Northwest Advanced Renewables Alliance

3^{RD} Cumulative Report

April 2014 - March 2015

Northwest Advanced Renewables Alliance

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

3RD Cumulative Report

April 2014 - March 2015

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.

TABLE OF CONTENTS

NARA
Northwest Advanced Renewables Alliance

Notice

The authors, their respective employers, corporate partners, affiliated universities, and government institutions prepared this annual report. The information within was obtained in the course of performing academic research supported by Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the United States Department of Agriculture National Institute of Food and Agriculture.

The opinions expressed in this report do not necessarily reflect those of the authors, their respective employers, corporate partners, affiliated universities, and government institutions and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

Further, the authors, their respective employers, corporate partners, affiliated universities, and government institutions make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report.

The authors, their respective employers, corporate partners, affiliated universities, and government institutions make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NARA Organizational Structure

3RD Cumulative Report

April 2014 - March 2015

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

509-335-5581
cavalieri@wsu.edu

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, and currently serves as the Director of the FAA Center of Excellence for Alternative Jet Fuels and Environment (ASCENT) 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

509-335-6392
wolcott@wsu.edu

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
linda.beltz@nararenewables.org

Dr. Beltz is the President and Co-Founder of Steadfast Management Inc. Founded in April 2012, Steadfast Management Inc. provides management and consulting services and is providing Phase and Gate leadership to NARA.

Outside of NARA, Linda is currently VP, Commercial Aerospace Licensing for the Boeing Intellectual Property Licensing Company. Prior to that, Linda was Director, Technology Partnerships at Weyerhaeuser for 12 years, leaving in September 2013. In this role, Linda worked with John Tao to implement Open Innovation at Weyerhaeuser. Linda was responsible for alliances and partner activities with for-profit, non-profit, university and national laboratories, and focused on emerging technology areas such as bio-fuels, bio-products and bio-power. She was also responsible for government contracts.

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.

NARA 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.

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.

Michael Lakeman
Boeing

Dr. Michael Lakeman is currently the Regional Director of Biofuel Strategy for Boeing Commercial Airplanes. His focus is to build the capabilities needed to expand the scale of next-generation biofuels. He joined Boeing after holding the position of Senior Research Scientist at Imperium Renewables in Seattle. Michael serves on the Algae Foundation Board for 2013/2014 and as co-chair of the CAAFI Research and Development Team.

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.

Chuck Hersey
Washington State Department of Natural Resources

Chuck Hersey has worked for the Washington State Department of Natural Resources as a forest health planner since 2012. Chuck's work in the Forest Health Program focuses on forest restoration in eastern Washington including coordination of the forest health hazard warning process, forest landowner outreach, education and technical assistance and biomass utilization. Chuck also serves as the agency's wood energy policy lead and coordinates the Washington State Forest Biomass Coordination Group.

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.

Compañía Logística de Hidrocarburos CLH S.A.

CLH is Spain's leader for oil product transportation and storage. CLH Aviation has operated for over 85 years and is dedicated to hydrocarbon storage and logistics in Spain. CLH Aviation will provide a cross-national comparison of fuel logistics, policy, and corporate social responsibility (CSR) issues.

Cosmo Specialty Fibers, Inc.

Cosmo Specialty Fibers, Inc. (CSF) is an affiliate of The Gores Group and was created to restore, restart and operate Weyerhaeuser's former specialty cellulose mill in Cosmopolis, Washington. This facility currently produces a high-quality dissolving wood pulp. As a NARA member organization, CSF will explore available markets for the simple sugars that could be derived from their residual streams.

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 for isobutanol, biojet fuel and other renewable chemicals.

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.

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.

Pennsylvania State University

Penn State is Pennsylvania's land-grant university. Research dedicated to the NARA project investigates the social sustainability of a wood-based biofuel industry.

Salish Kootenai College

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

Steadfast Management

Steadfast Management provides management and consulting services and contributes Phase and Gate and pretreatment/conversion leadership to NARA.

Thomas Spink Inc.

Thomas Spink Inc. is a consulting firm specializing in biomass chemical engineering and assists NARA in co-product development and economic analyses.

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.

University of Utah

Research at the University of Utah will measure the impacts of forest residuals removal on the forest ecology. Specifically, efforts from this NARA affiliate will measure runoff, nutrient export and sediment erosion from test plots with varying levels of harvest treatments. The effects on microbial communities will also be measured.

University of Washington

Researchers at the University of Washington lead NARA's efforts to develop a complete life cycle assessment 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 opportunities and forestry management analyses.

University of Wisconsin Extension

The University of Wisconsin Extension will contribute to NARA's goal of enhancing bioenergy literacy for students, educators and the general public.

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.

