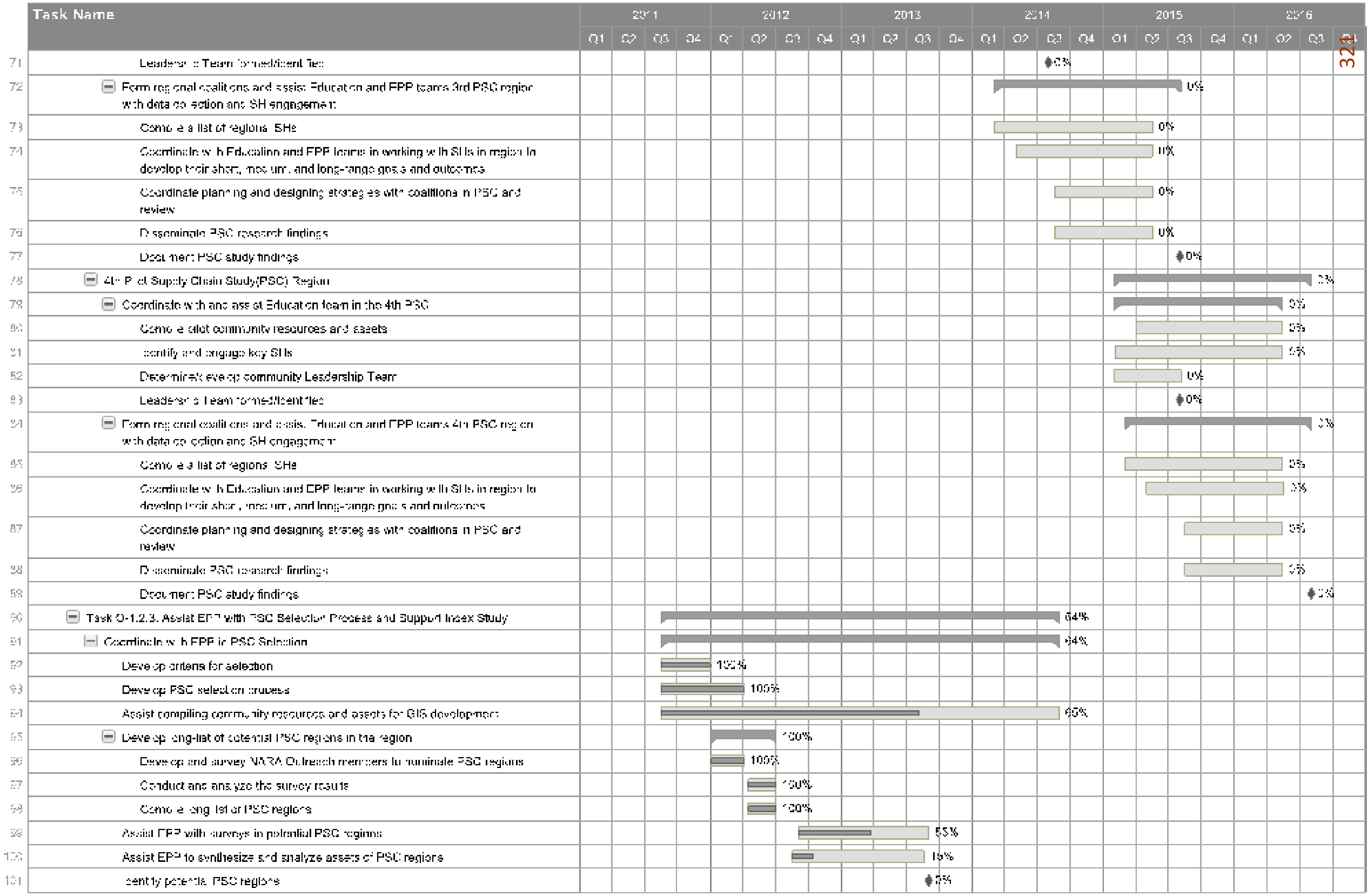
NARA

| | Task Name |
|---|---|
| 1 | O-1. Washington State University NARA Extension Initiative |
| 2 | Task O-1.1. Bioenergy Literacy |
| 3 | Task O-1.1.1. Develop an energy literacy platform for ease of communication |
| 4 | Establish technology transfer mechanisms |
| 5 | Coordinate and compile information from each of the NARA Research Teams |
| 6 | Network with Outreach Team Partners |
| 7 | Forest Business Network (FBN) |
| 8 | Link NARA on FBN |
| 9 | Integrate NARA into FBN newsletters |
| 10 | Assist NARA with MT Pilot Community |
| 11 | Assist NARA with other PSC study regions |
| 12 | Coordinate NARA's Role in Small Log Conf |
| 13 | USDA FS PNW |
| 14 | State Extension Personnel (OR, ID, MT) |
| 15 | Ruckelshaus Center |
| 16 | GreenWood Resources |
| 17 | Task O-1.1.2. Outreach Activities for Disseminating Knowledge and Receiving Feedback |
| 18 | Assess and determine dissemination mechanism |
| 19 | Design and draft agenda for the outreach activity in coordination with corresponding team |
| 20 | Disseminate NARA findings (Conferences, Fact Sheets, Knowledge Base, etc.) |
| 21 | Managing Woody Biomass Supply Chain Symposium |
| 22 | Compile and catalog activity outcomes |
| 23 | Program development and coordinate NARA related sessions for NW Bioenergy Research Symposium |
| 24 | Small Log Conference with FBN |
| 25 | Compile and catalog activity outcomes |
| 26 | Develop program, coordinate, and organize NARA Conference 1 |
| 27 | Compile and catalog conference proceedings |
| 28 | Develop program, coordinate, and organize NARA Conference 2 |
| 29 | Compile and catalog conference proceedings |
| 30 | Task O-1.1.3. Catalog Activity Outcomes and Benchmark Reports and Studies |
| 31 | Catalog benchmark reports and studies related to biofuels, bioenergy, and co products |
| 32 | Develop and conduct applied research on pre-conversion of woody biomass and alternative value-added options |
| 33 | Task O-1.2. Build Pilot Supply Chain Coalitions |
| 34 | Task O-1.2.1. Define Stakeholders and Articulate Communication Mechanisms |



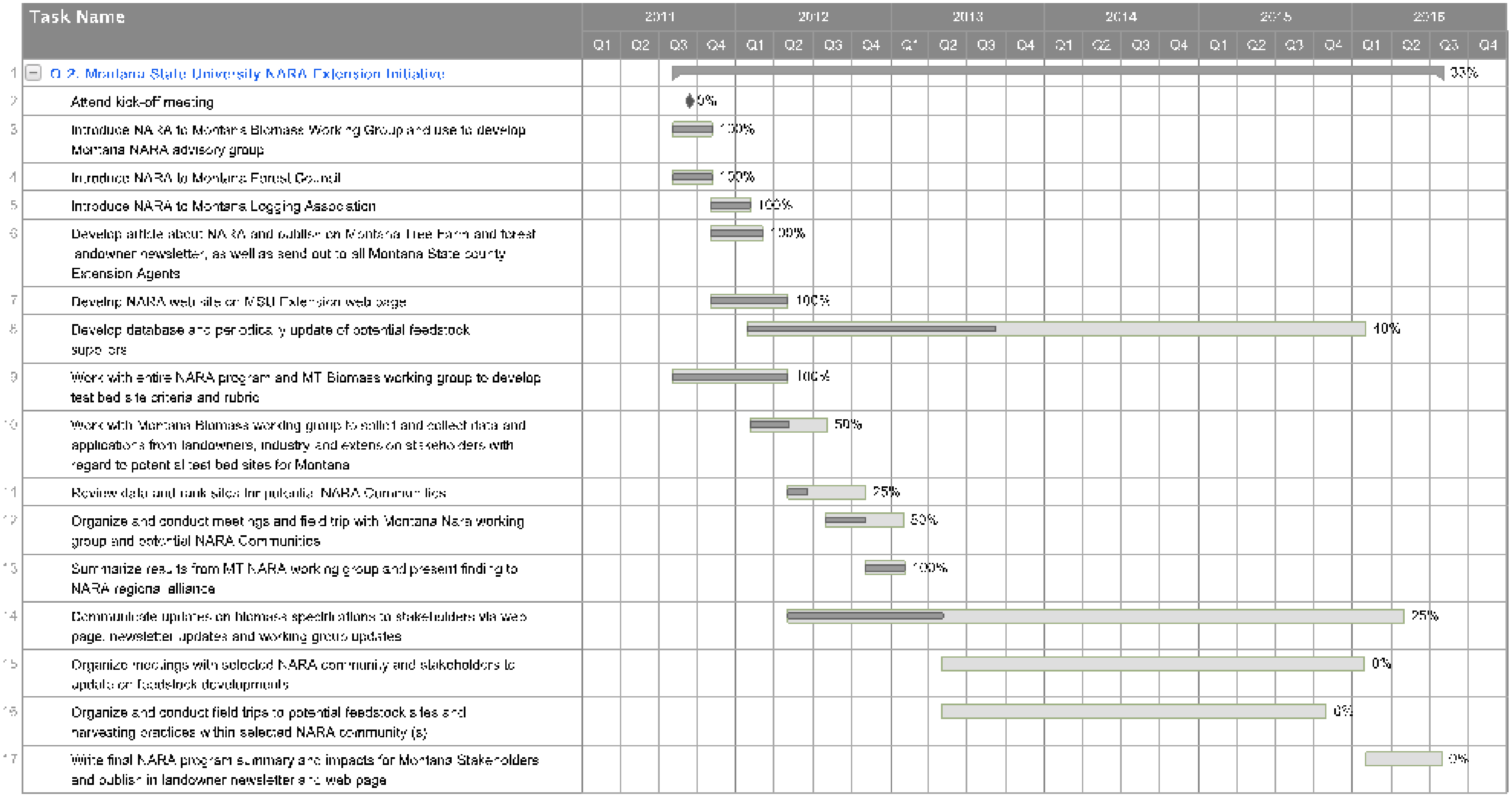


| | Task Name | |
|---|---|---|
| 35 | ⊟ Stakeholder (SH) Development | 100% |
| 36 | Identify potential SH groups | 100% |
| 37 | SH interaction model | ◆100% |
| 38 | ⊟ SH engagement | 100% |
| 39 | Plan and develop communication mechanism | 100% |
| 40 | Implement communication mechanism | ◆100% |
| 41 | ⊟ Task O 1.2.2 NARA Pilot Supply Chain Study Region Establishment and Development | 20% |
| 42 | ⊟ 1st Pilot Supply Chain Study(PSC) Region | 81% |
| 43 | ⊟ Coordinate with and assist Education team in the 1st PSC (WMC) | 83% |
| 44 | Compile pilot community resources and assets | 80% |
| 45 | Identify and engage key SHs | 80% |
| 46 | Determine/develop community Leadership Team | 100% |
| 47 | Leadership Team formed/identified | ◆100% |
| 48 | ⊟ Form regional coalitions and assist Education and EPP teams 1st PSC region with data collection and SH engagement. | 82% |
| 49 | Compile a list of regional SHs | 80% |
| 50 | Coordinate with Education and EPP teams in working with SHs in region to develop their short, medium, and long-range goals and outcomes | 80% |
| 51 | Coordinate planning and designing strategies with coalitions in PSC and review | 80% |
| 52 | Disseminate PSC research findings | 80% |
| 53 | Document PSC study findings | ◆0% |
| 54 | ⊟ 2nd Pilot Supply Chain Study(PSC) Region | 0% |
| 55 | ⊟ Coordinate with and assist Education team in the 2nd PSC | 0% |
| 56 | Compile pilot community resources and assets | 0% |
| 57 | Identify and engage key SHs | 0% |
| 58 | Determine/develop community Leadership Team | 0% |
| 59 | Leadership Team formed/identified | ◆0% |
| 60 | ⊟ Form regional coalitions and assist education and EPP teams 2nd PSC region with data collection and SH engagement | 0% |
| 61 | Compile a list of regional SHs | 0% |
| 62 | Coordinate with Education and EPP teams in working with SHs in region to develop their short, medium, and long-range goals and outcomes | 0% |
| 63 | Coordinate planning and designing strategies with coalitions in PSC and review | 0% |
| 64 | Disseminate PSC research findings | 0% |
| 65 | Document PSC study findings | ◆0% |
| 66 | ⊟ 3rd Pilot Supply Chain Study(PSC) Region | 0% |
| 67 | ⊟ Coordinate with and assist education team in the 3rd PSC | 0% |
| 68 | Compile pilot community resources and assets | 0% |
| 69 | Identify and engage key SHs | 0% |
| 70 | Determine/develop community Leadership Team | 0% |



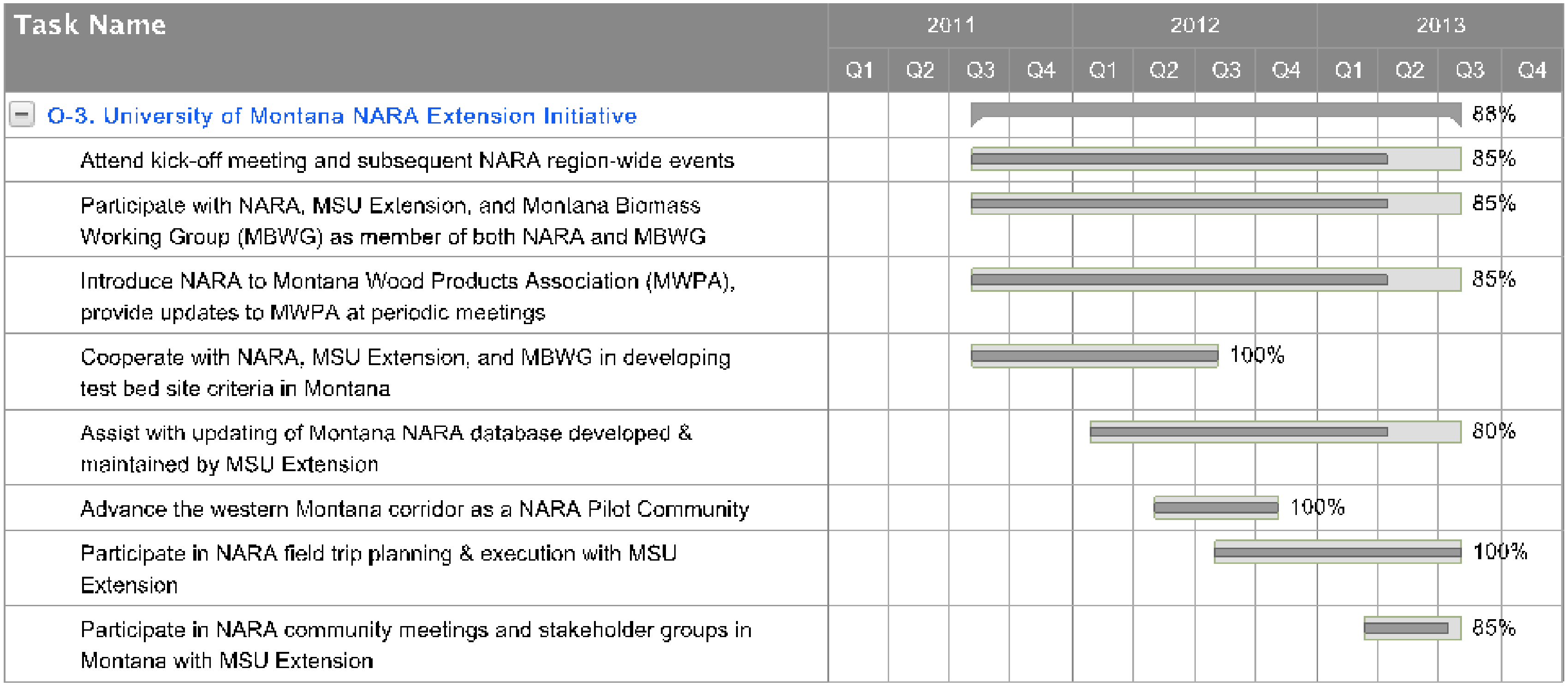
| | Task Name | |
|---|---|---|
| 71 | Leadership Team formed/identified | ◆0% |
| 72 | ⊟ Form regional coalitions and assist Education and EPP teams 3rd PSC region with data collection and SH engagement | 0% |
| 73 | Compile a list of regional SHs | 0% |
| 74 | Coordinate with Education and EPP teams in working with SHs in region to develop their short, medium, and long-range goals and outcomes | 0% |
| 75 | Coordinate planning and designing strategies with coalitions in PSC and review | 0% |
| 76 | Disseminate PSC research findings | 0% |
| 77 | Document PSC study findings | ◆0% |
| 78 | ⊟ 4th Pilot Supply Chain Study(PSC) Region | 0% |
| 79 | ⊟ Coordinate with and assist Education team in the 4th PSC | 0% |
| 80 | Compile pilot community resources and assets | 0% |
| 81 | Identify and engage key SHs | 0% |
| 82 | Determine/develop community Leadership Team | 0% |
| 83 | Leadership Team formed/identified | ◆0% |
| 84 | ⊟ Form regional coalitions and assist Education and EPP teams 4th PSC region with data collection and SH engagement | 0% |
| 85 | Compile a list of regional SHs | 0% |
| 86 | Coordinate with Education and EPP teams in working with SHs in region to develop their short, medium, and long-range goals and outcomes | 0% |
| 87 | Coordinate planning and designing strategies with coalitions in PSC and review | 0% |
| 88 | Disseminate PSC research findings | 0% |
| 89 | Document PSC study findings | ◆0% |
| 90 | ⊟ Task O-1.2.3. Assist EPP with PSC Selection Process and Support Index Study | 64% |
| 91 | ⊟ Coordinate with EPP in PSC Selection | 64% |
| 92 | Develop criteria for selection | 100% |
| 93 | Develop PSC selection process | 100% |
| 94 | Assist compiling community resources and assets for GIS development | 60% |
| 95 | ⊟ Develop long-list of potential PSC regions in the region | 100% |
| 96 | Develop and survey NARA Outreach members to nominate PSC regions | 100% |
| 97 | Conduct and analyze the survey results | 100% |
| 98 | Compile long list of PSC regions | 100% |
| 99 | Assist EPP with surveys in potential PSC regions | 55% |
| 100 | Assist EPP to synthesize and analyze assets of PSC regions | 15% |
| 101 | Identify potential PSC regions | ◆0% |

# Outreach_Kolb



| | Task Name | |
|---|---|---|
| 1 | O 2. Montana State University NARA Extension Initiative | 33% |
| 2 | Attend kick-off meeting | 0% |
| 3 | Introduce NARA to Montana Biomass Working Group and use to develop Montana NARA advisory group | 100% |
| 4 | Introduce NARA to Montana Forest Council | 100% |
| 5 | Introduce NARA to Montana Logging Association | 100% |
| 6 | Develop article about NARA and publish on Montana Tree Farm and forest landowner newsletter, as well as send out to all Montana State county Extension Agents | 100% |
| 7 | Develop NARA web site on MSU Extension web page | 100% |
| 8 | Develop database and periodically update of potential feedstock suppliers | 40% |
| 9 | Work with entire NARA program and MT Biomass working group to develop test bed site criteria and rubric | 100% |
| 10 | Work with Montana Biomass working group to solicit and collect data and applications from landowners, industry and extension stakeholders with regard to potential test bed sites for Montana | 50% |
| 11 | Review data and rank sites for potential NARA Communities | 25% |
| 12 | Organize and conduct meetings and field trip with Montana Nara working group and potential NARA Communities | 50% |
| 13 | Summarize results from MT NARA working group and present finding to NARA regional alliance | 100% |
| 14 | Communicate updates on biomass specifications to stakeholders via web page, newsletter updates and working group updates | 25% |
| 15 | Organize meetings with selected NARA community and stakeholders to update on feedstock developments | 0% |
| 16 | Organize and conduct field trips to potential feedstock sites and harvesting practices within selected NARA community (s) | 0% |
| 17 | Write final NARA program summary and impacts for Montana Stakeholders and publish in landowner newsletter and web page | 0% |

# Outreach_Morgan

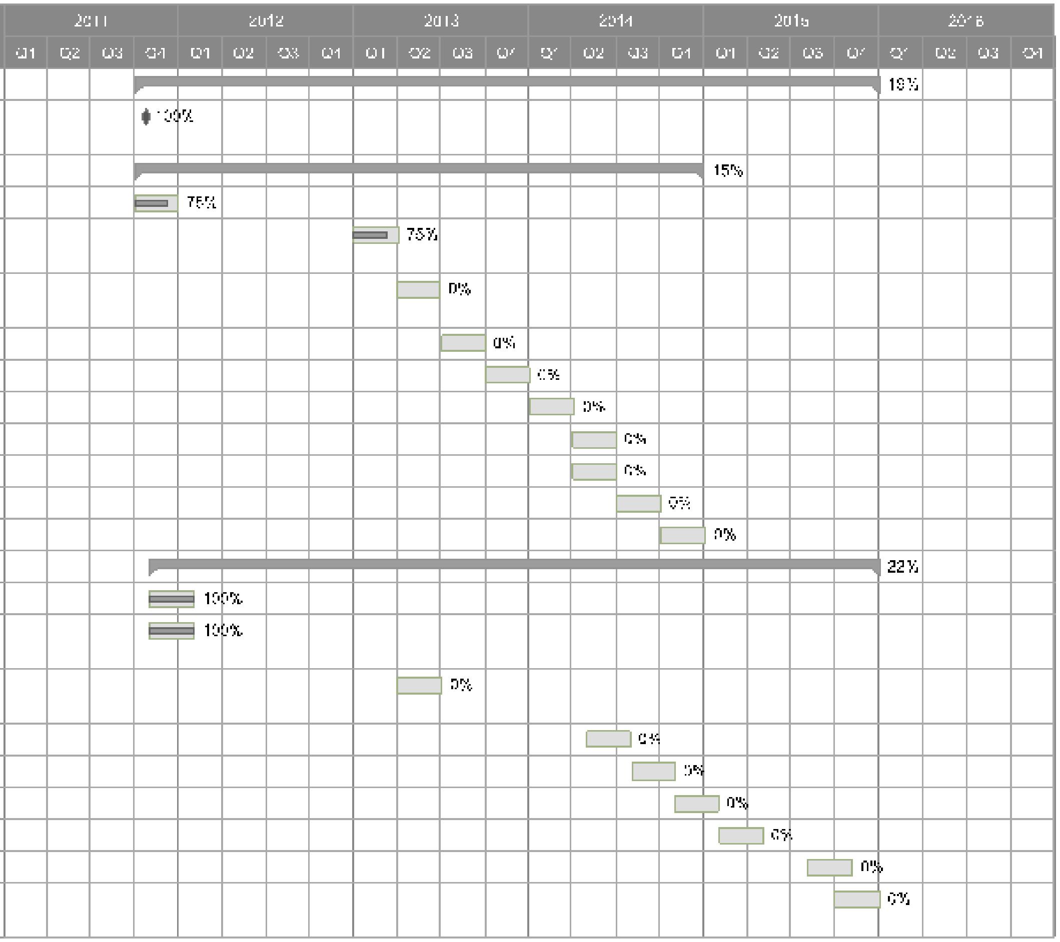


| | Task Name | |
|---|---|---|
| 1 | ⊟ O-3. University of Montana NARA Extension Initiative | 88% |
| 2 | Attend kick-off meeting and subsequent NARA region-wide events | 85% |
| 3 | Participate with NARA, MSU Extension, and Montana Biomass Working Group (MBWG) as member of both NARA and MBWG | 85% |
| 4 | Introduce NARA to Montana Wood Products Association (MWPA), provide updates to MWPA at periodic meetings | 85% |
| 5 | Cooperate with NARA, MSU Extension, and MBWG in developing test bed site criteria in Montana | 100% |
| 6 | Assist with updating of Montana NARA database developed & maintained by MSU Extension | 80% |
| 7 | Advance the western Montana corridor as a NARA Pilot Community | 100% |
| 8 | Participate in NARA field trip planning & execution with MSU Extension | 100% |
| 9 | Participate in NARA community meetings and stakeholder groups in Montana with MSU Extension | 85% |

# Outreach_Leavengood

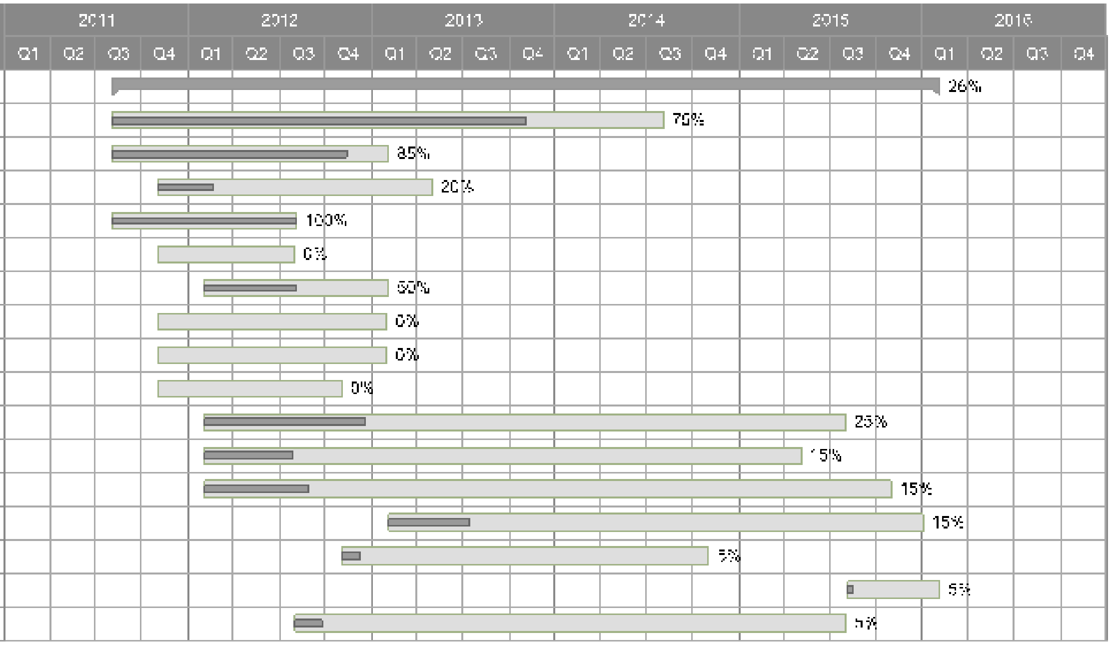
NARA

|  | Task Name |
|---|---|
| 1 | ⊟ O-4. Oregon State University NARA Extension Initiative |
| 2 | Introduce project to OR Forest Biomass Wrkg Grp – solicit group's involvement as advisory committee (AC) |
| 3 | ⊟ Task O 4.1. NARA Regional Alliances |
| 4 | Review existing data & reports on potential test sites |
| 5 | Convene 1-day meeting of AC to review NARA community criteria & identify 2 test sites |
| 6 | Convene focus grp meeting at test site 1 – discuss feedstock specs & logistics, tech. adoptions w/existing infra., etc. |
| 7 | Convene focus grp meeting at test site 2 – (same as above) |
| 8 | Meet with suppliers for site 1 |
| 9 | Meet with industrial stakeholders for site 1 |
| 10 | Host community forum for site 1 |
| 11 | Meet with suppliers for site 2 |
| 12 | Meet with industrial stakeholders for site 2 |
| 13 | Host community forum for site 2 |
| 14 | ⊟ Task O 4.2. NARA Extension Engine |
| 15 | Develop NARA page on OSU Forestry Extension website |
| 16 | Develop newsletter article on NARA project; send to OSU Extension Foresters for newsletters |
| 17 | Develop briefing paper on NARA community criteria and post to project website |
| 18 | Develop detailed report on each test site; post to project website |
| 19 | Meet with policymakers re: project results |
| 20 | Organize field trips to key supply sites & ind. facilities for site 1 |
| 21 | Organize field trips to key supply sites & ind. facilities for site 2 |
| 22 | Organize and deliver statewide conference (OR) on NARA research findings |
| 23 | Develop NARA update newsletter article; send to OSU Extension Foresters for newsletters |

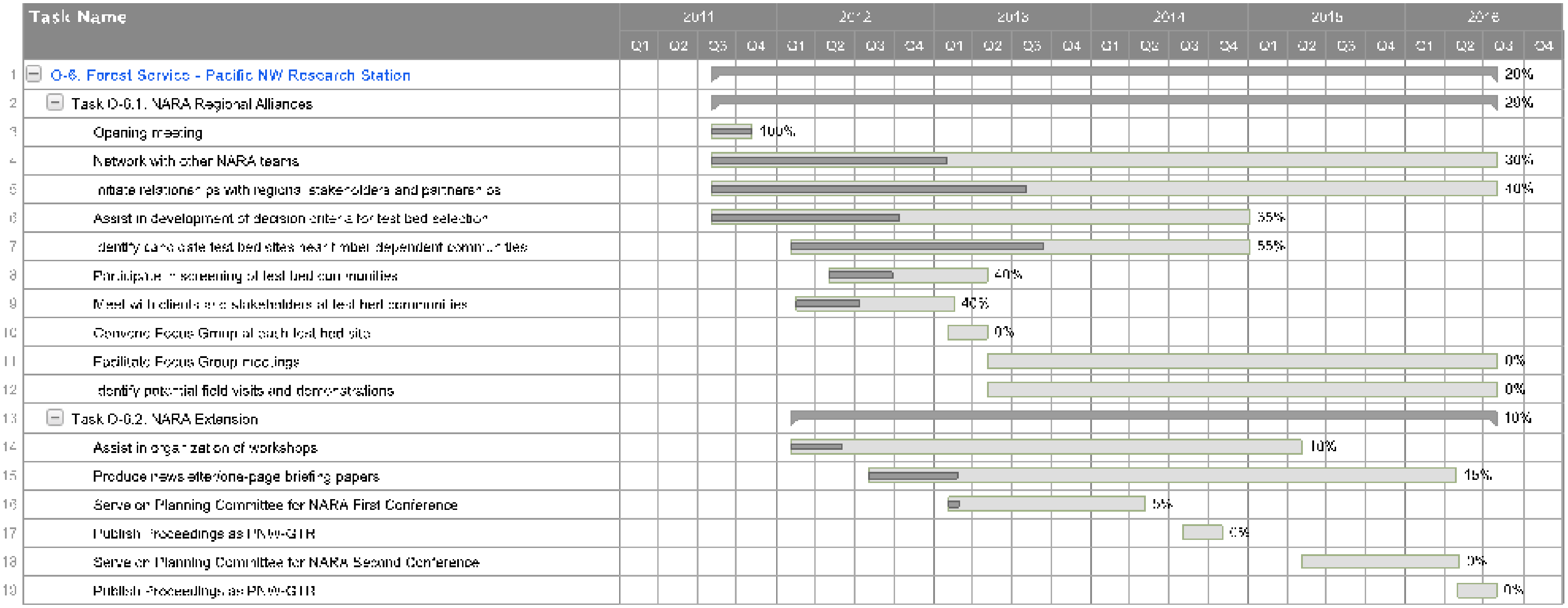


# Outreach_Brooks

|  | Task Name |  |
|---|---|---|
| 1 | ⊟ O-5. University of Idaho NARA Extension Initiative | 26% |
| 2 | Network with NARA research and industry partners | 75% |
| 3 | Initiate relationships with stakeholders | 85% |
| 4 | Establish working relationship w/ regional cooperators | 20% |
| 5 | Help identify test-bed sites | 100% |
| 6 | Help develop survey w/ EPP group | 0% |
| 7 | Help survey potential test-bed sites | 50% |
| 8 | Help establish working relationship w/ test-bed sites | 0% |
| 9 | Communicate NARA goals to test-bed sites | 0% |
| 10 | Establish focus groups with test-bed sites | 0% |
| 11 | Help plan, organize and coordinate workshops | 25% |
| 12 | Help plan, organize and coordinate stakeholder mtgs | 15% |
| 13 | Help distribute newsletters/articles/briefs to communities | 15% |
| 14 | Evaluate impact of workshops | 15% |
| 15 | Assist with synthesis of survey results | 5% |
| 16 | Help publish impact of program | 5% |
| 17 | Help organize/conduct field trips for stakeholders | 5% |