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

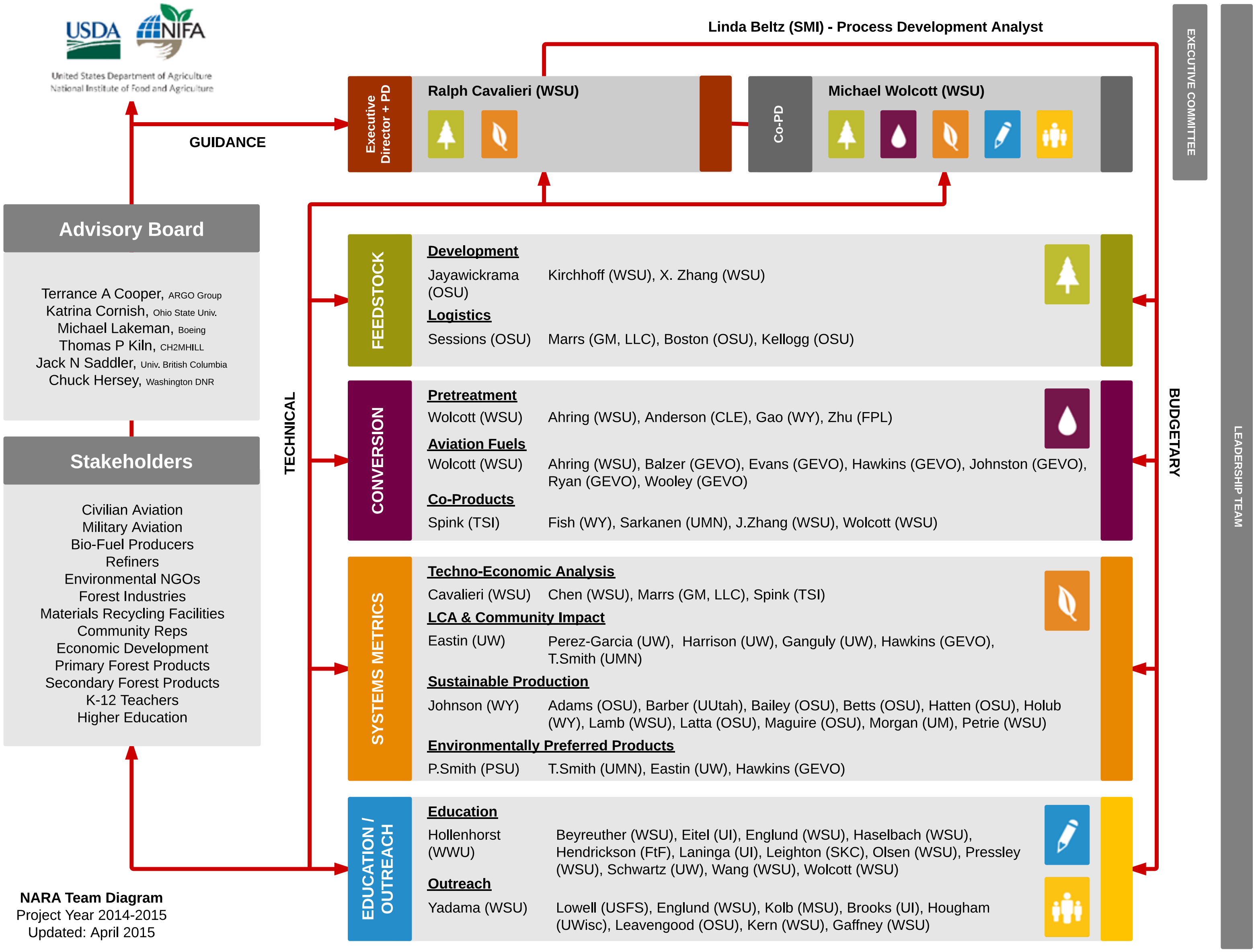
Faculty in Western Washington University's Huxley College of the Environment, along with university's Institute for Energy Studies (IES), are involved in the education and outreach goals of the NARA project.

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 continues to provide research expertise and leadership to important aspects of the NARA project, specifically with emphasis on feedstock sustainability and sourcing. Through year 3, Weyerhaeuser provided 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 (see Figure OS-1). NARA has implemented multiple strategies to provide administrative services and management tools to the project.



USDA NIFA

United States Department of Agriculture
National Institute of Food and Agriculture

GUIDANCE

Linda Beltz (SMI) - Process Development Analyst

Executive Director + PD — **Ralph Cavalieri (WSU)**

Co-PD — **Michael Wolcott (WSU)**

EXECUTIVE COMMITTEE

LEADERSHIP TEAM

TECHNICAL

BUDGETARY

Advisory Board

Terrance A Cooper, ARGO Group
Katrina Cornish, Ohio State Univ.
Michael Lakeman, Boeing
Thomas P Kiln, CH2MHILL
Jack N Saddler, Univ. British Columbia
Chuck Hersey, Washington DNR

Stakeholders

Civilian Aviation
Military Aviation
Bio-Fuel Producers
Refiners
Environmental NGOs
Forest Industries
Materials Recycling Facilities
Community Reps
Economic Development
Primary Forest Products
Secondary Forest Products
K-12 Teachers
Higher Education

FEEDSTOCK

Development	
Jayawickrama (OSU)	Kirchhoff (WSU), X. Zhang (WSU)
Logistics	
Sessions (OSU)	Marrs (GM, LLC), Boston (OSU), Kellogg (OSU)

CONVERSION

Pretreatment	
Wolcott (WSU)	Ahring (WSU), Anderson (CLE), Gao (WY), Zhu (FPL)
Aviation Fuels	
Wolcott (WSU)	Ahring (WSU), Balzer (GEVO), Evans (GEVO), Hawkins (GEVO), Johnston (GEVO), Ryan (GEVO), Wooley (GEVO)
Co-Products	
Spink (TSI)	Fish (WY), Sarkanen (UMN), J.Zhang (WSU), Wolcott (WSU)

SYSTEMS METRICS

Techno-Economic Analysis	
Cavalieri (WSU)	Chen (WSU), Marrs (GM, LLC), Spink (TSI)
LCA & Community Impact	
Eastin (UW)	Perez-Garcia (UW), Harrison (UW), Ganguly (UW), Hawkins (GEVO), T.Smith (UMN)
Sustainable Production	
Johnson (WY)	Adams (OSU), Barber (UUtah), Bailey (OSU), Betts (OSU), Hatten (OSU), Holub (WY), Lamb (WSU), Latta (OSU), Maguire (OSU), Morgan (UM), Petrie (WSU)
Environmentally Preferred Products	
P.Smith (PSU)	T.Smith (UMN), Eastin (UW), Hawkins (GEVO)

EDUCATION / OUTREACH

Education	
Hollenhorst (WWU)	Beyreuther (WSU), Eitel (UI), Englund (WSU), Haselbach (WSU), Hendrickson (FtF), Laninga (UI), Leighton (SKC), Olsen (WSU), Pressley (WSU), Schwartz (UW), Wang (WSU), Wolcott (WSU)
Outreach	
Yadama (WSU)	Lowell (USFS), Englund (WSU), Kolb (MSU), Brooks (UI), Hougham (UWisc), Leavengood (OSU), Kern (WSU), Gaffney (WSU)

NARA Team Diagram
Project Year 2014-2015
Updated: April 2015

Figure OS-1. The NARA team diagram as of April 2015

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. NARA 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 as well as technical to social work encompassed within the NARA project. Each phase covers key areas of: Technical, Market, Business Models / Integration, Manufacturing, Financial, Health/Safety and Intellectual Assets. Figure OS-2 shows NARA project flow diagram with desired outcomes by project area.