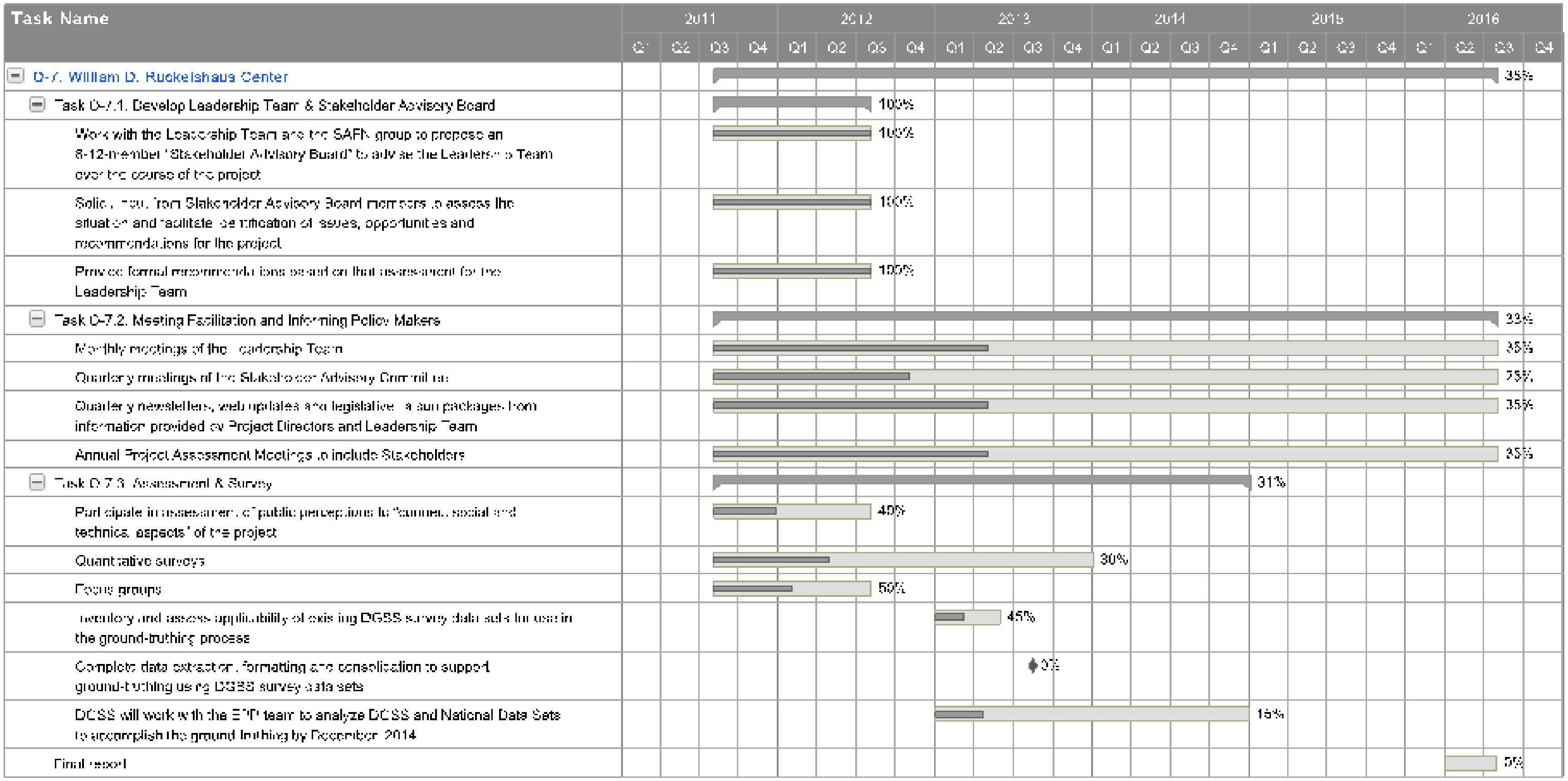


# Outreach_Lowell



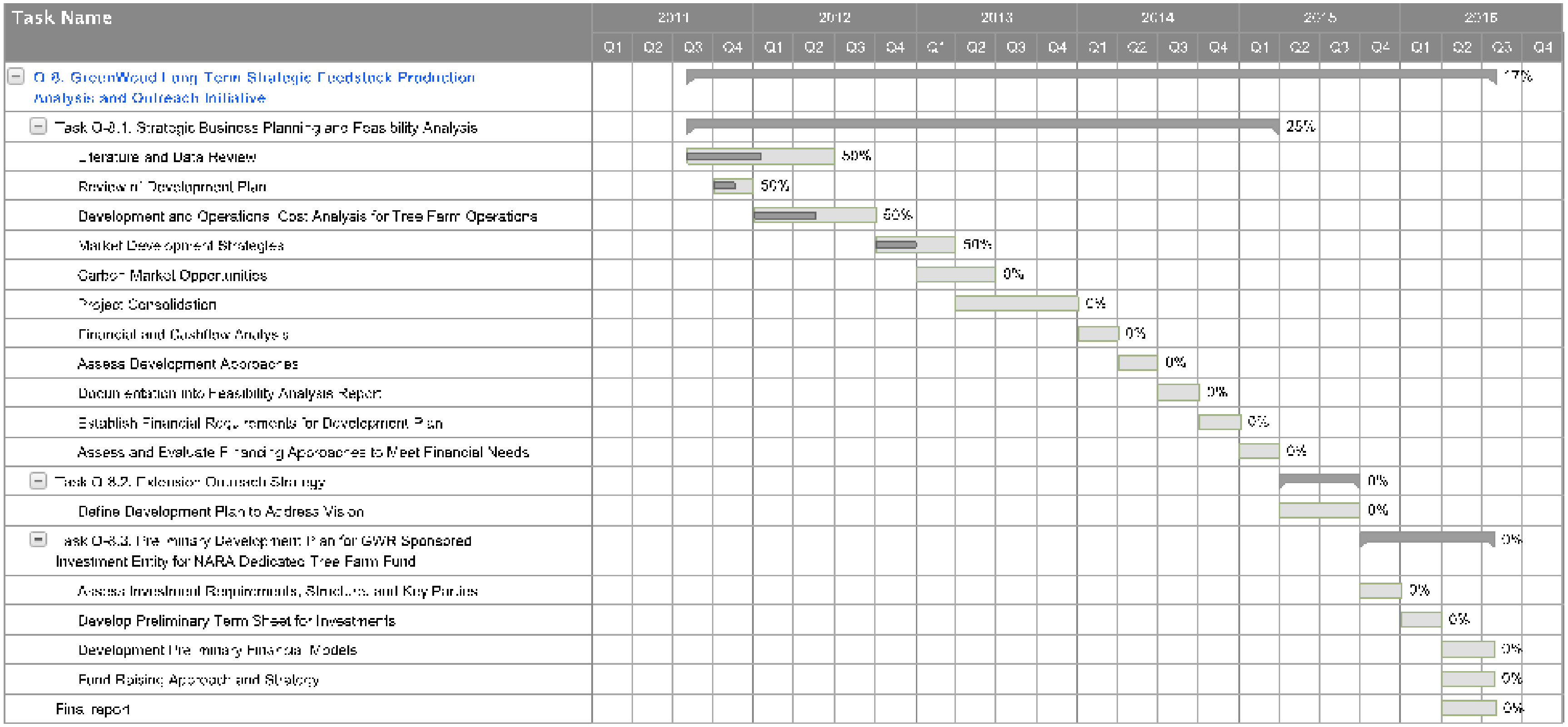
| | Task Name | |
|---|---|---|
| 1 | O-6. Forest Service - Pacific NW Research Station | 20% |
| 2 | Task O-6.1. NARA Regional Alliances | 20% |
| 3 | Opening meeting | 100% |
| 4 | Network with other NARA teams | 30% |
| 5 | Initiate relationships with regional stakeholders and partnerships | 10% |
| 6 | Assist in development of decision criteria for test bed selection | 55% |
| 7 | Identify candidate test bed sites near timber dependent communities | 55% |
| 8 | Participate in screening of test bed communities | 40% |
| 9 | Meet with clients and stakeholders at test bed communities | 40% |
| 10 | Convene Focus Group at each test bed site | 0% |
| 11 | Facilitate Focus Group meetings | 0% |
| 12 | Identify potential field visits and demonstrations | 0% |
| 13 | Task O-6.2. NARA Extension | 10% |
| 14 | Assist in organization of workshops | 10% |
| 15 | Produce newsletter/one-page briefing papers | 15% |
| 16 | Serve on Planning Committee for NARA First Conference | 5% |
| 17 | Publish Proceedings as PNW-GTR | 0% |
| 18 | Serve on Planning Committee for NARA Second Conference | 0% |
| 19 | Publish Proceedings as PNW-GTR | 0% |

# Outreach_RuckelshausCtr



| | Task Name | |
|---|---|---|
| 1 | D-7. William D. Ruckelshaus Center | 35% |
| 2 | Task D-7.1. Develop Leadership Team & Stakeholder Advisory Board | 100% |
| 3 | Work with the Leadership Team and the SAFN group to propose an 8-12-member "Stakeholder Advisory Board" to advise the Leadership Team over the course of the project | 100% |
| 4 | Solicit input from Stakeholder Advisory Board members to assess the situation and facilitate identification of issues, opportunities and recommendations for the project | 100% |
| 5 | Provide formal recommendations based on that assessment for the Leadership Team | 100% |
| 6 | Task D-7.2. Meeting Facilitation and Informing Policy Makers | 33% |
| 7 | Monthly meetings of the Leadership Team | 35% |
| 8 | Quarterly meetings of the Stakeholder Advisory Committee | 25% |
| 9 | Quarterly newsletters, web updates and legislative information packages from information provided by Project Directors and Leadership Team | 35% |
| 10 | Annual Project Assessment Meetings to include Stakeholders | 35% |
| 11 | Task D-7.3. Assessment & Survey | 31% |
| 12 | Participate in assessment of public perceptions to "human, social and technical aspects" of the project | 40% |
| 13 | Quantitative surveys | 30% |
| 14 | Focus groups | 50% |
| 15 | Inventory and assess applicability of existing DGSS survey data sets for use in the ground-truthing process | 45% |
| 16 | Complete data extraction, formatting and consolidation to support ground-truthing using DGSS survey data sets | 0% |
| 17 | DGSS will work with the EFP team to analyze DGSS and National Data Sets to accomplish the ground truthing by December 2014 | 15% |
| 18 | Final report | 0% |

# Outreach_Greenwood



| | Task Name | |
|---|---|---|
| 1 | O.8. GreenWood Long Term Strategic Feedstock Production Analysis and Outreach Initiative | 17% |
| 2 | Task O-8.1. Strategic Business Planning and Feasibility Analysis | 25% |
| 3 | Literature and Data Review | 50% |
| 4 | Review of Development Plan | 50% |
| 5 | Development and Operations Cost Analysis for Tree Farm Operations | 50% |
| 6 | Market Development Strategies | 50% |
| 7 | Carbon Market Opportunities | 0% |
| 8 | Project Consolidation | 0% |
| 9 | Financial and Cashflow Analysis | 0% |
| 10 | Assess Development Approaches | 0% |
| 11 | Documentation into Feasibility Analysis Report | 0% |
| 12 | Establish Financial Requirements for Development Plan | 0% |
| 13 | Assess and Evaluate Financing Approaches to Meet Financial Needs | 0% |
| 14 | Task O-8.2. Extension Outreach Strategy | 0% |
| 15 | Define Development Plan to Address Vision | 0% |
| 16 | Task O-8.3. Preliminary Development Plan for GWR Sponsored Investment Entity for NARA Dedicated Tree Farm Fund | 0% |
| 17 | Assess Investment Requirements, Structures and Key Parties | 0% |
| 18 | Develop Preliminary Term Sheet for Investments | 0% |
| 19 | Development Preliminary Financial Models | 0% |
| 20 | Fund Raising Approach and Strategy | 0% |
| 21 | Final report | 0% |

# NARA | GOAL FIVE

August 2011 - March 2013 Cumulative Report

BIOENERGY LITERACY

Northwest Advance Renewables Alliance

# Goal Five: 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 biofuels industry sustainability 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.

Programs targeted to **K-12 students and teachers** provide curriculum development and educational programs. The NARA Education Team developed ten energy and biofuels related lesson plans for middle and high school students. These lesson plans were field-tested with students and educators at the University of Idaho's McCall Outdoor Science School (MOSS) and through webinars sponsored by Facing the Future (FtF). Once field-testing is complete, FtF will offer the lesson plans to educators worldwide through web-based delivery (Task E-2; each task progress is detailed in progress reports following this summary).

NARA has partnered with the annual Imagine Tomorrow Renewable Energy challenge for 9th-12th graders at Washington State University. In 2012, NARA's involvement expanded the competition to attract student teams from Oregon, Idaho and Montana as well as Washington, and to include a new "biofuels" competition category. As a result, 433 students participated in 2012 as compared to 363 students in 2011, and the number of biofuels projects increased from 3 to 14 teams over the same time period. An assessment team has been established to evaluate the effects of Imagine Tomorrow on students' STEM career choices and energy literacy. In 2012, this team conducted a preliminary student survey with a 35% response rate and results suggests that participation is having positive effects on students' STEM career related attitudes and interests (Task E-4).

MOSS provided workshops to educate K-12 teachers on bioenergy lesson plans. In addition, MOSS graduate students mentored teachers in preparing students to participate in the Imagine Tomorrow Competition. Assessments that measured teacher literacy and experience followed the workshops. To provide educational resources to K-12 teachers, a web-based bioenergy matrix (http://energyliteracyprinciples.org) was developed that allows teachers to locate bioenergy related resources (lesson plans, images, reference materials) based on energy literacy concepts outlined by the U.S. Department of Energy (Task E-2).

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 bio-products research. In 2012, eleven students applied and eight were selected and teamed with NARA principal investigators to conduct research and showcase their projects at a poster symposium sponsored by Washington State University. Demographics of 2012 applicants were 36% women, 64% men; and 18% Hispanic, 9% Native American, 9% Asian, and 64% Caucasian (Task E-5).

The IDX course involved 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 Clearwater Basin and Western Montana Corridor atlases described in the Goal 4 segment of this report. (Task E-5)

Graduate students associated with the University of Washington, Salish Kootenai College and IDX comprise a NARA Tribal Team who are working with tribal foresters on biomass and cost of transport assessments that integrate with landscape management goals for the Confederated Salish and Kootenai Tribe (CSKT) reservation (Task T-E1, T-E6).

Lastly, as of March 31, 2013, NARA funds have supported 43 graduate students working on tasks assigned to the NARA project.

To promote **stakeholder professional development**, web-based mechanisms are established to receive and disseminate information to stakeholders. These mechanisms include a knowledge base repository, a monthly E-newsletter with over 230 subscribers as of March 2013 and a presence in social media. NARA maintains a stakeholder mailing list of over 120 individuals who receive updates to NARA's progress. The NARA project is also linked to various websites hosted by extension groups within the Outreach Team. NARA has co-hosted three symposia/conferences in 2011 and 2012 and has had representative speakers at over 40 conferences worldwide. Eight "NARA one-pagers" have been produced, disseminated to audiences, and posted on the NARA website (Goal 4; Task O-1).

To raise **public energy literacy**, 35 news articles have been published about NARA. The NARA project, in connection with WSU, is featured on a display at the Future of Flight Aviation Center and Boeing Tour, Mukilteo, Washington and was featured at the 2012 Smithsonian Folklife Festival at the Washington Mall. The Future of Flight Aviation Center and Boeing Tour attracts over 225,000 regional, national, and international visitors annually. An additional 75,000 people visit the facility to participate in special events, such activities surrounding delivery of Boeing aircraft, receptions, and school activities. The Smithsonian Folklife Festival attracts over one million visitors each year. To inform policy makers about NARA, the NARA Outreach Team, led by the Ruckelshaus Center, assembled a list of over 1,500 policy-makers in Washington, Oregon, Idaho, Montana and Northern California (Goal 4; Task O-7).

Policy-makers receive quarterly reports of NARA's progress that direct these stakeholders to the NARA web assets. NARA maintains a website which experienced 20,539 individual visits with 83,270 page views from September 2011 to March 2013. Visitations were from all 50 US states and from 114 countries. The term "NARA" in Google now ranks nararenewables.org third. Analytics provided by Alexa indicate that the nararenewable.org web traffic was ranked 2,059,772 worldwide in May, 2013. Rankings for similar AFRI projects during the same time period are 23,772,075 for Advance Hardwood Biofuels

Northwest and 18,970,588 for the Southern Partnership for Integrated Biomass Supply Systems (Goal 4; Task O-1).

Significant internal outputs to date for this team are listed below. Additional outputs are listed at the end of each progress report.

- Based on measured outcomes, both the K-12 student and teacher programs have elevated the level of bioenergy literacy of participants. As a result, the three-pronged approach of direct K-12 student programming, teacher professional development, and development of the web-based Energy Literacy Principle Matrix will be continued (Task E-2).

- The collaborative investment by the K-12 group in teacher mentoring, education in energy literacy and student team support for Imagine Tomorrow has generated increased awareness and participation. Over 20 biofuel projects are entered for the 2013 competition compared to 14 in 2012. This event draws news coverage (see outputs in Task E-4) and introduces NARA to over 140 science and resource based industry leaders as judges to the event. In addition, over 400 high-school students interested in science are exposed to the NARA project. The marketing campaign for 2013 also includes the distribution of energy-based literature in news media (see outputs in Task E-4) that is expected to enhance the interest in the competition and also increase energy knowledge in those who are not able to directly participate (Task E-2, Task E-4).

- The NARA SURE program exposed students to biofuels research work. In 2013, the number of applications tripled from the previous year and the trend should provide a pipeline for research assistance and increase the number of undergraduate students with work experience related to the NARA project. To date, a total of 38 applicants have been received and offers are currently being made to selected students (3 to date). Demographics of 2013 applicants are 61% women, 39% men; and 11% Hispanic, 3% Native American, 8% African American, 34% Asian/Pacific, and 39% Caucasian (Task E-5).

- The Knowledge Base repository contains unbiased information that covers a broad coverage of biofuels development. It is available to the general public and to date has had a total of 1710 visits from 23 states and 10 countries (Task O-1).

- Establishing a biofuel display at the Future of Flight Aviation Center and Boeing Tour has spurred discussions with Boeing’s education outreach staff to include biofuel lessons to K-12 students (Task O-1).

## Outcomes/Impacts:

- K-12 Teachers are more knowledgeable about biofuels, biofuels research, and energy. All participants in teacher workshops showed a statistically significant increase in content knowledge related to biofuels, water resources and climate change. K-12 Teachers apply knowledge in energy literacy to assist students successfully develop an approach to answering a problem-based energy issue. In a 9-month follow-up survey, 68% of teachers report being more likely to use a problem-based learning pedagogy after being involved in a MOSS teacher workshop. 90% of teachers report that they learned new ways of teaching. 66% percent of teachers agree or strongly agree that they have a good understanding of biofuels, that they understand key parts of the supply chain and that they have enough of an understanding to have developed an informed opinion about the feasibility of a woody biomass biofuel program in the Pacific Northwest. 45.8% of teachers say that they have been able to incorporate biofuels into their teaching (Task E-2).

- NARA’s partnership with the Imagine Tomorrow competition changed this event from a statewide to a Pacific Northwest regional activity and injected biofuels research as a main focus (Task E-2).