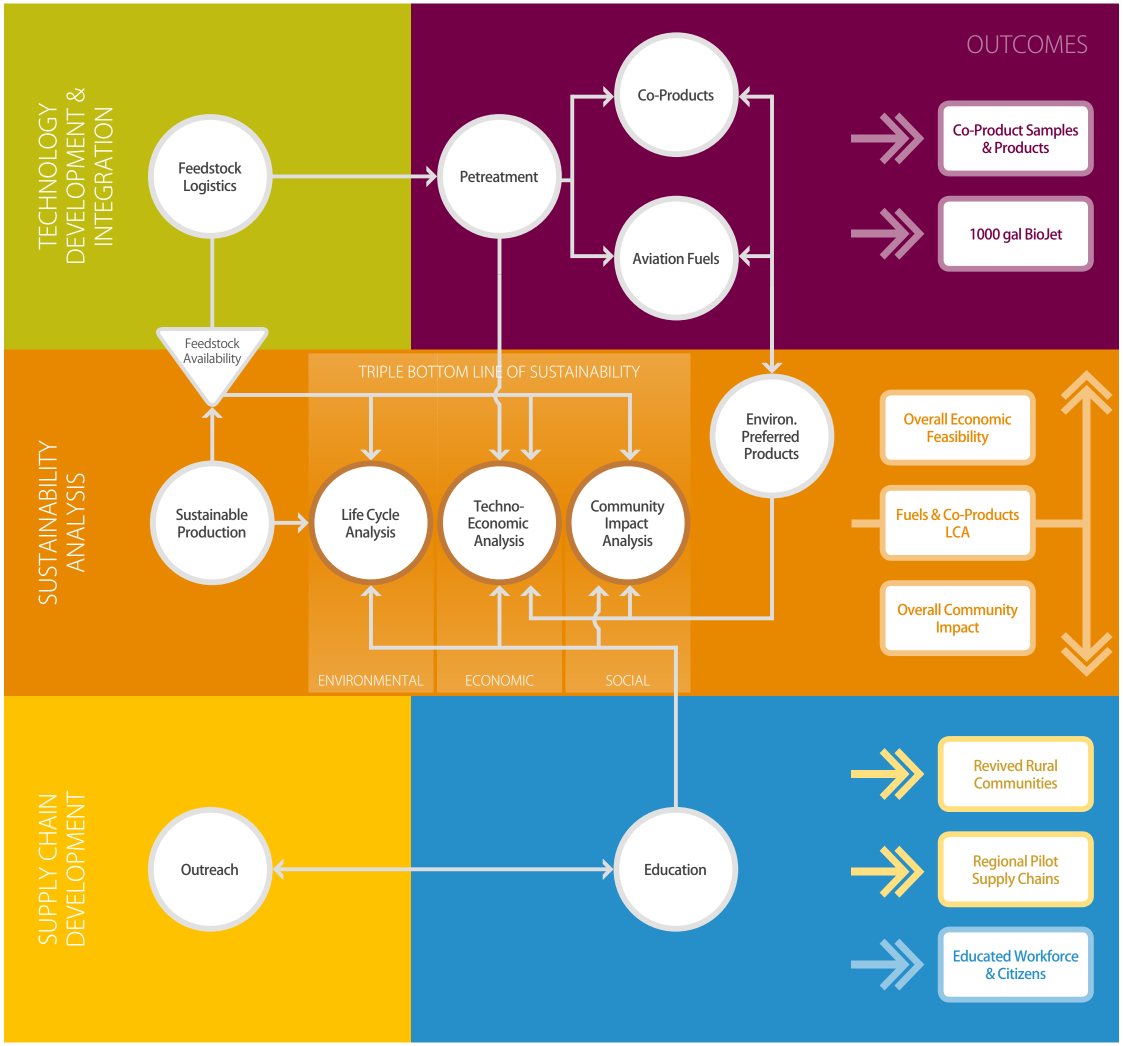


Figure OS-2. NARA project flow diagram with desired outcomes by project area

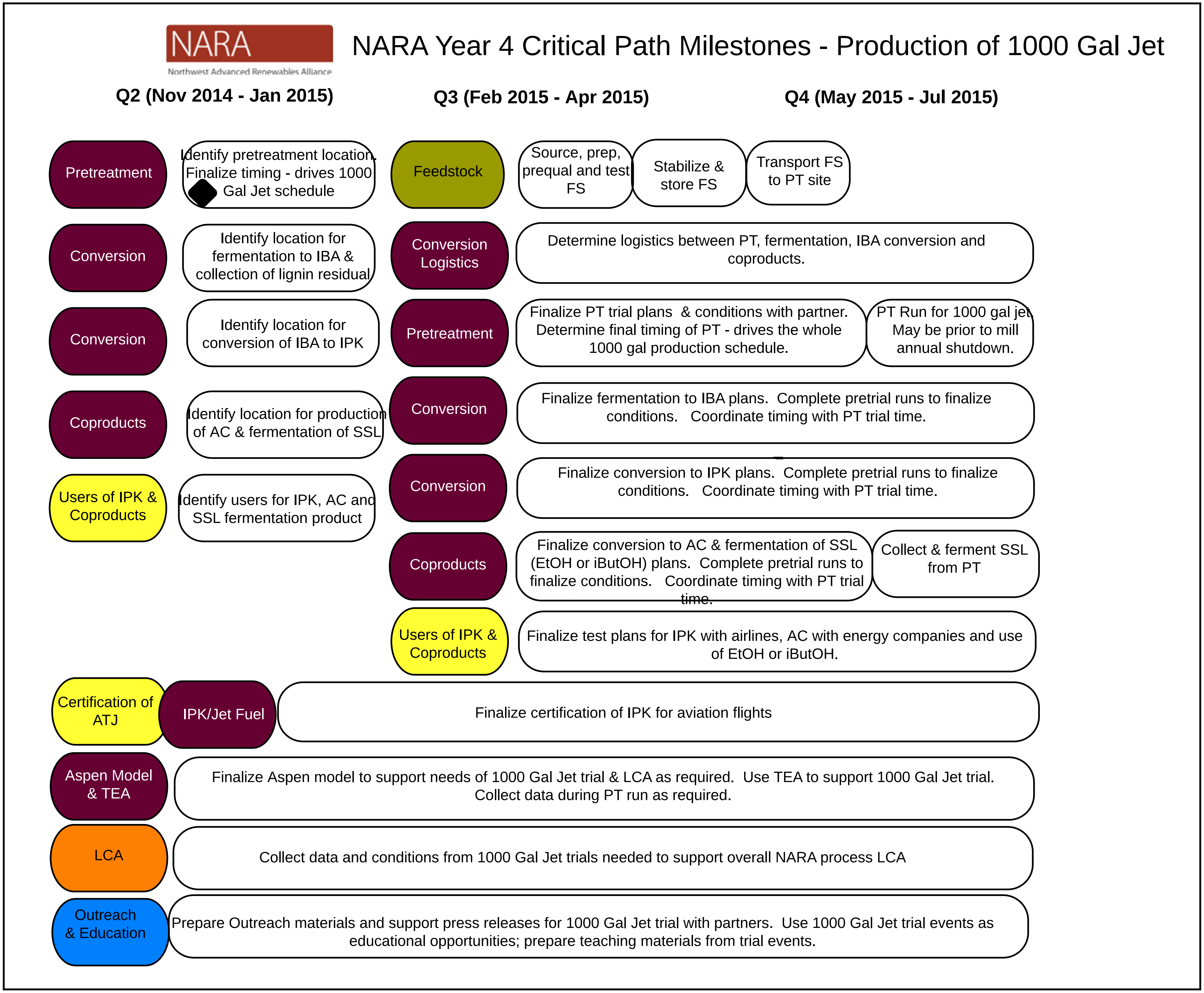
Activities and Results

Two major Phase and Gate activities were developed during the reporting period of December 2014-March 2015: (1) Initiation of anew Critical Path Milestone map for the overall NARA project and (2) Development of Gate 3 Scale Up Readiness Packet for 1000 Gal Jet and facilitation of the 1000 Gal Jet Gate Review. Alignment of the 1000 Gal Jet project tasks to the 1000 Gal Jet Critical Path Milestones (CPM) previously mapped (3) is in progress.

For activity (1), the 1000 Gal Jet CPM chart (shown in Figures OS-1 and OS-4) was revised based on input from the NARA team during participation in the 1000 Gal Jet planning meeting. The revised CPM chart served as a basis for the task planning for production of 1000 Gal Jet. A key result was NARA's understanding of the timing for biomass pretreatment and production of isobutanol (IBA) and iso-paraffinic kerosene (IPK) in order to meet the goal of flying a jet using the 1000 Gal Jet by the end of NARA Year 5. The timing for these activities is earlier than expected, with a plan to complete the production of jet fuel by the end of 2015. This allows time for other related project tasks to be completed by the end of NARA Year 5.

For activity (2), a template was created and sent to NARA Team Leaders to collect each team's CPM's. There have been delays in getting input from the teams, but 90% have been collected. The CPM's have been reviewed. The CPM's from each team have started to be condensed into the overall CPM's for the NARA project, which will allow the NARA project to determine dependencies in task activities needed for completion of all NARA outputs.

For activity (3), a gate packet template was created for the Gate 3 Scale Up Readiness, 1000 Gal Jet Gate Review. The Gate Packet was used in the March 17, 2015 Gate Review to decide on the facilities and budget for production of 1000 Gal Jet. This activity also included facilitation of the Gate 3 Review. The proposed budget was higher than acceptable to the Gate Keeper. The Gate recommendation was not accepted and a recycle on the budget elements of the recommended path was requested. Once revised budget recommendations are ready for review, another Gate 3 Review will be completed with focus on the budget element.