## Training

| Name | Affiliation | Role | Contribution |
|---|---|---|---|
| Kenneth Faires (Lumbee) | Univ of WA | Undergraduate Student | Tribal project organization |
| Ikechwuku Nwaneshiudu | Univ of WA | Undergraduate Student | ASPEN Simulation, data |
| Blake Hough | Univ of WA | Undergraduate Student | Biomass quantities, data |
| Beth Kochevar<br>Brett Miller<br>Carmen DeLeon<br>Claire Deters<br>Carrie Anderson<br>Christa Shier<br>Dawn Harfmann<br>Elinor Israel<br>Kate McGraw<br>Kelly Martin<br>Jim Casey<br>Joy Adams<br>Jyoti Jennewein<br>Lauren Smith<br>Nell Davis<br>Sara Anderegg | University of Idaho | Graduate Students | Understand NARA objectives, goals, and scientific advances. Creating lesson plans using NARA concepts for K12 students. Mentoring and coaching K12 teacher/student teams for the WSU IT competition. |
| Quinn Langfitt | WSU Student | Assessment team member | Energy literacy assessment activities |
| Chad Gotch | Research Associate –WSU | Assessment team member | Database development and management; supervisor of graduate student for survey research |
| Jessica Beaver | WSU Doctoral Student | Assessment team member | Survey research, data analysis, and assist with writing of reports |

|  |  |  |  |
|---|---|---|---|
| Burdette Birdinground* | Univ. WA | Undergraduate Student | Scale up of an ultra-low cost in-forest thermal processing of biomass |
| Maggie Buffum | OSU | Undergraduate Student | Moisture Content in Biomass Piles |
| Lucy Cheadle | Univ. WA | Undergraduate Student | Analysis of Bioproducts from Ultra-Low Cost Biomass Processing |
| Brady Do | OSU | Undergraduate Student | Assessing Risks of Arson in Biomass Piles |
| Madeline Fuchs | WSU | Undergraduate Student | NARA Biofuels Production Emissions |
| Pedro Guajardo Jr. | WSU | Undergraduate Student | Diluted acid and peroxide pretreatments of Douglas fir biomass |
| Anthony Lathrop | WSU | Undergraduate Student | Effect of Hot Water Extraction on Mechanical Properties of Ponderosa Pine Chips |
| Ellen Simonsen | WSU | Undergraduate Student | Biobased Curing Agent for Epoxy |
| Cody Siford | SKC | intern | GIS support to CSKT Tribe |
| Burdette Birdinground | SKC | intern | Portable Pyrolysis blanket research |
| Hannah Funke | SKC | intern | CSKT woody biomass availability |

## Resource Leverage

| **Resource Type** | **Resource Citation** | **Amount** | **Relationship or Importance to NARA** |
|---|---|---|---|
| Everett Isaac | NSF IGERT | $20,000 | Tribal forestry expertise |
| Gift | Steven C. Luethold Family Foundation | $15,000 | Provides general operating support for the MOSS program. |
| Award | Albertson Foundation ID21 program | $50,000 | Provides general operating support for the MOSS program. |

| | | | |
|---|---|---|---|
| Gift | Idaho Community Foundation Shelton Fund | $2,500 | Provides general operating support for the MOSS program. |
| Gift | Whittenberger Foundation | $4,300 | Provides general operating support for the MOSS program. |
| Gift | Lightfoot Foundation | $10,000 | Provides general operating support for the MOSS program. |
| Donations | | | NARA partially supports the cost of the Imagine Tomorrow program, leveraging over $200,000 in other private donations to run the program. |
| Assessment donations | | $15,000<br>$15,000 match | Ecoworks<br>Bank of America |
| Financial support for end of the summer poster symposium. | | | NARA SURE organization is being co-advertised and co-hosted with existing NSF funded REU programs on the WSU campus. The Office of Undergraduate Research, University College at WSU, is assisting in setting up housing and running the summer poster symposium. |
| | USDA NIFA Tribal College Research Grant | | Two NARA interns assisted research to investigate woody biomass availability for the Confederated Salish and Kootenai Tribes. One focused on GIS, the other on field measurement and biomass assessment. |
| | | | Summer intern Burdette Birdinground attended SACNAS (Society for the Advancement of Chicanos and Native Americans in Science) |

# EDUCATION

## Education Team

### Task E-1: Bioenergy and Bioproducts Graduate Education and Research in Partnership with Northwest Tribes

| Key personnel | Affiliation |
|---|---|
| Daniel T Schwartz | University of Washington |

#### Task Description

The goal of this task is to educate next-generation scholars with unique skills for devising integrated resource management and technical designs that deliver bioenergy and bioproduct systems tailored to the resource, ecologic, and economic development needs of a community. To accomplish this, we will work with tribes, tribal organizations, and each partner campus to offer graduate student tribal research projects that integrate with other student activities in an area. Specifically, student teams will work collaboratively with Northwest tribes to provide integrative research on technical issues tied to feedstocks, their sustainable production and logistics, and conversion to value-added products. System metrics will assess the overall performance of the integrated student design. Students will benefit from outstanding training in interdisciplinary communications and research. Tribes will benefit by collaborating to define, research, and assess a technical problem that is deemed a tribal priority for ecologic or economic development purposes. Each student team will make several trips to the partner tribe's reservation. A field trip initiates each project. After the field trip, a statement of work is developed, and then students typically reconvene two more times at the reservation to present oral and written reports. Because this is a multi-campus activity, the reservation trips are a key mechanism for building team synergy. Each student team is expected to perform publishable work. To have maximum impact, this task has significant liaison activities with tribes, tribal organizations, and campus offices that coordinate with tribal student recruiting and retention programs.

#### Activities and Results

During the project period, the NARA Tribal Projects Partnership Team had in-person project discussions and presentations with the Confederated Tribes of the Umatilla Indian Reservation (OR), Confederated Tribes of the Warm Springs Reservations (OR), and Confederated Salish and Kootenai Tribes (MT), as well as telephone and e-mail communications with representatives of the Nez Perce (ID) and Colville Tribes (WA). In January 2013, the NARA Tribal Partnership Projects established a Memorandum of Agreement (MOA) with the Confederated Salish and Kootenai Tribes (CSKT), Forestry Department. The

MOA is in effect for the year 2013. Students, faculty, and staff have made several trips to the reservation to clarify the project goals and to acquire continuous forest inventory data. Because the CSKT are also located within the Western Montana Corridor, we are coordinating with this year's BioIDEX team. Our MOA allows for data sharing between the BioIDEX team, UW graduate student team, and Tribe. The ongoing project has two dimensions; an assessment of biomass residues and cost of transport to Pablo Montana based on the ten-year harvest schedule developed by the tribe, and an ASPEN simulation of sugar production at the scale of biomass resources available on the reservation and in the Western Montana Corridor. The work is being coordinated with CSKT forest management to ensure our approach matches their goals and practices, including potential fuels prescriptions for fire prevention Biomass generated by fuels reduction, and forest structural change, will rely on CSKT Forest Inventory datasets and the Forest Service Forest Vegetation Simulator (FVS), with assessments provided by our contract forester, during the current NARA quarter. The Inland Empire calibration set is appropriate for the Western Montana landscape. Inventory data will be projected onto the landscape in line with CSKT forest management schemes. Transportation assessments will be completed by the GIS team members to mesh well with data developed for the Western Montana Corridor project. High quality road network GIS data (including metrics of road quality) have been shared between the UW and BioIDEX team. CSKT will gain analyzed data, providing for further management capabilities in forestry, fire and fuels management. This collaboration ties in well with the NARA Western Montana Corridor Project, utilizing GIS analysts from both WSU and Salish Kootenai College. The ASPEN simulations are building from prior process simulation carried out by NREL. We are assuming ground wood is delivered. Our initial simulations assume the use of dilute acid pretreatment, followed by enzyme hydrolysis to sugars by-products. The process considers each recovery step as well as drying or concentrating the final sugar products. We are investigating purity, capital, and operating costs.

## Recommendations/Conclusions

Tribal engagement and participation has been excellent, and the project has advanced significantly in the 3 months since the MOA was signed. Timber harvest tables have been established for the next decade, up to the allowable cut of 18 mmbf. A tribal forester has been identified to assist with the prescriptions to be used in FVS. The tribal partnership team has begun to develop plans for the next coordinated project in the Washington/Oregon emphasis area for the 2013-14 academic year. In the initial stages of planning, we have been invited to submit a proposal to the Intertribal Timber Council to host a workshop at their National Indian Timber Symposium, to be held in June 2013 at the Menominee Casino Resort. This workshop would highlight our MOA and partnership with CSKT. This would also identify the opportunities for tribal programs to gain an understanding of the overall NARA goals and objectives, work completed as a part of the Western Montana Corridor project and the resulting information that was produced as a result of our MOA with CSKT. This proposal is pending panel acceptance by ITC, to be decided in early May.

We recommend early identification of the OR/WA region of interest, identify possible tribal partners within the region, then seek a regional agreement (possibly via the Bureau of Indian Affairs (BIA)). This would protect tribally sensitive data from regional partners, while still incorporating tribal numbers into regional assessment. Deliverables for each individual tribe could be identified with the assurance that individual local numbers would not be utilized, however a regional number could reflect all tribes within the region.

## Physical and Intellectual Outputs

### Physical

- *Negotiation of Memorandum of Agreement and data sharing agreement with Confederated Salish and Kootenai Tribes, September, 2012 - January, 2013.*
- *Project Prospectus was negotiated with CSKT, December, 2012-January, 2013.*
- *NARA tribal meeting on Flathead Reservation, January, 2013*
- *High quality GIS tribal road layer data was shared with BioIDEX team, February, 2013.*

### Research Presentations

D.T. Schwartz and L.L. James. 2012. NARA tribal partnership projects. Oral presentation at Confederated Tribes of the Umatilla Indian Reservation, Pendleton, OR, Sept 13-14, 2012.

L.L. James and D.T. Schwartz. 2012. NARA tribal partnership projects. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

### Other Publications

Tabish, Dillon. "Confederated Salish and Kootenai Tribes Partner on Biofuel Research. Tribes collaborating on $40 million project studying the ability to create jet fuel using wood debris." Flathead Beacon. 21 February 2013. Online. http://www.flatheadbeacon.com/articles/article/confederated_salish_and_kootenai_tribes_partner_on_biofuel_research/31831/

Miller, Alice. "*Tribal forest biomass could become jet fuel*." 21 March 2013. Page 10. Print. At: http://www.leaderadvertiser.com/news/article_22f2d800-91a1-11e2-98f2-0019bb2963f4.html

Burke, C. 2013. Landscape planning on a large scale: Confederated Salish and Kootenai Tribes partner with NARA. February 2013 NARA newsletter. http://nararenewables.org/feature/newsletter-3

NARA advertisement, provided by Stephen Locker (WSU) included in the 2012-2013, 19th Annual, Special College Issue of the *Winds of Change*, magazine.

James, L. 2012 NARA tribal projects team advertisement in the American Indian Science and Engineering Society, Winds of Change magazine.

James, L. 2012. Northwest Advanced Renewables Alliance Offers Nine-Month Internships. March newsletter of Teru-talk at: http://www.terutalk.com/March-2012.html

### Trainings, Education and Outreach Materials

January 15-16, 2013: NARA Tribal Partnership project kick-off meeting held at the KwaTaqNuk Resort in Polson, MT. Introduction of NARA project personnel and CSKT Forestry personnel with a short field tour of CSKT tribal forest lands and Salish Kootenai College.

February 5, 2013: Formal presentation of NARA and Tribal Partnership Projects to the Confederated Salish and Kootenai Tribes, Tribal Council (at the request of the tribe). Mike Wolcott and Laurel James, presenters.

April 19, 2013: Presentation of the tribal partnership project to the Tribal Summit held on the University of Washington Campus. Laurel James, presenter.

## Task E-2: GreenSTEM K-12 Initiatives

| Key Personnel | Affiliation |
|---|---|
| Tammi Laninga | University of Idaho |
| Steve Hollenhorst | Western Washington University |
| Danica Hendrickson | Facing the Future |
| Karla Eitel | University of Idaho |

### Task Description

The NARA Education Initiative, or ***GreenSTEM***, includes an imaginative suite of programs that seamlessly link an array of educational and training programs with our university and commercial partners in order to meet the region's most compelling energy development needs. The overarching goal of the GreenSTEM is to increase the capacity of the region for a transition to biofuels. This will be accomplished through four interrelated goals:

1. Meet the workforce needs of the bio-energy/bioproducts economy;
2. Develop the next generation of energy leaders for industry, government, and the civic sector;
3. Improve the biofuels literacy of teachers educating our future citizens; and
4. Strengthen the overall science literacy of these same young citizens in areas particular to the biofuels debate.

The program develops energy and biofuel curricula, which are field-tested at UI's award winning *McCall Outdoor Science School (MOSS)*, annually reaching 2,500 K-12 students and 150 teachers. This curricula will then be delivered via the web and social networking approach pioneered by *Facing the Future (FtF*), a Seattle-based non-profit renowned for web-based sustainability curricula. K-12 teacher training will also be achieved through MOSS teacher institutes and FtF webinars and professional development workshops. Teachers and students will be impacted through this work and outcomes- through assessment and evaluation - will show that:

1. K-12 students are becoming more knowledgeable about biofuels, biofuels research, and energy.
2. K-12 students apply knowledge in energy literacy to successfully develop an approach to answering a problem-based energy issue.
3. K-12 teachers are more knowledgeable about biofuels, biofuels research, and energy.
4. K-12 teachers apply knowledge in energy literacy to help their students successfully develop an approach to answering a problem-based energy issue.
5. K-12 teachers participating in professional development programs will integrate problem-based learning and energy content in their home classrooms with increased confidence.

### Task E-2.1. K-12 Students (MOSS)

The McCall Outdoor Science School delivers biofuel education programs to 2,500 middle and high school students annually both during the school year and during the summer. New biofuel lesson plans are created and field-tested in partnership with FtF. Select students will participate in conjunction with their teacher and MOSS graduate students as they prepare a problem-based project to compete in the Washington State University (WSU) Imagine Tomorrow (IT) Competition.

### Task E-2.2. K-12 Teachers (MOSS)

The McCall Outdoor Science School delivers a summer workshop and an annual biofuel Teacher Institute for 12- 14 middle school to high school teachers. Teachers are paired with a MOSS graduate student who serves as a coach and technical resource for a team of students developing a problem-based energy project to compete in the Imagine Tomorrow Competition. An additional 40—50 teachers follow the IT competition preparation process via the web. Fifty teachers that accompany their 6th grade students to MOSS residential school programs participate by observing their students as they participate in biofuel focused education lessons. Teachers are also supported through a web-based “Energy Literacy Principle Matrix” (ELPM), designed to house and effectively organize educational materials covering a broad spectrum of subjects related to biofuels. Its design is flexible and adapts well to NARA activities while providing a single site where teachers or community members can effectively find information about biofuels.

### Task E-2.3: Energy Curriculum Web Delivery (FtF)

Facing the Future creates interdisciplinary K–12 curriculum resources that equip and motivate students to develop critical thinking skills, build global awareness, and engage in positive solutions for a sustainable future. These resources use global sustainability as a framework to present engaging, real-world issues such as energy to K-12 students. Our resources reach 1.5 million students each year and are used in all 50 states and 135 countries through web-based delivery.

Facing the Future provides K-12 educators with high quality, free and low-cost curriculum resources through the web that engage students in learning math, science, language arts and social studies through the context of real-world social, environmental, and economic issues such as energy. Our curriculum resources align with standards in all U.S. states. FtF’s professional development services equip school districts, schools and educators with sustainability and global education frameworks and content, instructional strategies, and curriculum resources to help students excel academically. Facing the Future works with 12 peer educators from around the country who provide professional development to other educators based on FtF resources.

## Activities and Results

### Task E-2.1. K-12 Students (MOSS)

*Task 1 activities* are currently ongoing. The McCall Outdoor Science School has trained 34 University of Idaho graduate students from the College of Natural Resources to teach biofuel science to K-12 students. New lessons centered on energy literacy were adapted from FtF’s energy curriculum. These lessons were piloted in the summer of 2012 and throughout the 2012-2013 school year. An additional lesson involving the calculation of how much jet fuel can be created from one tree was created at MOSS during the summer of 2012. Throughout the school year graduate students have refined and further developed these lessons. All K12 students who attend MOSS will do at least four energy literacy lessons while in residence at MOSS. Currently, a MOSS graduate student is developing an entire Energy Literacy themed day that will be taught to new MOSS graduate students in summer 2013.

*Task 1 results:* A random sample of students participating in MOSS residential programs in Fall 2012 and Winter 2013 (n=129) showed a statistically significant increase in energy literacy as measured by a four-item instrument. Mean scores were 2.3 out of 4 for Time 1, and 2.6 out of 4 for Time 2. While this is not a large gain, it is moving in a positive direction. A new instrument is being designed that will include more items and curriculum is being modified to more consistently address content related to energy literacy.

## Task E-2.2. K-12 Teachers (MOSS)

*Task 2 activities* are currently ongoing. One of five major goals for the NARA project is to elevate the level of bioenergy literacy, particularly as it relates to biofuels and the NARA supply chain. Two five-day teacher workshops were conducted during the summer of 2012 focused on problem-based learning about biofuels, water resources and climate change. Each participating teacher was required to recruit teacher “followers’ to follow the workshops online via the “adventure learning at MOSS” blog. In addition, MOSS staff held a three-day workshop, “MOSS Imagines Tomorrow” (MIT) in the fall of 2012 with 14 teachers to initiate training for teachers to create teams of high school students to take to the IT competition in May 2013. The training included an in-depth discussion of NARA’s goals and achievements. MIT is a teacher professional development effort that aims to integrate multiple pieces of the NARA project by offering curriculum support, content support and coaching for teachers as they develop and coach teams of students who will participate in the IT competition this May. MOSS held a kick-off weekend in November 2012 where teachers were introduced to the NARA project and developed new understandings about the various challenges being undertaken by NARA scientists in developing aviation biofuels. The teachers identified various pieces of the NARA puzzle that their students might address in developing a project for IT. Additionally, IT staff attended the workshop to present on the competition itself to help teachers understand the logistics of bringing a team to the competition. MOSS graduate students are mentoring these high school teams throughout Idaho to participate in the IT competition, and they have been meeting monthly with the teachers to monitor their progress. Currently, 11 teams mentored by MOSS graduate students are registered for the competition. All MOSS graduate students and several staff will attend the competition in May to serve as judges.

In addition to direct teacher contact, MOSS has also created a web-based “Energy Literacy Principle Matrix” (ELPM), designed to house and effectively organize educational materials covering a broad spectrum of subjects related to biofuels. Its design is flexible and adapts well to NARA activities while providing a single site where teachers or community members can effectively find information about biofuels. For K-12 educators, this web-based resource is unique in that it cross-references written, image and video materials to both fundamental science concepts and to the energy literacy concepts outlined by the U.S. Department of Energy. If a teacher requires materials such as lesson plans, data sets, videos, images, activities software and modules to support specific science standards or topics, they can easily discover and retrieve it through the ELPM. Additionally, content can be screened for those tailored to specific grade levels. The matrix has already been a great help to middle and high school teachers developing projects for the upcoming IT competition.

## Task 2 results:

For all teacher workshops:

- All participants showed a statistically significant increase in content knowledge related to biofuels, water resources and climate change.
- In a 9-month follow-up survey, 68% of teachers report being more likely to use a problem-based learning pedagogy after being involved in a MOSS teacher workshop.
- 90% of teachers report that they learned new ways of teaching.
- 66% percent of teachers agree or strongly agree that they have a good understanding of biofuels, that they understand key parts of the supply chain and that they have enough of an understanding to have developed an informed opinion about the feasibility of a woody biomass biofuel program in the Pacific Northwest.
- 45.8% of teachers say that they have been able to incorporate biofuels into their teaching.

### Task E-2.3. Energy Curriculum Web Delivery (FtF)

*Task 3 activities*: Over the last two years, Facing the Future (FtF) has researched and developed a 2-week energy unit for middle school students and a 2-week energy unit for high school students. The purpose of these units is to provide classroom teachers with accessible, interdisciplinary lessons that will expose students to foundational energy concepts and provide students the opportunity to critically think about the sustainability of alternative energy sources such as woody biomass.