NARA
Northwest Advanced Renewables Alliance

NARA Year 4 Critical Path Milestones - Production of 1000 Gal Jet

Q2 (Nov 2014 - Jan 2015)

Q3 (Feb 2015 - Apr 2015)

Q4 (May 2015 - Jul 2015)

Pretreatment — Identify pretreatment location. Finalize timing - drives 1000 Gal Jet schedule ◆

Conversion — Identify location for fermentation to IBA & collection of lignin residual

Conversion — Identify location for conversion of IBA to IPK

Coproducts — Identify location for production of AC & fermentation of SSL

Users of IPK & Coproducts — Identify users for IPK, AC and SSL fermentation product

Feedstock — Source, prep, prequal and test FS — Stabilize & store FS — Transport FS to PT site

Conversion Logistics — Determine logistics between PT, fermentation, IBA conversion and coproducts.

Pretreatment — Finalize PT trial plans & conditions with partner. Determine final timing of PT - drives the whole 1000 gal production schedule. — PT Run for 1000 gal jet. May be prior to mill annual shutdown.

Conversion — Finalize fermentation to IBA plans. Complete pretrial runs to finalize conditions. Coordinate timing with PT trial time.

Conversion — Finalize conversion to IPK plans. Complete pretrial runs to finalize conditions. Coordinate timing with PT trial time.

Coproducts — Finalize conversion to AC & fermentation of SSL (EtOH or iButOH) plans. Complete pretrial runs to finalize conditions. Coordinate timing with PT trial time. — Collect & ferment SSL from PT

Users of IPK & Coproducts — Finalize test plans for IPK with airlines, AC with energy companies and use of EtOH or iButOH.

Certification of ATJ — IPK/Jet Fuel — Finalize certification of IPK for aviation flights

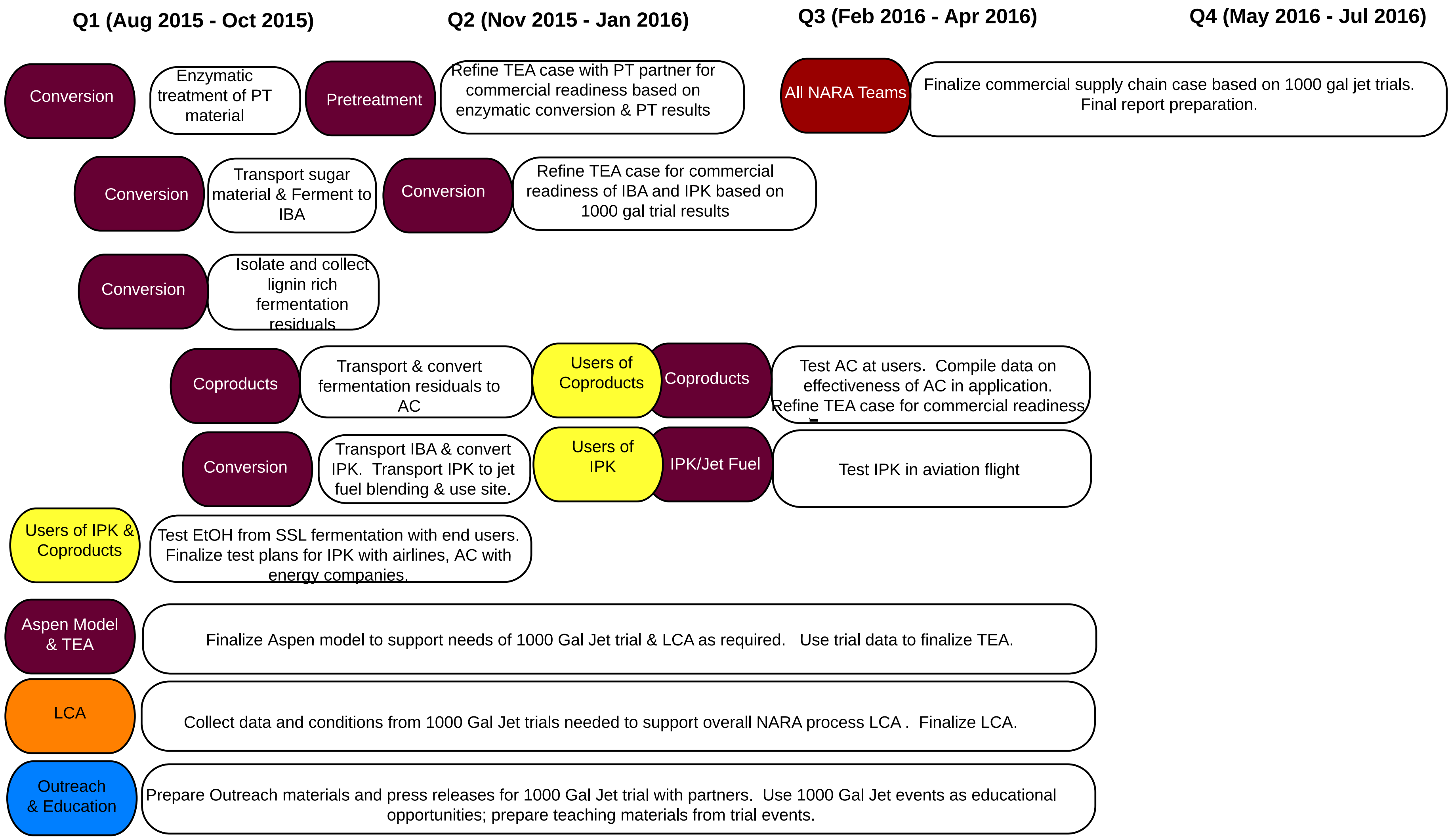
Aspen Model & TEA — Finalize Aspen model to support needs of 1000 Gal Jet trial & LCA as required. Use TEA to support 1000 Gal Jet trial. Collect data during PT run as required.

LCA — Collect data and conditions from 1000 Gal Jet trials needed to support overall NARA process LCA

Outreach & Education — Prepare Outreach materials and support press releases for 1000 Gal Jet trial with partners. Use 1000 Gal Jet trial events as educational opportunities; prepare teaching materials from trial events.

Figure OS-3. NARA Year 4 CPM's for 1000 Gal Jet

NARA Year 5 Critical Path Milestones - Production of 1000 Gal Jet



Q1 (Aug 2015 - Oct 2015)

Q2 (Nov 2015 - Jan 2016)

Q3 (Feb 2016 - Apr 2016)

Q4 (May 2016 - Jul 2016)

Conversion – Enzymatic treatment of PT material

Pretreatment – Refine TEA case with PT partner for commercial readiness based on enzymatic conversion & PT results

All NARA Teams – Finalize commercial supply chain case based on 1000 gal jet trials. Final report preparation.

Conversion – Transport sugar material & Ferment to IBA

Conversion – Refine TEA case for commercial readiness of IBA and IPK based on 1000 gal trial results

Conversion – Isolate and collect lignin rich fermentation residuals

Coproducts – Transport & convert fermentation residuals to AC

Users of Coproducts / Coproducts – Test AC at users. Compile data on effectiveness of AC in application. Refine TEA case for commercial readiness

Conversion – Transport IBA & convert IPK. Transport IPK to jet fuel blending & use site.

Users of IPK / IPK/Jet Fuel – Test IPK in aviation flight

Users of IPK & Coproducts – Test EtOH from SSL fermentation with end users. Finalize test plans for IPK with airlines, AC with energy companies.

Aspen Model & TEA – Finalize Aspen model to support needs of 1000 Gal Jet trial & LCA as required. Use trial data to finalize TEA.

LCA – Collect data and conditions from 1000 Gal Jet trials needed to support overall NARA process LCA . Finalize LCA.

Outreach & Education – Prepare Outreach materials and press releases for 1000 Gal Jet trial with partners. Use 1000 Gal Jet events as educational opportunities; prepare teaching materials from trial events.

Figure OS-4. NARA Year 5 CPM's for 1000 Gal Jet

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

All NARA members endorse a common Intellectual Property (IP) Management Plan and Non-Disclosure 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 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 of the NDA is to allow companies to talk freely and exchange ideas with the government labs and university researchers without worry that their proprietary information will be disclosed or rendered not patentable.

NARA Staff

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

Charles Burke Communications and Publicity Director	ccburke@nararenewables.org
Janet Duncan Project Coordinator	duncanj@nararenewables.org
Norman Ong Intellectual Property Management	norman.ong@wsu.edu
Julie Semler Project Coordinator	jsemler@nararenewables.org
Jacob Smith Graphic Designer/Web Coordinator	jsmith@nararenewables.org

COMMUNICATIONS

NARA communicates progress to NARA members, Advisory Board, and the USDA-NIFA leadership. In addition, research and event information is provided to regional stakeholders 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 2014 annual meeting was held at the Museum of Flight in Seattle. 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 working 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; hosts portals like "woodtobiofuels.org" used as a data retrieval tool for educators, professionals and the general public; and contains an intranet feature used to share project information internally among NARA researchers. As of March 31, 2015, the website experienced 59,255 visits with 195,512 page views. The NARA website is at http://nararenewables.org.

NARA Newsletters

NARA distributes a monthly newsletter and a blog 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

3RD Cumulative Report

April 2014 - March 2015

Background

As NARA moves towards the goal to "facilitate the establishment of regional systems for the sustainable production of bioenergy and biobased products[1]" in the Pacific Northwest, we have progressed each year to refine our vision of sustainable systems that could utilize existing forest residuals towards production of alternative jet fuel and co-products. Efforts through project Year 3 were focused on (1) assessing viable systems using technological, economic, and environmental assessments of various pathways and (2) engaging stakeholders with educational and outreach programs to garner regional input of needs. Collectively, these components were used to guide processes for down selecting options for two primary pathways; an integrated biorefinery and distributed cellulosic sugar production. These options are articulated in the Year 3 NARA Cumulative Report[2]. With the technical pathways established, Year 4 activity has focused on establishing the foundation for the final capstone components of the NARA project to be delivered at the end of Year 5.