FtF has conducted a teacher pilot for the middle and high school lessons. Teachers that participated in the Fall 2012 Energy Unit Pilot viewed an FtF-created webinar, *Fueling the Future*, which provided an overview of the lessons and discussed the importance of fostering energy literacy in our youth.

*Task 3 results:* Staff at MOSS reviewed early drafts of the two-week energy unit for middle school. FtF's Professional Development Manager, Dave Wilton, and Curriculum Developer, Danica Hendrickson, introduced these lessons to MOSS graduate students via an interactive webinar. The MOSS graduate students piloted the lessons during the MOSS 2012 summer programs. MOSS graduate students continue to use these lessons during their 2012-2013 school year programs and **student pre- and post-tests have shown significant growth in student's knowledge of energy concepts after having used these lessons (see MOSS Task 1 results above).**

After the middle and high school lesson pilot, eight middle school teachers (including one special education teacher) and three high school teachers provided FtF with feedback on these lessons. This included the feedback from at least one teacher from Idaho, Washington, and Oregon. Feedback was anecdotal and most teachers found the lessons effective in stating the learning objectives. Feedback also suggests that the lessons were easy to use and helped challenge student misconceptions about energy. For example:

### If you were to tell a colleague or co-worker about this resource, what would you say?

> "Activity 6: This activity helped my students to understand that aviation is not used just for recreational purposes. I had my students do both Baggage Claim and Air Routes online activities which helped them to understand how much the aviation is tied to our daily lives and how much the industry has grown over the years." (Teacher from ID)

> “The lesson enables students to see that all sources of energy have positive and negative considerations and to discuss the real world dilemmas that include global concerns, costs, and environmental impacts.”

**Did you notice any commonly held misconceptions about energy? What were they? How well did the lessons address these misconceptions?**

> “Did not know all the ways we get or use energy.”

> “They didn’t know there were so many alternatives to fossil fuels.”

> “Students didn’t understand that energy just changes from one form to another, and I think these lessons helped with gaining this knowledge.”

> “Misconceptions: Energy appears and disappears rather than changing forms. They did not have a good concept of what it means to be *stored* energy.”

> “Lesson 1 really made the students aware that energy is not ‘saved’ and only transformed. Also, the students realized that they are constant users of energy whether at rest or in motion. Lesson 2 made students aware of how large consumers of oil the United States is. Also, that we do produce quite a great amount of oil, yet still rely on other countries. Great conversations were brought up over this!”

**Were any concepts lacking from the unit that you consider essential for teaching about energy or biofuels?**

> “I don’t feel there were any concepts about energy that were lacking. As for biofuels, I must say that I was learning about them right along with the students!”

**Would you use this lesson in your classroom in the future? Please explain why or why not.**

> “Yes, I will use this unit in the future. I started designing a similar energy unit last year and this lesson was more elegant and all the information was in one place for me.”

**General Feedback**

> “For all of the lessons I used, I would say they are well planned for the time recommended; they are engaging and give students many opportunities for discussion. The background materials and support is helpful and detailed. The lessons were easy to adapt for IEP [individualized education program] students and gave them many opportunities for success.”

Over the last two years, FtF’s Educational Technology Manager, Alicia Keefe has also developed, customized, and piloted the digital platform that will be used for the energy units mentioned above.

## Recommendations/Conclusions

### MOSS

Based on measured outcomes, both the K12 student and K12 teacher programs have elevated the level of bioenergy literacy of participants. As a result, we will continue the three-pronged approach of direct K12 student programming, teacher professional development, and development of the web-based Energy Literacy Principle Matrix.

Moving forward, MOSS and FtF will continue to integrate their efforts especially in the areas of K12 and teacher assessment and teacher professional development. The current integration of MOSS teacher professional development with the IT competition is a positive one for both programs in terms of teacher recruitment. As NARA scientific discoveries are made and communicated to the K12 education team in years 3-5, MOSS will integrate this new science into new and existing lesson plans for K12 students and teachers and graduate students. Additionally, MOSS teacher professional development will focus on and occur in NARA communities in years 3-5. Finally, a cohesive and comprehensive set of energy literacy assessment tools will be developed for K12 students, K12 teachers and MOSS graduate students. A new K12 assessment instrument is being designed that will include more items and curriculum is being modified to more consistently address content related to energy literacy.

### FtF

FtF plans to develop a Moodle version and Smart Board lessons by the end of July. A print version of both the middle and high school energy units will be available on their website. The digital versions of the energy units will be updated with NARA-based science information as it is made available. FtF will also conduct Professional Development webinars for teachers that involve NARA scientists and regional stakeholders (e.g., private timber landowners, federal and state land management agencies, economic development specialists).

## Physical and Intellectual Outputs

### Biofuel Lesson Plans

1. *Value of a Tree* – how much biojet is in one tree?
2. *Hydroboxes Demonstration* - Students will see the impact of surface types on surface and ground water.
3. *Wind and Solar Audit* - Students will investigate the feasibility and practicality of installing wind and/or solar panels on MOSS campus as a viable source of energy.
4. *Toil for Oil* (adapted from FtF) - Students will explore the difficulties and limitations of extracting oil from the ground. Students will learn about the limitations of non-renewable resources and various renewable resources.
5. *Energy Audit* (adapted from FtF) - Students will investigate the energy needed to power various electronics on MOSS's campus which will include a discussion of energy sources within the state of Idaho.
6. *Renewable Energy* (adapted from FtF) – Pro and Con exploration.
7. *Biofuel* (adapted from FtF) - students learn about various sources of biofuel and evaluate their sustainability.
8. *Planes In Flight* (adapted from FtF) - students evaluate the sustainability of jet fuel from the perspective of various government agencies.

9. *Lifecycle of a Fuel* (adapted from FtF) - students use a lifecycle assessment framework to evaluate the impacts of producing various types of fuel.
10. *Fuel Debate* (adapted from FtF) - students debate about the more sustainable fuel option for our region.

### Refereed Publications (accepted or completed)

Hougham, R. J., Eitel, K. B., & Miller, B. G. (2013). *AL@: Combining the strengths of adventure learning and place based education*. 2012 CLEARING Compendium.

Eitel, K.B., Hougham, R.J., Miller, B.G., Schon, J. & LaPaglia, K. (2013). *Upload/download: Empowering students through technology-enabled problem-based learning*. Science Scope, Vol. 36, No. 7.

Hougham, R. J., Bradley Eitel, K., & Miller, B. G. (2013). *Technology-enriched STEM Investigations of Place: Using Technology to Extend the Senses and Build Connections to and between Places in Science Education.* Manuscript in review at the Journal of Geoscience Education.

Eitel, K.B., R.J. Hougham, B.G. Miller, and J.S. Schon. A technology-enabled problem-based learning approach to connect teachers online and face-to-face to content and experiences in water resources, climate change and biofuels (in preparation for the Journal of Digital Learning in Teacher Education).

Schon, J., R.J. Hougham, and K.B. Eitel. The Value of a Tree. (in preparation for The Science Teacher).

### Conference Proceedings and Abstracts from Professional Meetings

Hougham, R.J. (2013). *Education at the Speed of Adventure: Global and Local Student Inquiry in Climate Science Education.* Northern Rockies URISA -Intermountain GIS Users Conference, Invited Keynote.

Hougham, R.J., Miller, B.G., Cox, C., & Walden, V. (2012). *Communicating Science Research to High School Students in the Arctic: Adventure Learning @ Greenland*. Poster presentation accepted, American Geophysical Union (AGU) Annual Meeting, San Francisco, CA.

Hougham, R.J. (2012). *Endangered Futures, Voices for Change: Global and Local Student Inquiry of our Changing World Through Adventure Learning.* National Council for Geographic Education (NCGE), San Marcos, TX.

Hougham, R.J., J.A. Schon, K.B. Eitel, and S.A. Hollenhorst. 2012. *Education at the Speed of Research: Communicating the Science of Biofuels.* In Proceedings of the Sun Grant Initiative. New Orleans, LA.

Veletsianos, G., B. Miller, K.B. Eitel, J.U.H. Eitel, and R.J. Hougham. 2012. *Localizing Adventure Learning: Teachers and Students as Expedition Leaders and Members.* In Proceedings of Society for Information Technology & Teacher Education International Conference 2012 (pp. 2164-2169). Chesapeake, VA.

## Research Presentations

Veletsianos, G., B.G. Miller, K. Eitel, J. Eitel, and R.J. Hougham. 2012. Localizing adventure learning: Teachers and students as expedition leaders and members. Presented at: *Society for Information Technology & Teacher Education (SITE) Annual International Conference*, Austin, TX. March 5, 2012.

Miller, B.G., R.J. Hougham, and K.B. Eitel. 2012. AL@UI: Connecting people to places for meaningful learning. Presented at: *Society for Information Technology & Teacher Education (SITE) Annual International Conference*, Austin, TX. March 5, 2012

Eitel, K.B., and R.J. Hougham. 2012. Adventures in learning the MOSS way: A new PD model using problem-based learning. Presented at: *Tri-State EPSCoR Consortium Annual Meeting*, Sun Valley, ID. April 4, 2012.

Hougham, R.J., J.A. Schon, K.C.B. Eitel, D. Hendrickson and S.A. Hollenhorst. 2012. *Education at the Speed of Research: Communicating the Science of Biofuels*. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Hougham, R.J., J.A. Schon, B. Schroeder, K.C.B. Eitel, and S.A. Hollenhorst. 2012. NARA energy literacy matrix: http://energyliteracyprinciples.org. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Hendrickson, D. 2012. Facing the Future: Energy unit overview. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Hendrickson, D. 2012. Life cycle assessment lesson: Feedback on a working draft. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

Schon, J., R.J. Hougham, K. Eitel and S. Hollenhorst. 2012. Value of a Tree. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

## Other Publications

MOSS Blog. *Teaching Adventure Learning @ MOSS*. http://www.teachingadventurelearningatmoss.wordpress.com - Blog site we used for the teacher workshops.

Hougham, R.J. *Energy Literacy Principl*es. http://energyliteracyprinciples.org/ - the Energy Literacy Principles Matrix

CSS 566. *Biofuels*. http://ecosensing.org/teaching/css-566/group-products/biofuels/ - graduate student products from CSS 566

One-page K12 Education Team marketing piece for both internal and external constituents.

Two-page Energy Literacy Principles Matrix promotional piece for both internal and external constituents

## Videos and Webinars

The University of Idaho McCall Outdoor Science School was featured September 19, 2012 in a KTVB (Boise NBC) news story < http://www.ktvb.com/news/slideshows/Outdoor-school-helps-students-experience-science-170502646.html>

Combined efforts with the NARA Outreach Team to build first draft of project feedstock video.

Wilton, Dave. *Fueling the Future: Energy Explorations Webinar*, recorded in Fall 2012 for teachers piloting Facing the Future's energy curriculum. http://www.youtube.com/watch?v=SGWTh_irMVU&feature=youtu.be

## Trainings, Education and Outreach Materials

MOSS Summer Teacher Workshop**,** June 18 – 22, 2012 (14 teachers plus 47 online followers) engaged in problem-based learning about biofuels, water resources and climate change.

ISTEM Summer Teacher Workshop**,** June 25 – 29, 2012 (14 teachers plus 47 online followers) engaged in problem-based learning about biofuels, water resources and climate change

MOSS Imagines Tomorrow, November 9 – 11, 2012 (12 teachers) plus Spring 2013 follow-up in helping teachers to coach Imagine Tomorrow teams.

CSS 566, Spring 2013**,** 16 MOSS Graduate Students learning about biofuels, climate change and water resources; developing curricular material to support MOSS K12 programming. Sixteen lesson plans have been developed in support of teaching energy literacy, climate change and water resources concepts.

# Task E-4: Imagine Tomorrow with BioFuels

| Key Personnel | Affiliation |
|---|---|
| Liv Haselbach | Washington State University |
| David Bahr* | Washington State University |

*Dr. Bahr has moved and is no longer affiliated with the NARA project.

## Task Description

The NARA Imagine Tomorrow program is designed to engage high school students in developing creative solutions to society's energy challenges. This project builds on the Imagine Tomorrow high school science competition at Washington State University. Now in its sixth year, the goal of Imagine Tomorrow is to unite educators, scholars, and industry leaders to teach students of all backgrounds and high school grade levels how to translate ideas into results. This energy-based competition program has been expanded to include a biofuel track, with the following objectives:

1. Engage future energy innovators. Students find ways to shift the public mindset, reshape governance and policy, reengineer technologies, and redesign communities toward a new energy future.
2. Foster collaboration. The competition shows students how collaborative actions make a difference in meeting the challenge of energy production and use in the 21st century.
3. Support educators. High school teachers inspire students to think bigger, gather information from diverse resources, and jointly develop new ideas.
4. Strengthen our community. Imagine Tomorrow creates connections among students, research faculty, and industry leaders. Students build confidence in their ability to make a positive difference in their communities.
5. Raise energy literacy. Imagine Tomorrow builds awareness of energy issues among students, educators, and the general population.

## Activities and Results

This project has provided support of Tasks 1 and 2, engagement of future energy innovators and fostering collaboration, in its first and second years of involvement (2012 and 2013) extending the reach of the competition from one state (Washington) to three additional states (Idaho, Montana and Oregon). In 2012 433 students participated as compared to 363 students in 2011. High registration numbers to date point to an even higher level of student participation in 2013, and with the addition of the biofuels category in 2012, the number of biofuels projects increased that year from 3 to 14 teams. An assessment team has been set-up to evaluate the effects of Imagine Tomorrow on students' STEM career choices and energy literacy. In 2012, this team conducted a very preliminary student survey with a 35% response rate which suggests that participation is having positive effects on students' STEM career related attitudes and interests.Results for attitude for engagement and STEM interest are encouraging and summarized in Figures 1 and 2. The project has also supported Task 3, supporting educators, with the involvement of more schools and the collaborative work with the NARA researchers from MOSS to mentor teachers involved in the competition. In both 2011 and 2012 there were 46 schools. However the current registration indicates more schools will participate in the May 2013 event. The competition is also strengthening connections among students, faculty and industry (Task 4) with the vast number of judges volunteering for the competition (117 in 2011, 119 in 2012 and 120 to date in 2013). Results from the 2012 survey also indicate positive comments as listed in Table 1. An energy literacy assessment process began in early 2013. The goal is to use the competency rubrics in Tables 2 and 3 to rate the level of energy literacy demonstrated through two available deliverables, the *abstract* and the *poster*. Final abstracts are available for the 2009, 2010, 2011 and 2012 competitions and using this rubric as a guide, each abstract has been rated on a scale from Absent to Mastering for both general energy literacy and also biofuel literacy (some projects dealt with biofuels even before the *biofuels* category was implemented). The expectation is that most of the abstracts will not exceed “emerging” in quality. This is not considered to be a weak point as the expectation is that after the project is done the students will have learned more and that their poster score will show improvement. In a similar manner, when the posters are ranked after the competition in May, it is not expected that the grading rubric will exceed the *competent* level, as beyond this would entail additional dedicated energy curricula that students would not be exposed to at this level. Figure 3 provides a comparison of how the abstracts show improvement in energy literacy competency in 2012. Figure 4 provides some insight into the initial influence of the addition of the biofuels category. Note that in 2009, the beginning of the recession and high fuel prices may also have influenced the outcomes. Future assessment activities will provide additional information.

Figure 1: Attitudes: Pursing careers where I could work on Imagine Tomorrow like projects would be:

Figure 2. Degree of Interest in STEM Careers after Participating in Imagine Tomorrow

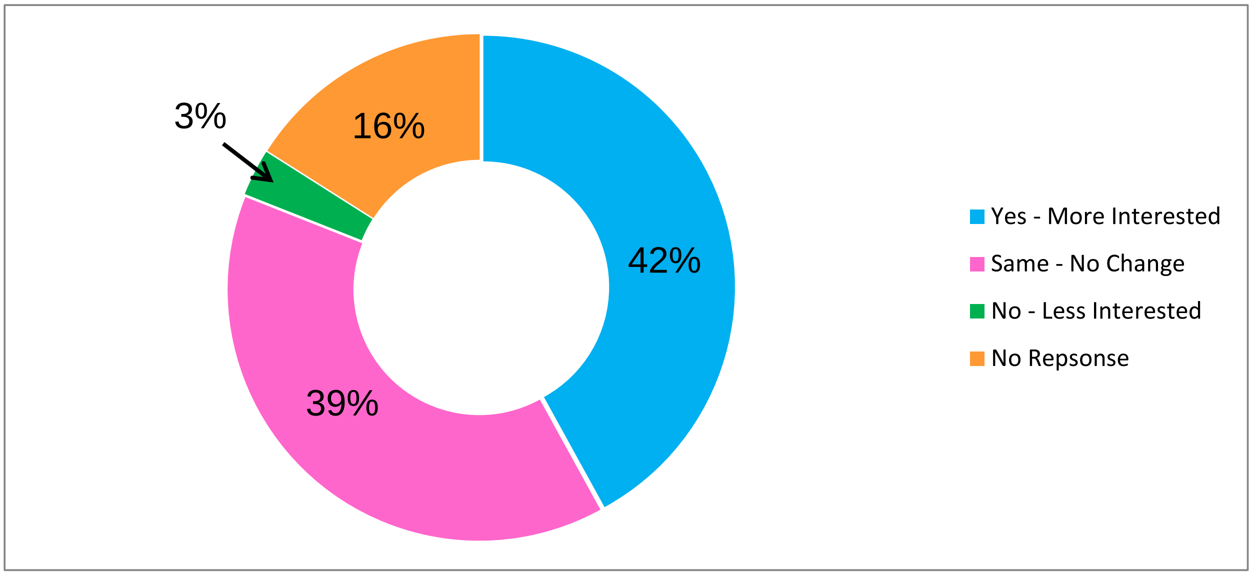


**Table 1.** Students' Revelatory Comments – Sample Quotes 2012

(*Research Team's Assessment)