Specifically, these deliverables include:
(1) demonstration of the integrated technology for production of alternative jet fuel through production of 1,000-gallons of isoparaffinic kerosene
(2) demonstration of the scale feasibility for select co-products
(3) final economic, environmental, and social assessments of production models to assess overall sustainability
(4) stakeholder integration efforts around a commercial flight of the produced alternative jet fuel

Progress Towards Capstone Deliverables

The **Feedstock, Pretreatment, Conversion, and Co-Products Teams** have all progressed to refine and scale up technologies that improve the flexibility and performance of the integrated technologies. Energy requirements, grinding specifications, and loading techniques to guide feedstock collection, processing, and transport have been thoroughly assessed and refined to reduce overall costs and environmental burdens. Severity of the SPORL mild bisulfite process has been decreased and flexibility in the bisulfite cation has been demonstrated so that the pretreatment technology can be more readily adapted to either existing pulping infrastructure or greenfield facilities. Evolution of the Gevo biocatalyst has continued, and effective growth and yield is demonstrated allowing the team to move to refining process conditions for scale deployment. Establishment of the Alcohol-to-Jet (ATJ) ASTM Alternative Jet Fuel standard, an additional key milestone not funded by USDA, has neared completion.

Collectively, this progress in the production pathway has readied us to develop the demonstration supply chain for producing 1,000-gallons of isoparaffinic kerosene (IPK) to be certified as alternative jet fuel upon passage of the ASTM ATJ standard. Towards this project milestone, we have identified and evaluated all potential tolling partners for this production. To support the evaluation of partners, we developed a detailed mass flow of our process for determining materials and equipment requirements. Representative feedstock has been harvested from Weyerhaeuser and tribal lands from around the NARA region and processed by regional stakeholder partners. A detailed draft production schedule is complete. A national flight partner has been identified and will be announced soon. However, we are still awaiting complete delineation of co-product tolling opportunities and partners. In aggregate, these efforts have prepared us to implement the production process in the remainder of Project Year 4 and 5 and complete our vision for allied demonstration efforts.

The collective **System Metrics Teams** have focused on solidifying the foundational models and data that will underpin our sustainability assessment. Key to this effort is the establishment of an ASPEN process simulation model for the integrated biorefinery envisioned. This model provides the mass and energy balance needed to compute (1) the operational and capital expenditures for the techno-economic analysis (OpEx and CapEx) and (2) the environmental burdens as determined in the life cycle assessment (LCA). In turn, the costs and impact of the feedstock requirements for the facility are computed using the NARA biomass assessment models and all of the biomass and facility employment estimates are used to quantify the holistic economic benefits using the community impact models. All of these elements are in-place to be deployed using a set of integrated production scenarios in Year 5.

The **NARA Outreach and Education Teams** have continued to build regional stakeholder capacity by involving them to assess the regional supply chain development and concepts around the distributed production of cellulosic sugar. This has resulted in established curriculum for K-12 students, increasing

---

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

[2] Northwest Advanced Renewables Alliance (2014) Second Cumulative Report. Retrieved from https://nararenewables.org/2014-report/

visibility of undergraduate research opportunities, and record involvement of regional high schools in our Imagine Tomorrow program. Energy literacy assessments provide us a tool to assess the efficacy of these programs. Most importantly, the survey of the informed stakeholder groups is providing a clear vision that their concerns around sustainability focus on retention of soil nutrient capacity for future forest health, economic viability of the process, and interaction with rural communities. These results verify and focus our sustainability assessment.

Future Directions

From our Year 4 efforts, it is clear that Year 5 will focus heavily on the culmination of our key capstone deliverables of technology demonstration, sustainability assessments, and stakeholder engagement. A focal point for many of our efforts will be the alternative jet fuel production and the goal of launching the first commercial flight using cellulosic-based biofuels.

NARA Goal One

3RD Cumulative Report

April 2014 - March 2015

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

Monitoring moisture in slash piles. NARA image

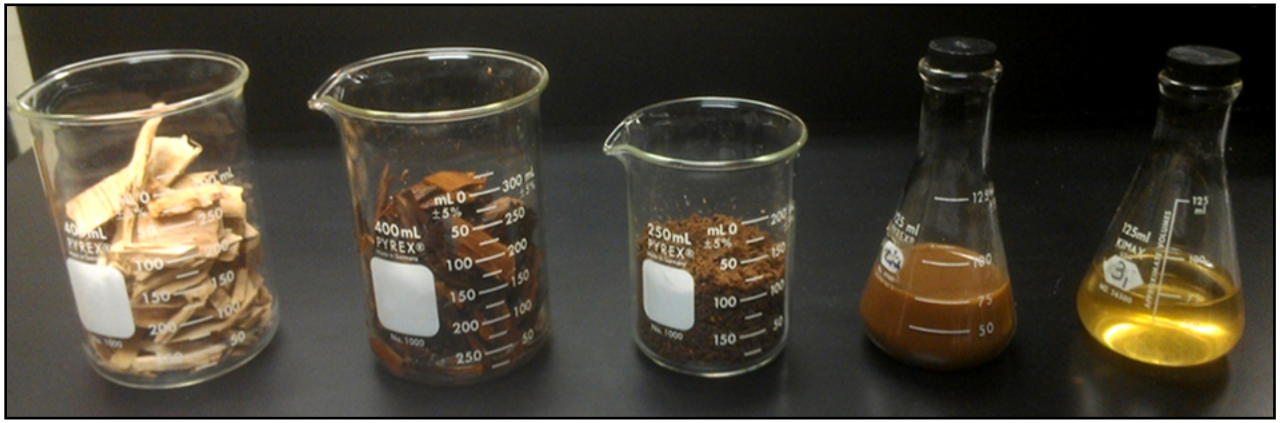
FEEDSTOCK LOGISTICS

The NARA Feedstock Team is divided into two efforts: feedstock logistics and feedstock development. The feedstock logistics efforts for this reporting period provided improved cost estimates associated with processing and transporting forest residual feedstock to a conversion facility. These data are being integrated into the NARA techno-economic analysis (TEA; Task SM-TEA-1), Life cycle assessment (LCA; SM-LCA-1.2) and biomass supply model (see task SM-SP-3).

Forest residual feedstock samples were analyzed at the Weyerhaeuser Analytical Laboratory using NREL protocols, which provided near 100% accounting for chemical components. These results will serve as a reliable chemical component benchmark for varied feedstock supplies in the Idaho, Washington, Montana and Oregon region. Ash content and “accepts” and “fines” distribution among the samples were determined (Task FL-1.1.2). The results show that all the samples tested are suitable for biojet conversion and comply with reasonable feedstock specifications. Live branch moisture content was recorded and compared between varied western softwood species, and a moisture and temperature model is being developed based on slash pile monitoring data (Task FL-2). Grinding trials were conducted on various feedstock classes to evaluate best practices for improved processing economics. These trials suggest that the use of best practices can improve logistics about $15/BDT, which improves the internal rate of return (IRR), calculated using the NARA

TEA model, for the conversion of forest residuals to biojet fuel and co-products by 0.8% (Task FL-1).

Using the improved NARA biomass supply model, cost curves were generated for feedstock costs to the mill gate at three putative conversion sites (one in Oregon and two in Washington). Average feedstock cost was $67.05 per bone-dried ton (BDT) (Task FL-1.1). The variation in feedstock cost, as determined in the three scenarios, had minimal impact (variation of 1.4%) towards the internal rate of return (IRR). The combined cost curve and grinding trial data suggest that improvements to feedstock costs can positively impact IRR, however, the impact will be relatively minimal.


Samples from wood-to-biojet conversion. NARA image

FEEDSTOCK DEVELOPMENT

For this reporting period, the feedstock development effort used technology at the WSU phenomics facility to screen ninety-eight Douglas-fir tree families with nine plants per family totaling 882 plants for drought response (Task FD-2). The screening revealed Douglas-fir candidates for further in-depth analysis by the gene chip approach developed in NARA Task FD-3. The aim is to identify differences in gene expression in the selected drought-sensitive and drought-tolerant families.

Narrow-sense heritabilities, genetic correlations between traits, and predicted genetic gains for pretreatment yield, pretreated holocellulose, enzymatic hydrolysis yield, and recalcitrance factor were predicted for 284 progeny trees, 30 woodsrun (unimproved) trees, 28 crosses (between 6 and 12 progeny per cross) and 46 parents. The estimates of heritability and predicted genetic gain indicate that Douglas-fir trees can likely be genetically selected for traits that favor their use to produce biojet fuel and co-products without sacrificing characteristics suitable for traditional timber use and justify efforts to identify genetic markers for improved Douglas-fir tree breeding (Task FD-5).

To develop the tools necessary to identify genetic markers, that contribute to favorable traits for biojet production and drought stress, a file of 221,674 targeted single nucleotide polymorphisms (SNPs) was assembled and submitted to GeneSeek/Affymetrix for construction of a genotyping array, which should be completed in April 2015. DNA samples from nearly 2000 selected Douglas-fir trees were collected and will be screened against the developing genotype array. In addition, 1,420 Douglas-fir seedlings were planted in southern Oregon to be used for genomic selection studies (Task FD-3).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR THE FEEDSTOCKS TEAMS

- A peer-reviewed manuscript (Geleynse et al) was published titled “A multi-level analysis approach to measuring variations in biomass recalcitrance of Douglas fir tree samples” doi: 10.1007/s12155-014-9483-z (Task FD-5).
- A peer-reviewed manuscript (Kirchhoff, H) was published titled “Diffusion of molecules and macromolecules in thylakoid membranes” doi:10.1016/j.bbabio.2013.11.003 (Task FD-2).
- A peer-reviewed manuscript (Zamora-Cristales et al) was published titled “Effect of high speed blowing on bulk density of ground residues” doi: 10.13073/FPJ-D-14-00005 (Task FL-2).
- Four slash moisture monitoring stations were established, including in-pile sensors, weather stations, and data loggers (Task FL-2).
- Forest residuals were acquired from sites in western Oregon, western Washington and western Montana to be used to produce 1000 gallons of biojet fuel for demonstration purposes (Task FL-1)
- A peer-reviewed manuscript (Zamora-Cristales et al) was published titled “Economic Optimization of Forest Biomass Processing and Transport” doi: 10.5849/forsci.13-158 (Task FL-2).
- A peer-reviewed manuscript (Zamora-Cristales et al) was published titled “Ground-based thinning on steep slopes in Western Oregon: Soil exposure and strength effects” doi:10.5849/forsci.12-525 (Task FL-2).
- 1,420 Douglas-fir seedlings were planted in southern Oregon to be used for genomic selection studies (Task FD-3).
- 882 Douglas-fir seedlings were screened for drought resistance using Phenomics technology (Task FD-2).

SIGNIFICANT OUTCOMES

- None reported

PRETREATMENT

The Pretreatment Team's efforts this year focused on optimizing and evaluating the mild bisulfite pretreatment protocol under conditions suitable for a standard pulp mill. This effort will help integrate the pretreatment technology to existing industries and assist in the development of 1000 gallons of biojet fuel to be produced at the end of NARA Year-4. To do this, they bubbled SO_2 into a hydroxide solution to produce a sulfite solution rather than directly applying H_2SO_4 and sodium bisulfite as done in the laboratory. They also conducted enzymatic hydrolysis and fermentation directly to pretreated whole slurry at high solids without solids washing or slurry detoxification to simplify process integration. Under these conditions, substrate enzymatic digestibility reached 92% with a glucose titer of 97 g/L. A 284 L/tonne ethanol yield was obtained using Saccharomyces cerevisiae YRH-400. Additional modifications such as substituting $Mg(HSO_3)_2$, for $Ca(HSO_3)_2$, higher temperature or higher SO_2 loading for shorter pretreatment time, and eliminating solids milling were applied to accommodate specific pulp mill specifications in the Pacific Northwest. Enzymatic and fermentation experiments from the pretreated material based on these modifications are underway. The lignin product was also characterized under the modified mild bisulfite conditions and was determined to have comparable properties to commercial lignosulfonate (Task C-P-4).

In an effort to reduce the amounts of enzymatic and fermentation inhibitors present after sulfite-based pretreatment, a pH profiling process was evaluated and shown to significantly reduce inhibitor formation (Task C-P-1).

A final optimization was conducted for the wet oxidation pretreatment protocol that was under Gate review in NARA Year-3. Based on the optimization, a mass balance provided for the pretreatment of FS-10 forest residuals records a recovery rate of 99.9% glucan and 78.6% xylans. Initial lignin characterization indicated no structural modifications to the lignin occurred due to the wet oxidation pretreatment protocol (Task C-P-3).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR THE CONVERSION TEAMS