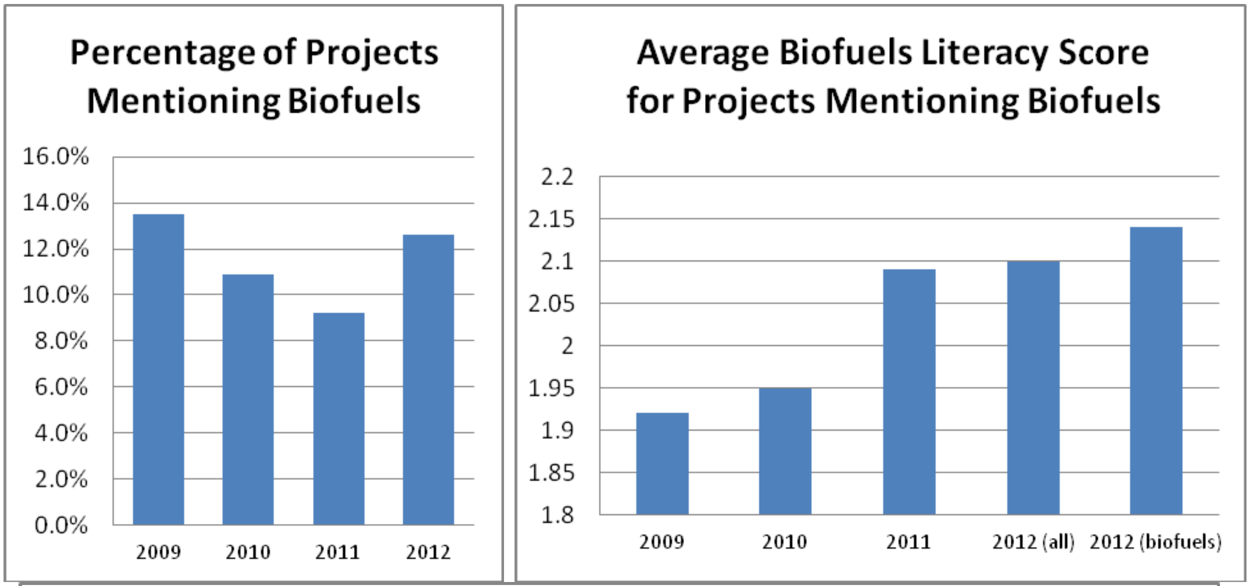
| |
|---|
| *"I will want to be a cardiovascular surgeon but <u>I might change</u> my mind before I graduate and become something having to work with biofuel"* **[Reveals that IT competition can help change career interest]**[*] |
| *"I'm <u>more interested</u> in helping the environment and making people more aware of what is going on around the world and what we can do to stop it."* **[Reveals that IT competition can help enhance interest]** |
| *"I realized what it took and that <u>I can do it</u>."* **[Reveals that IT competition can help cultivate more confidence]** |
| *"After <u>seeing all the designs of the others</u> I am more interested in coming up with designs of my own."* [**Reveals that IT competition can help uncover interest which they never knew they had]** |
| *My project <u>exposed me to the process</u> required to obtain materials such as nitrogen cylinders and provided me with opportunities to meet scientists.* **[Reveals that IT competition provides exposure that students may not get at their schools]** |
| *Engineering is a very interesting subject. It involves a lot of thinking and creativity. This project really helped me <u>to understand what it would be working in that field</u>.* **[Reveals that IT competition can enhance learning]** |
| *I've always wanted to be an engineer and this <u>made me more sure of that</u>"* **[Reveals that IT competition can help reinforce student choices]** |
| *I've always wanted to go into science and this has <u>reaffirmed</u> that"* **[ Reveals that IT competition can help reinforce student choices]** |
| *This competition had me realize that we need to help <u>make a difference</u> for our future.* **[Reveals that IT competition can enhance students' social responsibility]** |

**Table 2:** Energy Literacy Rubric (Version April 2013)

<table>
<tr><th colspan="7">Energy Literacy</th></tr>
<tr><th>Absent</th><th>Pre-Emerging</th><th>Emerging</th><th>Developing</th><th>Competent</th><th>Effective</th><th>Mastering</th></tr>
<tr><td colspan="3">Students:<br>- Do not identify issue<br>- Do not summarize the issue<br>- Do not consider stakeholders<br>- Focus on their own perspective<br>- Do not consider impact or context<br>-Do not consider current information available on the issue</td><td colspan="2">Students:<br>- Begin to frame the issue, but gloss over key details<br>- Discuss approaches to resolve issue<br>- Discuss the impact in one or two contexts<br>- May consider perspectives of some stakeholders<br>-Mention available information</td><td colspan="2">Students:<br>-Frame professional challenge<br>-Develop appropriate approaches to resolve the issue<br>-Deeply examine impact<br>-Seek and evaluate outside sources<br>-Examine current information as it relates to their research</td></tr>
</table>

**Table 3:** Biofuel Energy Literacy Rubric (Version April 2013)

<table>
<tr><th colspan="7">Biofuel Energy Literacy</th></tr>
<tr><th>Absent</th><th>Pre-Emerging</th><th>Emerging</th><th>Developing</th><th>Competent</th><th>Effective</th><th>Mastering</th></tr>
<tr><td colspan="3">Students:<br>-Do not address biofuels<br>-Do not explain why alternative fuels are needed<br>-Do not mention potential impacts of biofuels<br>-Do not consider challenges associated with biofuels</td><td colspan="2">Students:<br>-Address a specific biofuel<br>-Briefly state why they are needed<br>-Discuss one or two possible impacts<br>-Mention possible technology or market challenges</td><td colspan="2">Students:<br>-Address feedstock, processing, etc. of a particular biofuel<br>-Explain with specific facts why they are needed<br>-Explain specific future impacts associated with particular fuels<br>-Explain potential challenges in terms of technology and market</td></tr>
</table>



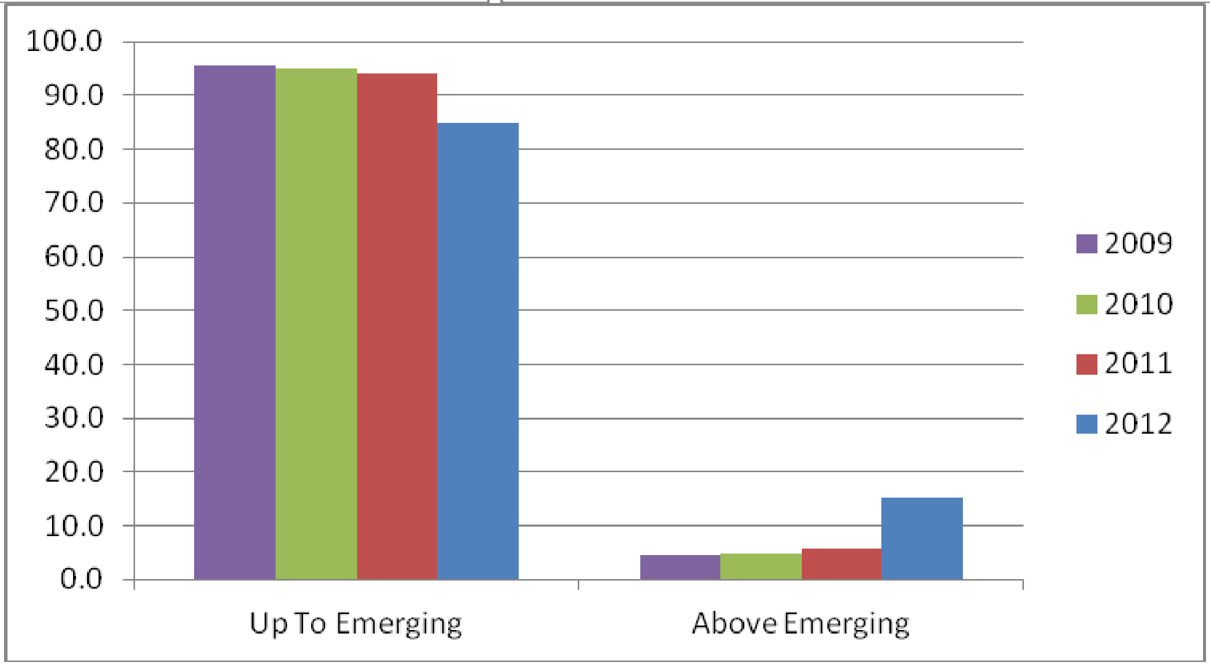


**Figure 3:** Results of the general energy literacy assessment for 2009 through 2012 relative to emerging.

**Figure 4**: Preliminary biofuels ranking on the abstracts: Percentage mentioning biofuels and score

## Recommendations/Conclusions

Support for the Imagine Tomorrow Competition has not only seen expansion in the numbers of participants and states involved, but is also apparently impacting energy literacy and STEM interest in positive ways. Addition of the biofuels category is also providing a larger platform for promoting alternative fuel knowledge and growth in the region. Additional assessment of these outcomes is growing with the leveraging of additional funds from other sources for the assessment research activities, and will be applied in additional ways during the May 2013 and future competitions. The STEM surveys will be expanded and compiled into databases and the energy literacy rubric will be piloted on the main competition deliverable; the *poster,* in addition to collection of supporting information from other competition outputs such as PowerPoint files and demonstrations. The collaborative work among other NARA education team members with the Imagine Tomorrow is making the potential for positive outcomes even more possible, particularly with the investment by the MOSS team in teacher mentoring and education in energy literacy and student team support. The marketing campaign for 2013 also included distribution of energy-based literature in new media that is expected to enhance the interest in the competition and also increase energy knowledge in those who are not able to directly participate. It is recommended that the level of support for the competition increase with the prediction of higher rates of participation, additional assessment and a more widespread reach. Continued participation by high profile executives such as the Washington State Superintendent Randy Dorn and 2013 keynote speaker Bob Peters, Washington State President of the Bank of Americapoint towards even greater success and engagement in collaboration and strengthening our communities for the future.

## Physical and Intellectual Outputs

### Research Presentations

Haselbach, L. 2012. Imagine Tomorrow – 6th annual problem-solving competition for grades 9-12. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

### Other Publications

About a dozen regional newspapers have highlighted the NARA supported Imagine Tomorrow program. Please see http://imagine.wsu.edu/news/default.aspx for an up to date list.

- Imagine Tomorrow: How to deliver a memorable presentation (pdf), ***The Seattle Times***, November 27, 2012
- Imagine Tomorrow: A better world through technology (pdf), ***The Seattle Times***, November 20, 2012
- Imagine Tomorrow: A better world through design (pdf), ***The Seattle Times***, November 13, 2012
- Imagine Tomorrow: A better world by changing behavior (pdf), ***The Seattle Times***, November 6, 2012
- Imagine Tomorrow: A better world through biofuels (pdf), ***The Seattle Times***, October 30, 2012
- Green Washington Awards 2012: Government/Academia, ***Seattle Business***, November 7, 2012

- EHS students take home prizes on Imagine Tomorrow competition, ***The Daily Record***, June 22, 2012
- CHS aims for a healthier world, Camas School District, June 8, 2012
- Yelm students earn honors at 'Imagine Tomorrow' contest, Yelm KOMO News, June 7, 2012
- Todd Beamer Students Win Imagine Tomorrow Regional Science Fair, Federal Way Public Schools, May 25, 2012
- Missoula students take first place in science competition, KPAX.com, Missoula, MT, May 24, 2012
- Students Work With DEA To Grow Sustainable Garden, NBCMontana.com, May 24, 2012
- Students propose energy solutions, compete for $100k, WSU News, May 22, 2012
- Sentinel High team gets win at problem-solving competition, Missoulian, May 21, 2012
- Toward a sustainable future: MHS students win second place in biofuels category at 'Imagine Tomorrow' event, ***Moscow-Pullman Daily News***, May 21, 2012

Award winners and event programming at http://imagine.wsu.edu/past/2012/default.aspx

**Videos and Webinars**

Missoula Students Take First Place in Science Competition. KPAX.com, Missoula, MT, May 24, 2012. http://www.kpax.com/videos/missoula-students-take-first-place-in-science-competition/

YouTube video thanking the USDA is at http://www.youtube.com/watch?v=6Lr0mLrTwbk

**Trainings, Education and Outreach Materials**

Imagine Tomorrow Competition. 2012. Washington State University, Pullman, WA. May 18-20, 2012.

# Task E-5: Summer Undergraduate Research Experiences (BF-SURE)

| Key Personnel | Affiliation |
|---|---|
| Shelley Pressley | Washington State University |
| David Bahr* | Washington State University |

*Dr. Bahr has moved and is no longer affiliated with the NARA project.

## Task Description

BF-SURE is a summer immersion research experience for undergraduates aimed at giving them hands on skills in biofuels and bioproducts research, feeding the pipeline into energy research careers.

SURE participants participate in full time research experiences for a summer (10 week) program that provides laboratory, fieldwork, and research skills in the broad area of biofuels and bioproducts research. The SURE program goals are:

1. To excite undergraduate students about cutting edge research in the area of biofuels and bioproducts.
2. To develop skills needed for future biofuels and bioproducts research careers
3. To increase the number of students participating in biofuels and bioproducts research in the Northwest, including those from schools that do not have strong research efforts.
4. To integrate mentoring experiences for graduate students and post docs into a formalized training program.

## Activities and Results

### Recruit and Select SURE Students

The second group of SURE students is currently being recruited and accepted for the summer 2013 program. The first year (summer of 2012) there were a total of 11 applicants resulting in 8 students that were selected for participation. Primary recruitment efforts included development of a NARA SURE website (http://www.nararenewables.org/ed) and individual faculty members in NARA contacted students at their schools. Although the number of applications was low the first year, we were able to reach a very diverse group of applicants. Demographics of 2012 applicants were 36% women, 64% men; and 18% Hispanic, 9% Native American, 9% Asian, and 64% Caucasian.

Additional recruiting efforts were implemented in the Fall 2012/Spring 2013. An informational flyer advertising NARA SURE was developed and distributed at the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), the American Meteorological Society (AMS) Annual Meeting and the 2013 Small Log Conference. In addition, a notice was posted on the Institute for Broadening Participation: Pathways to Science website (http://www.pathwaystoscience.org/). To date, a total of 38 applicants have been received and offers are currently being made to selected students (3 to date). Demographics of 2013 applicants are 61% women, 39% men; and 11% Hispanic, 3% Native American, 8% African American, 34% Asian/Pacific, and 39% Caucasian.

## Recruitment of Faculty Mentors

For the first year individual faculty in NARA (as well as industrial partners) were solicited for their interest to host a summer student project. During the annual NARA meeting in Missoula, MT (Sept 13-14, 2012), a poster was presented on the SURE experience and multiple contacts were made with NARA members (both faculty and industrial partners) for the NARA:BF-SURE 2013 program. Currently 6 projects have been identified for 2013 including projects at Penn State, WSU tri-cities, WSU Pullman, US Forest Service in Madison, WI, and two projects at Weyerhaeuser (Federal Way, WA).

## SURE Experience

The students are paid a stipend of $5000 for the full summer of working full time, with additional costs for housing or tuition added for students depending on location and on–site needs. In 2012, students were placed at 4 different NARA locations: WSU Pullman (3), WSU-TC (1), Oregon State (2), and UW (1). In Pullman students are co-located in housing with other summer researchers. All students participated in the poster session on August 3, 2012 in Pullman. The final 7 student participants, their home schools, and their SURE appointment schools are listed here and shown in Figure 1.

1. Margaret Buffum (OSU/OSU)
2. Lucy Cheadle (Washington University / UW)
3. Brady Do (OSU/OSU)
4. Madeline Fuchs (Montana State / WSU-P)
5. Pedro Guajardo (WSU-TC / WSU-TC)
6. Anthony Lathrop (WSU-P / WSU-P)
7. Ellen Simonsen(WSU-P / WSU-P)
8. Burdette Birdinground* (Salish Kootenai College / UW)

SURE participants traveled to Pullman to present posters at the culminating poster symposium (Table 1), sponsored by the WSU Office of Undergraduate Research. Over 70 undergraduate researchers from various WSU sponsored programs participated along with the SURE students.

Figure 1: SURE participants on Aug 3, 2012 during the poster symposium. Front row, l to r: B. Birdinground, M. Buffum, Middle row, l to r: L. Cheadle, B. Do. Back row, l to r: P. Guajardo, Jr., M. Fuchs, E. Simonsen, A. Lathrop

Table 1: 2012 NARA SURE participants, poster title, and research advisor.

| Northwest Advanced Renewables Alliance; USDA-Funded | | | |
|---|---|---|---|
| **Sec.** | **Poster Title** | **Author** | **Advisor** |
| 1.1 | Scale up of an ultra-low cost in-forest thermal processing of biomass | Burdette Birdinground* | Daniel Schwartz |
| 1.2 | Moisture Content in Biomass Piles | Maggie Buffum | Glen Murphy |
| 1.3 | Analysis of Bioproducts from Ultra-Low Cost Biomass Processing | Lucy Cheadle | Daniel Schwartz |
| 1.4 | Assessing Risks of Arson in Biomass Piles | Brady Do | Glen Murphy |
| 1.5 | NARA Biofuels Production Emissions | Madeline Fuchs | Michael Wolcott |
| 1.6 | Diluted acid and peroxide pretreatments of Douglas fir biomass | Pedro Guajardo Jr. | Xiao Zhang |
| 1.7 | Effect of Hot Water Extraction on Mechanical Properties of Ponderosa Pine Chips | Anthony Lathrop | Vikram Yadama |
| 1.8 | Biobased Curing Agent for Epoxy | Ellen Simonsen | Jinwen Zhang |

*Burdette Birdinground worked under Dr. Daniel Schwartz, a UW NARA mentor; however he was not funded by the NARA SURE program.

## Recommendations/Conclusions

For We are headed into the second summer and everything appears to be on track. The next steps are to refine the projects with individual faculty members to ensure a successful summer experience for the students and mentors. In the future, students need to be notified sooner (ideally in March instead of April), as many of the students have already accepted other positions and are no longer available. In order to accomplish this, faculty need to submit project descriptions much sooner as well.

## Physical and Intellectual Outputs

### Physical

- Pre and post surveys were developed and administered to NARA SURE participants. The goal of the survey is to identify gains (from the student perspective) of the research experience, determine if career goals (i.e. decision to attend graduate school) change after a summer research experience, and establish how satisfied the students were with the program.

## Research Presentations

Bahr, D., S. Pressley and M. Wolcott. 2012. NARA SURE Summer Undergraduate Research Experiences. Poster presentation at NARA 2012 Annual Meeting, Missoula, MT, Sept 13-14, 2012.

## Other Publications

Sorensen, E. 2012. A Summer of Science, Washington State Magazine, Winter 2012/13, v12 n1, page 31-36. http://wsm.wsu.edu/s/index.php?id=998#.UVnCZqt36aI

Burke, C. 2012. Summer undergraduates = hot research. December 2012 NARA newsletter. http://nararenewables.org/feature/newsletter-2#story3

Makhani, B. 2012. WSU Hosts Summer 2012 Undergraduate Research Poster Symposium. University College News website, Aug. 9, 2012: http://universitycollege.wsu.edu/units/undergraduateresearch/News-Events/headlines/2012reupostersession/

Makhani, B. 2012. Summer Undergraduate Research Poster Symposium at CUE. WSU News, July 31, 2012: http://news.wsu.edu/pages/publications.asp?Action=Detail&PublicationID=32252&PageID=&RefererCode=uggc%3A%2F%2Farjf.jfh.rqh%2Fcntrf%2Ffrnepu.nfc%3FCntrVQ%3D%26Xrljbeqf%3DANEN

Makhani, B. 2012. Undergraduate Research poster Symposium August 3 at WSU Signals End of Summer STEM Programs and Special Efforts. University College News website, July 27, 2012: http://universitycollege.wsu.edu/units/undergraduateresearch/News-Events/headlines/2012SummerResearchSymposium/

Brickman, J. 2012. WSU Hosts Summer 2012 REU. University College News website, July 11, 2012: http://universitycollege.wsu.edu/units/undergraduateresearch/News-Events/headlines/reu2012kickoff/

One-page NARA SURE marketing piece for both internal and external constituents.

# Task E-6: Summer Undergraduate Research Experiences (SURE-SKC)

| Key Personnel | Affiliation |
|---|---|
| Adrian Leighton | Salish Kootenai College |

## Task Description

Biofuels and bioproducts offer a high value use for woody biomass. Tribal forestry operations generate substantial quantities of woody biomass during fuels reduction aimed at forest health, timber harvest, and other activities. These forestry operations are keen to realize the environmental, economic, and social benefits of developing high value products from the forest. In order to help accelerate the development of high value-added uses of woody biomass among Northwest tribal communities, NARA is partnering with the forestry program at Salish Kootenai College (SKC), a tribal university, to provide research opportunities tied to biofuels and bioproducts from woody biomass. Annual summer internship awards will be made to SKC Forestry students so they can join a NARA research university for a summer research experience.

SURE participants participate in full time research experiences for a summer (10 week) program that provides laboratory, fieldwork, and research skills in the broad area of biofuels and bioproducts research. The SURE program goals are:

1. To excite undergraduate students about cutting edge research in the area of biofuels and bioproducts.
2. To develop skills needed for future biofuels and bioproducts research careers.
3. To increase the number of students participating in biofuels and bioproducts research in the northwest, including those from schools that do not have strong research efforts.
4. To integrate mentoring experiences for graduate students and post docs into a formalized training program.

## Activities and Results

Three SKC students have interned in NARA related biomass research projects. All three have since leveraged this position in various ways at NARA related institutions. Two interns have been accepted to graduate school at the University of Washington with Dr. Ivan Eastin, who is involved in NARA's sister project. In the case of both students, the NARA internship proved to be a valuable asset in their applications and also their exposure to UW partners increased their interest in UW natural resource grad programs.

The third student successfully completed an internship in New Zealand studying fire ecology through a Montana State University PIRE grant. Again, NARA internship experience in biomass helped her leverage an internship (she had been unsuccessful in her previous application for the PIRE program) and she will be working with MSU researchers this summer in Yellowstone National Park on invasives and fire ecology.

Three internships will be set up this summer, including one that is with the Confederated Salish and Kootenai Tribes forestry department, building on biomass work that was done for them last summer.

## Recommendations/Conclusions

NARA has provided excellent opportunities for Native American undergraduates to conduct meaningful research. This has led to all three students to date pursuing other research internships and graduate school opportunities. This is creating a “ripple effect” at SKC that is leading to increased interest in NARA, in research and in graduate school.

## Physical and Intellectual Outputs

### Physical

- Two NARA interns have been accepted to Graduate School at the University of Washington. NARA related internship experience was an important factor in their acceptance (and the internships promoted interest in UW to start with).

### Research Presentations

None to date – though two NARA related student posters accepted for June 2013 Intertribal Timber Council Indian Timber Symposium

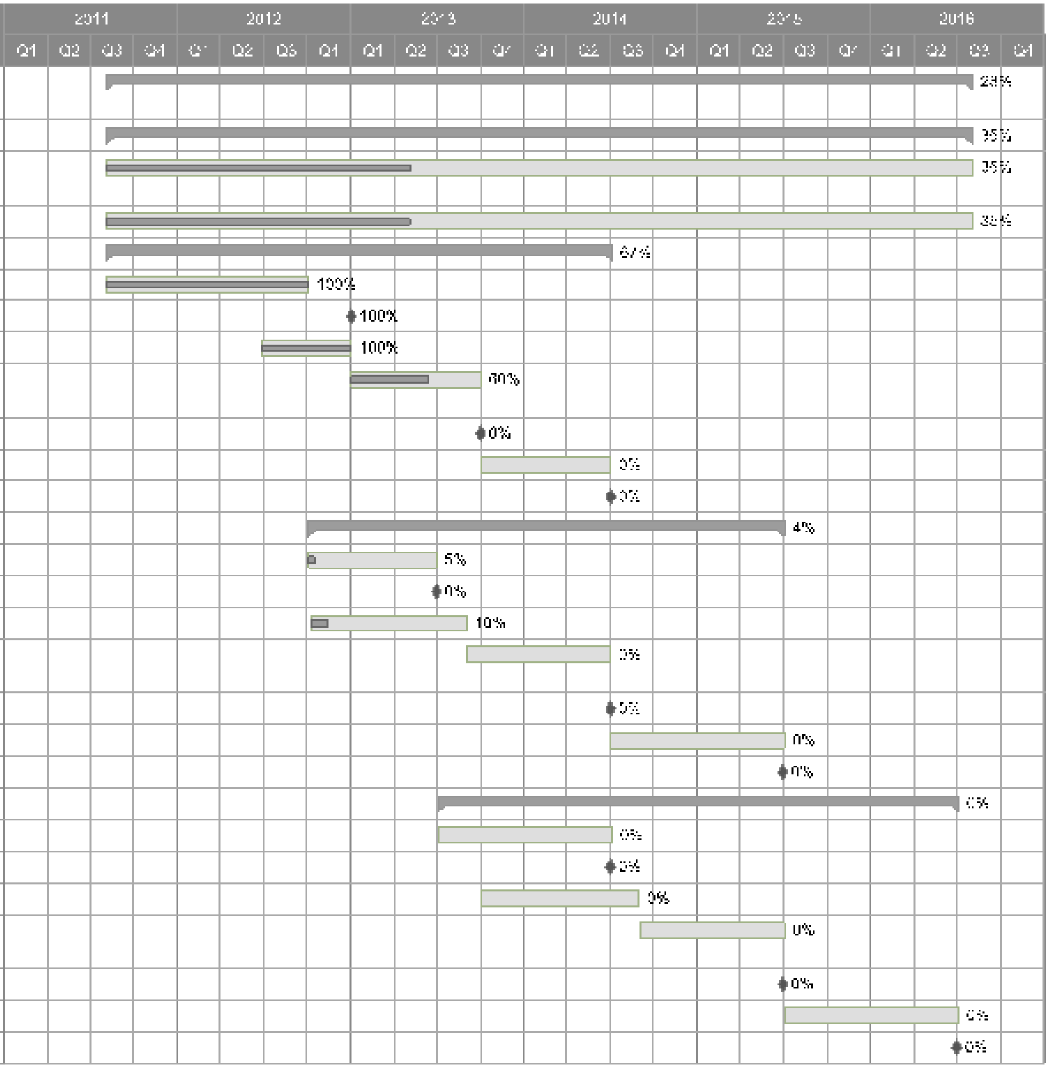
### Other Publications

**Tribal forest biomass could become jet fuel.** Lake County Leader, March 20, 2013. http://leaderadvertiser.com/news/article_22f2d800-91a1-11e2-98f2-0019bb2963f4.html

### Trainings, Education and Outreach Materials

Presentation on NARA project to student session of Traditional Knowledge and Fire Workshop, held at SKC on November 3-5, 2012

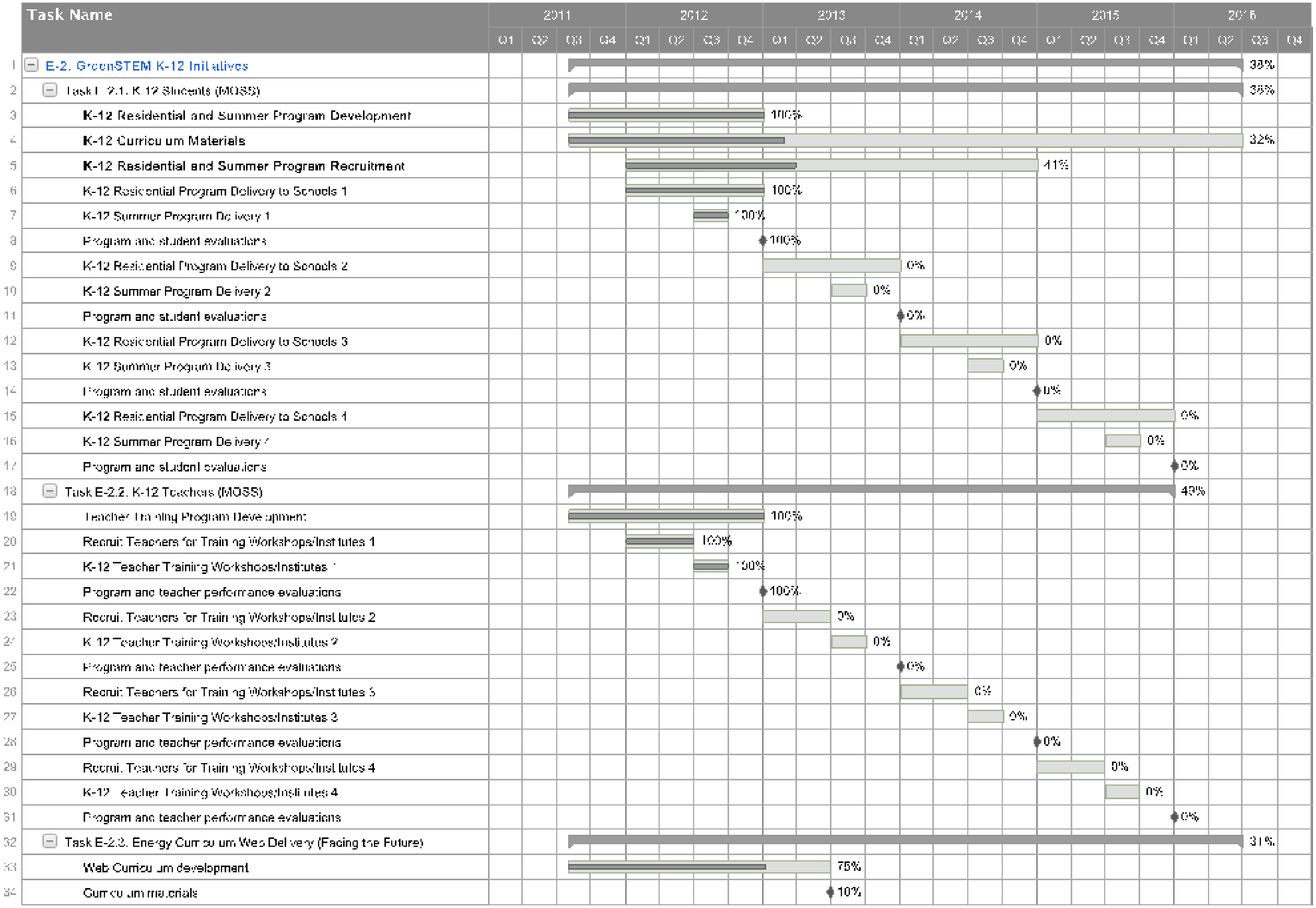
# Education_Schwartz



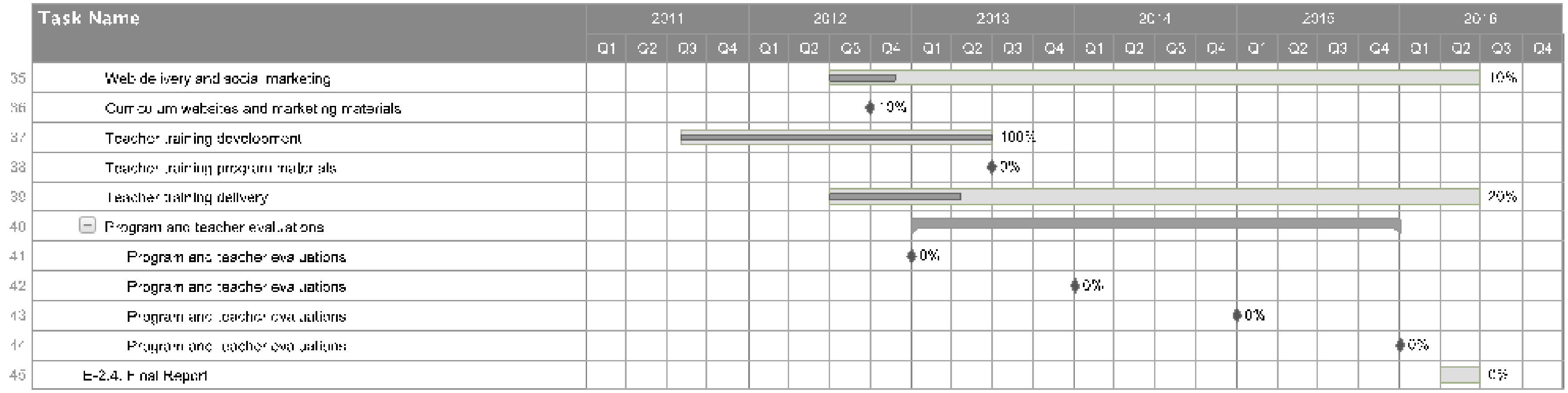
| | Task Name | |
|---|---|---|
| 1 | E-1. Bioenergy and Bioproducts Graduate Education and Research in Partnership with Northwest Tribes | 23% |
| 2 | Task E-1.1 Liaison functions with Tribes, Tribal Organizations, Campuses | 35% |
| 3 | Annual coordination with research sub-committee of Intertribal Timber Council | 35% |
| 4 | Annual coordination with campus Native American liaison officers | 35% |
| 5 | Task E-1.2 Tribal energy research project 1 | 67% |
| 6 | Establish research collaboration agreement and scope with tribal partner 1 | 100% |
| 7 | Collaboration agreement and scope documents | 100% |
| 8 | Student Selection for project 1 | 100% |
| 9 | Student activities: Field Trip, Statement of work, research, reporting (oral, written) | 80% |
| 10 | Student project reports published to web | 0% |
| 11 | Publications: tribal review, peer review, etc., publish | 0% |
| 12 | Publication of project final report and journal manuscripts | 0% |
| 13 | Task E-1.3 Tribal energy research project 2 | 4% |
| 14 | Establish research collaboration agreement and scope with tribal partner 2 | 5% |
| 15 | Collaboration agreement and scope documents | 0% |
| 16 | Student Selection for project 2 | 10% |
| 17 | Student activities: Field Trip, Statement of work, research, reporting (oral, written) | 0% |
| 18 | Student project reports published to web | 0% |
| 19 | Publications: tribal review, peer review, etc., publish | 0% |
| 20 | Publication of project final report and journal manuscripts | 0% |
| 21 | Task E-1.4 Tribal energy research project 3 | 0% |
| 22 | Establish research collaboration agreement and scope with tribal partner 3 | 0% |
| 23 | Collaboration agreement and scope documents | 0% |
| 24 | Student Selection for project 3 | 0% |
| 25 | Student activities: Field Trip, Statement of work, research, reporting (oral, written) | 0% |
| 26 | Student project reports published to web | 0% |
| 27 | Publications: tribal review, peer review, etc., publish | 0% |
| 28 | Publication of project final report and journal manuscripts | 0% |

# Education_Laninga

NARA



| | Task Name | |
|---|---|---|
| 1 | E-2. GreenSTEM K-12 Initiatives | 38% |
| 2 | Task E-2.1. K-12 Students (MOSS) | 35% |
| 3 | **K-12 Residential and Summer Program Development** | 100% |
| 4 | **K-12 Curriculum Materials** | 32% |
| 5 | **K-12 Residential and Summer Program Recruitment** | 41% |
| 6 | K-12 Residential Program Delivery to Schools 1 | 100% |
| 7 | K-12 Summer Program Delivery 1 | 100% |
| 8 | Program and student evaluations | 100% |
| 9 | K-12 Residential Program Delivery to Schools 2 | 0% |
| 10 | K-12 Summer Program Delivery 2 | 0% |
| 11 | Program and student evaluations | 0% |
| 12 | K-12 Residential Program Delivery to Schools 3 | 0% |
| 13 | K-12 Summer Program Delivery 3 | 0% |
| 14 | Program and student evaluations | 0% |
| 15 | K-12 Residential Program Delivery to Schools 4 | 0% |
| 16 | K-12 Summer Program Delivery 4 | 0% |
| 17 | Program and student evaluations | 0% |
| 18 | Task E-2.2. K-12 Teachers (MOSS) | 49% |
| 19 | Teacher Training Program Development | 100% |
| 20 | Recruit Teachers for Training Workshops/Institutes 1 | 100% |
| 21 | K-12 Teacher Training Workshops/Institutes 1 | 100% |
| 22 | Program and teacher performance evaluations | 100% |
| 23 | Recruit Teachers for Training Workshops/Institutes 2 | 0% |
| 24 | K-12 Teacher Training Workshops/Institutes 2 | 0% |
| 25 | Program and teacher performance evaluations | 0% |
| 26 | Recruit Teachers for Training Workshops/Institutes 3 | 0% |
| 27 | K-12 Teacher Training Workshops/Institutes 3 | 0% |
| 28 | Program and teacher performance evaluations | 0% |
| 29 | Recruit Teachers for Training Workshops/Institutes 4 | 0% |
| 30 | K-12 Teacher Training Workshops/Institutes 4 | 0% |
| 31 | Program and teacher performance evaluations | 0% |
| 32 | Task E-2.3. Energy Curriculum Web Delivery (Facing the Future) | 31% |
| 33 | Web Curriculum development | 75% |
| 34 | Curriculum materials | 10% |


Task Name
2011
2012
2013
2014
2015
2016
Q1
Q2
Q3
Q4
35 Web delivery and social marketing
36 Curriculum websites and marketing materials
37 Teacher training development
38 Teacher training program materials
39 Teacher training delivery
40 Program and teacher evaluations
41 Program and teacher evaluations
42 Program and teacher evaluations
43 Program and teacher evaluations
44 Program and teacher evaluations
45 E-2.4. Final Report
10%
10%
100%
0%
20%
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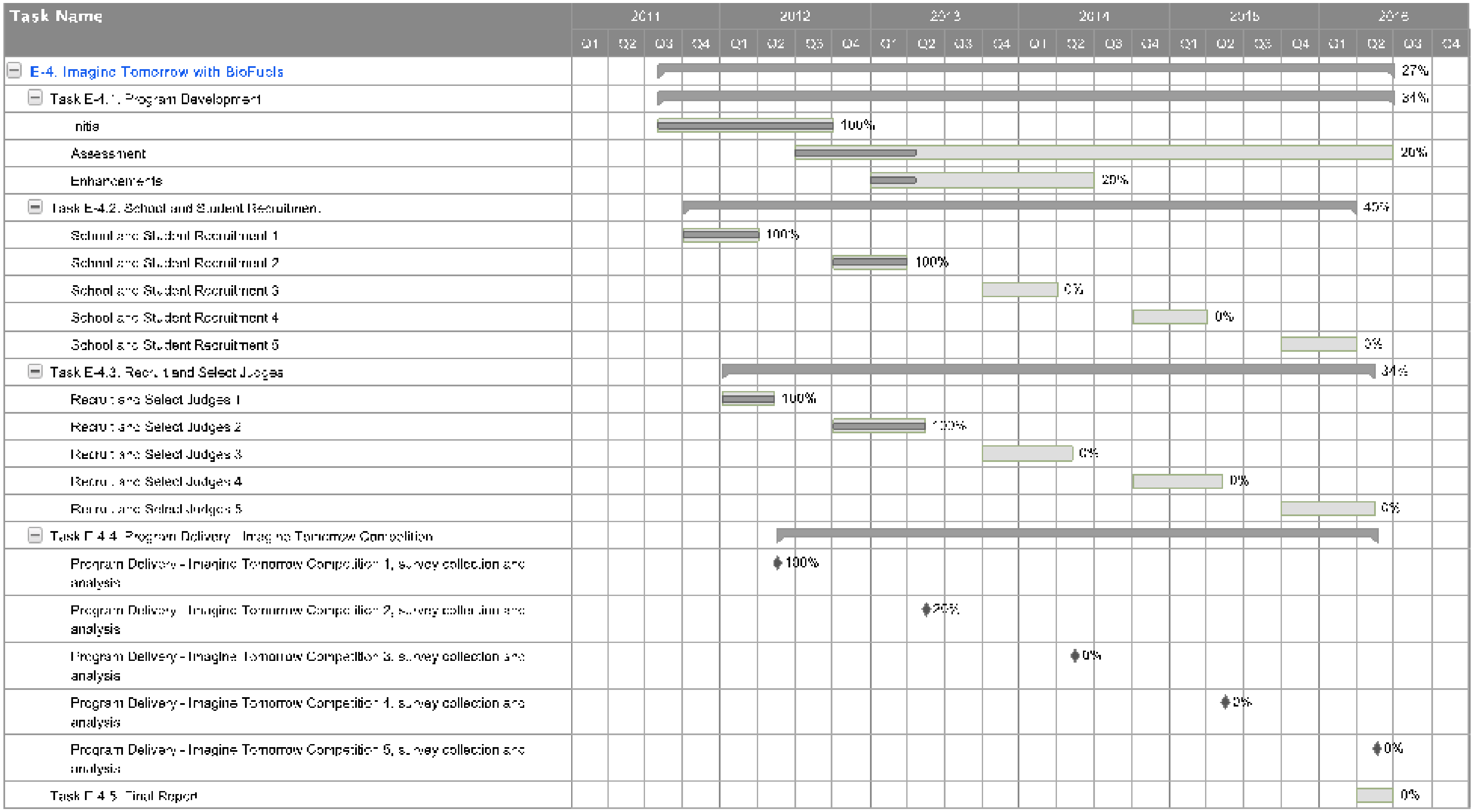
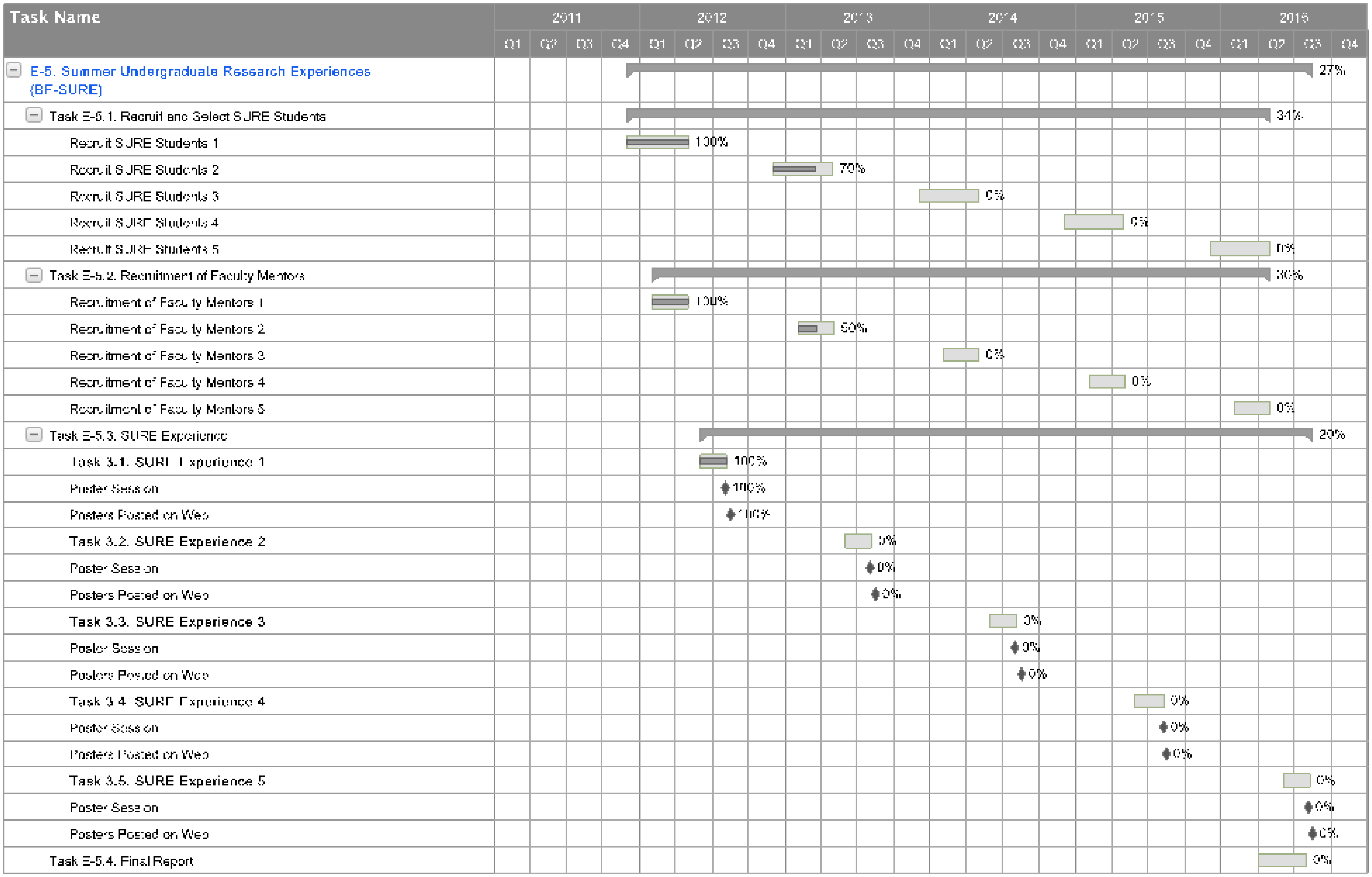
0%

# Education_Haselbach



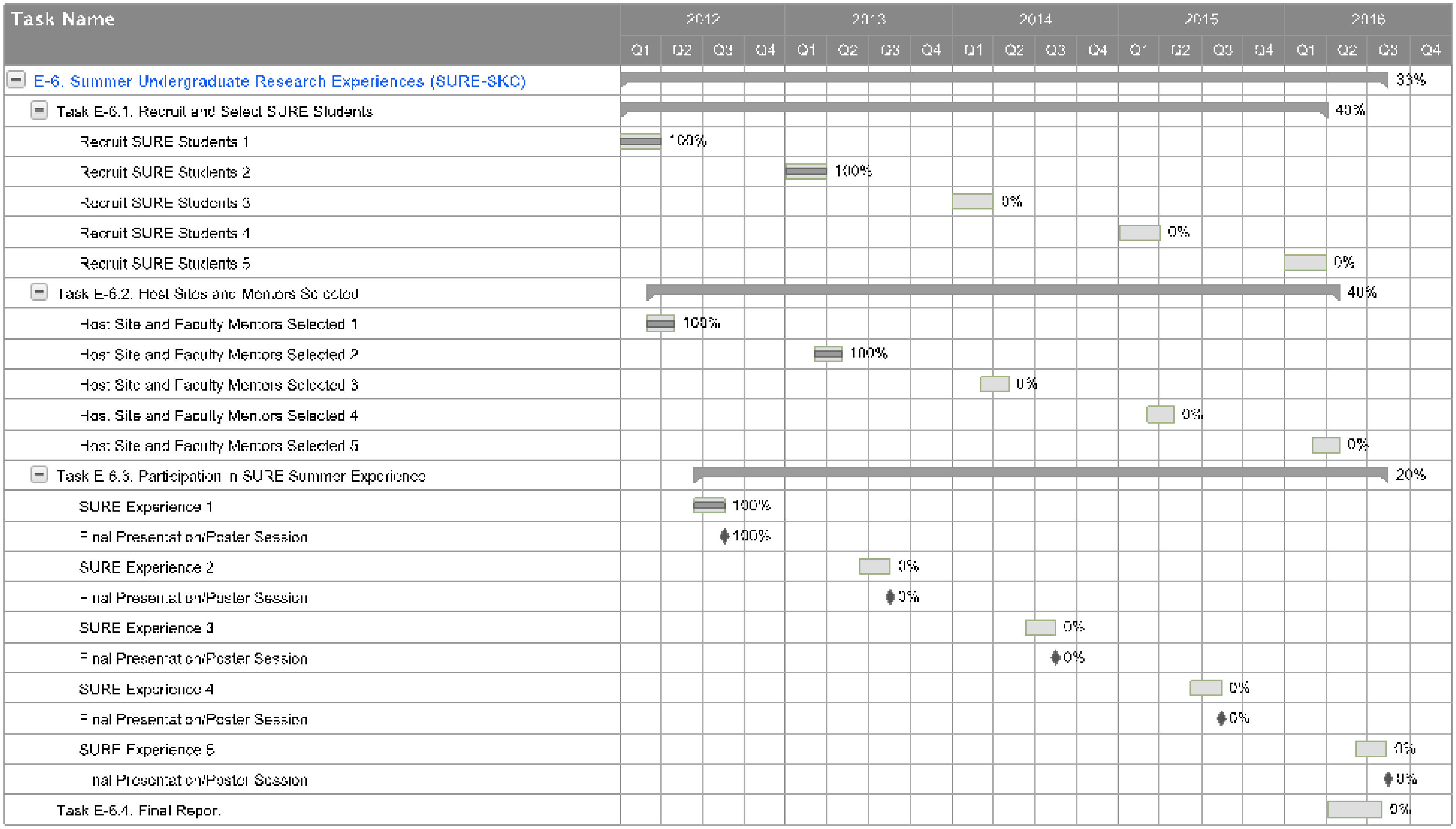
| | Task Name | |
|---|---|---|
| 1 | E-4. Imagine Tomorrow with BioFuels | 27% |
| 2 | Task E-4.1. Program Development | 31% |
| 3 | Initial | 100% |
| 4 | Assessment | 20% |
| 5 | Enhancements | 20% |
| 6 | Task E-4.2. School and Student Recruitment | 45% |
| 7 | School and Student Recruitment 1 | 100% |
| 8 | School and Student Recruitment 2 | 100% |
| 9 | School and Student Recruitment 3 | 0% |
| 10 | School and Student Recruitment 4 | 0% |
| 11 | School and Student Recruitment 5 | 0% |
| 12 | Task E-4.3. Recruit and Select Judges | 34% |
| 13 | Recruit and Select Judges 1 | 100% |
| 14 | Recruit and Select Judges 2 | 100% |
| 15 | Recruit and Select Judges 3 | 0% |
| 16 | Recruit and Select Judges 4 | 0% |
| 17 | Recruit and Select Judges 5 | 0% |
| 18 | Task E-4.4. Program Delivery - Imagine Tomorrow Competition | |
| 19 | Program Delivery - Imagine Tomorrow Competition 1, survey collection and analysis | 100% |
| 20 | Program Delivery - Imagine Tomorrow Competition 2, survey collection and analysis | 25% |
| 21 | Program Delivery - Imagine Tomorrow Competition 3, survey collection and analysis | 0% |
| 22 | Program Delivery - Imagine Tomorrow Competition 4, survey collection and analysis | 0% |
| 23 | Program Delivery - Imagine Tomorrow Competition 5, survey collection and analysis | 0% |
| 24 | Task E-4.5. Final Report | 0% |

# Education_Pressley



|  | Task Name |  |
|---|---|---|
| 1 | E-5. Summer Undergraduate Research Experiences (BF-SURE) | 27% |
| 2 | Task E-5.1. Recruit and Select SURE Students | 31% |
| 3 | Recruit SURE Students 1 | 100% |
| 4 | Recruit SURE Students 2 | 70% |
| 5 | Recruit SURE Students 3 | 0% |
| 6 | Recruit SURE Students 4 | 0% |
| 7 | Recruit SURE Students 5 | 0% |
| 8 | Task E-5.2. Recruitment of Faculty Mentors | 30% |
| 9 | Recruitment of Faculty Mentors 1 | 100% |
| 10 | Recruitment of Faculty Mentors 2 | 50% |
| 11 | Recruitment of Faculty Mentors 3 | 0% |
| 12 | Recruitment of Faculty Mentors 4 | 0% |
| 13 | Recruitment of Faculty Mentors 5 | 0% |
| 14 | Task E-5.3. SURE Experience | 20% |
| 15 | Task 3.1. SURE Experience 1 | 100% |
| 16 | Poster Session | 100% |
| 17 | Posters Posted on Web | 100% |
| 18 | Task 3.2. SURE Experience 2 | 0% |
| 19 | Poster Session | 0% |
| 20 | Posters Posted on Web | 0% |
| 21 | Task 3.3. SURE Experience 3 | 0% |
| 22 | Poster Session | 0% |
| 23 | Posters Posted on Web | 0% |
| 24 | Task 3.4. SURE Experience 4 | 0% |
| 25 | Poster Session | 0% |
| 26 | Posters Posted on Web | 0% |
| 27 | Task 3.5. SURE Experience 5 | 0% |
| 28 | Poster Session | 0% |
| 29 | Posters Posted on Web | 0% |
| 30 | Task E-5.4. Final Report | 0% |

# Education_Leighton



|  | Task Name |  |
|---|---|---|
| 1 | E-6. Summer Undergraduate Research Experiences (SURE-SKC) | 33% |
| 2 | Task E-6.1. Recruit and Select SURE Students | 40% |
| 3 | Recruit SURE Students 1 | 100% |
| 4 | Recruit SURE Students 2 | 100% |
| 5 | Recruit SURE Students 3 | 0% |
| 6 | Recruit SURE Students 4 | 0% |
| 7 | Recruit SURE Students 5 | 0% |
| 8 | Task E-6.2. Host Sites and Mentors Selected | 40% |
| 9 | Host Site and Faculty Mentors Selected 1 | 100% |
| 10 | Host Site and Faculty Mentors Selected 2 | 100% |
| 11 | Host Site and Faculty Mentors Selected 3 | 0% |
| 12 | Host Site and Faculty Mentors Selected 4 | 0% |
| 13 | Host Site and Faculty Mentors Selected 5 | 0% |
| 14 | Task E-6.3. Participation in SURE Summer Experience | 20% |
| 15 | SURE Experience 1 | 100% |
| 16 | Final Presentation/Poster Session | 100% |
| 17 | SURE Experience 2 | 0% |
| 18 | Final Presentation/Poster Session | 0% |
| 19 | SURE Experience 3 | 0% |
| 20 | Final Presentation/Poster Session | 0% |
| 21 | SURE Experience 4 | 0% |
| 22 | Final Presentation/Poster Session | 0% |
| 23 | SURE Experience 5 | 0% |
| 24 | Final Presentation/Poster Session | 0% |
| 25 | Task E-6.4. Final Report | 0% |