- A peer-reviewed manuscript (Zhu et al) was published titled "Using sulfite chemistry for robust bioconversion of Douglas-fir forest residue to high titer bioethanol and lignosulfonate: A pilot-scale demonstration". doi:10.1016/j.biortech.2014.12.052 (Task CP-4).
- A peer-reviewed manuscript (Cheng et al) was published titled "High titer and yield ethanol production from undetoxified whole slurry of Douglas-fir forest residue using pH-profiling in SPORL". doi:10.1186/s13068-015-0205-3 (Task CP-4).
- A peer-reviewed manuscript (Zhang et al) was published titled "Using a combined hydrolysis factor to optimize high titer ethanol production from sulfite pretreated poplar without detoxification". doi:10.1016/j.biortech.2015.03.080 (Task CP-4).
- A peer-reviewed manuscript (Cheng et al) was published titled "High solids quasi-simultaneous enzymatic saccharification and fermentation of un-detoxified whole slurry of SPORL pretreated Douglas-fir forest residue" Link (Task CP-4).
- A peer-reviewed manuscript (Zhang et al) was published titled "Effect of hot-pressing temperature on the subsequent enzymatic saccharification and fermentation SPORL of pretreated forest biomass" doi: 10.1007/s12155-014-9530-9 (Task CP-4).
- A peer-reviewed manuscript (Lou et al) was published titled "Understanding the Effects of Lignosulfonate on Enzymatic Saccharification of Pure Cellulose" doi: 10.1007/s10570-014-0237-z (Task CP-4).
- A peer-reviewed manuscript (Zhang et al) was published titled "Using low temperature to balance enzymatic saccharification and furan formation during SPORL pretreatment of Douglas-fir" doi:10.1016/j.procbio.2013.12.017 (Task CP-4).
- A peer-reviewed manuscript (Zhang et al) was published titled "Comparison of dilute acid and sulfite pretreatment for enzymatic saccharification of earlywood and latewood of Douglas-fir" doi:10.1007/s12155-013-9376-6 (Task CP-4).
- A U.S Utililty Patent Application was submitted titled "Methods of Pretreating Lignocellulosic Biomass with Reduced Formation of Fermentation Inhibitors" (Task C-P-1)

SIGNIFICANT OUTCOMES

- None reported

AVIATION BIOFUELS

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.

Over NARA Year-4, Gevo continued to receive pretreated hydrolysate samples for sugar and inhibitor characterization and for fermentation experiments. The primary samples evaluated this year were hydrolysates derived from variations of the mild bisulfite protocol (also termed SPORL) adapted for specific pulp mill specifications (see task C-P-4) and hydrolysate from milled wood (MW) (Task E-8). Yeast biocatalyst growth rates were similar for the MW and FS-10 SPORL-Mg2+ hydrolysate samples; however, isobutanol production was higher (26.4%) with the FS-10 SPORL-Mg2+ hydrolysate.

Due to Gevo's extensive experimentation using hydrolysate produced through the mild bisulfite pretreatment protocol, selected in NARA Year-3 as the preferred pretreatment protocol, Gevo has supplied the NARA LCA (SM-LCA-1.1) and TEA (SM-TEA-1) teams with the necessary CapEx and mass and energy balance information to complete their analyses involving Gevo's proprietary technology.

Two adapted biocatalysts (LB21 and LB23) are undergoing further adaptation. A nutrient package and pH specifications were established to maximize biocatalyst growth and isobutanol production; the isobutanol produced did not contain any impurities detrimental to the biojet conversion process. Gevo's biocatalyst LB23 is currently the superior biocatalyst as it produced 20% higher isobutanol concentrations that LB21 when directly pitched into FS-10 SPORL-Mg2+ hydrolysate. LB23 will be used in scaling the GIFT™ fermentation process to produce NARA's target of 1000 gallons of biojet fuel made from forest residuals.

Gevo will begin scale-up operations to produce 40,000 L of isobutanol once the hydrolysate from feedstock samples FS-17 (see Task FL-1) arrive (Task C-AF-1).

Research aligned with WSU's BioChemCat process compared a mesophilic fermentation approach to the thermophilic approach reported in previous years. The mesophilic fermentation approach is conducted at a significantly lower temperature (37°C) to the thermophilic approach (50°C) and produces some advantageous results; for instance, greater overall conversion was achieved to C-2 and C-3 volatile fatty acids plus C-4 and C-7 organic acids were produced. The process does not require sterile conditions, which significantly reduces production costs. Further studies are currently being done to optimize and characterize the catalyst for effective vapor-phase hydrogenation to produce alcohols (Task C-AF-2; concluded this reporting period).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR THE AVIATION BIOFUEL TEAMS

- Yeast biocatalyst LB23 will be used to produce GIFT scale up for 1000-gallon biojet production (Task C-AF-1).

- Yeast nutrient package and growth conditions have been established for isobutanol scale-up production (Task C-AF-1).

- Isobutanol was recovered from 2L GIFT scale fermentations on various hydrolysate samples (Task C-AF-1).

- Optimal conditions were established for the wet-oxidation pretreatment protocol using FS-10 feedstock samples (Task C-AF-2).

SIGNIFICANT OUTCOMES

- None reported

TRAINING

Name	Affiliation	Role	Contribution
Matt Trappe	Oregon State University	Faculty Research Assistant	Sample collection, DNA extraction, seedling tagging, site layout, reporting
Rene Zamora	OSU	Post-Doc	Transportation model development and manuscript preparation
Francisca Belart	OSU	Graduate Student	Moisture Management --Field Research, Model development
Michael Berry	OSU	Graduate Student	GIS Model Development
Janna Loeppky	OSU	Graduate Student	Data Analysis, Report Preparation
Jorge Delgado	OSU	Graduate Student	Data Analysis, Report Preparation
Chet Miller	OSU	Undergraduate Student	Data collection, Data analysis, Report Preparation.
Subhash Chandra	USFS, FPL	Visiting Scholar	Ethanol fermentation
Feng Gu	USFS, FPL	Post-Doc	Separation of lignosulfonate
Yanlin Qin	USFS, FPL	Visiting PhD Student	Lignosulfonate property
Ricarda Hoehner	WSU	Post-Doc	Together with Magnus Wood, Dr. Hoehner organized, designed, and performed the Phenomics experiments. She analyzed the huge data sets from the Phenomics analysis

RESOURCE LEVERAGING

Resource Type	Resource Citation	Amount	Relationship or Importance to NARA
DOE BRDI	Awarded May, 2014. Humboldt State University, Lead	$300,000 sub-award to John Sessions as Co-PI.	Additional Funds for residue treatments including residue sorting and screening technologie
Salary	US Forest Service		Support of J.Y. Zhu & Roland Gleisner
Scholarship	China Scholarship Council		Support Yanlin QIN
Grant	USDA SBIR Phase II program to Biopulping International (Contract Number: 2010-33610-21589)		

FEEDSTOCK

FEEDSTOCK LOGISTICS TEAM

TASK FL-1: FEEDSTOCK SOURCING

Key Personnel	Affiliation
Gevan Marrs	Weyerhaeuser

Task Description

Gevan Marrs LLC will work collaboratively with Oregon State University (OSU) and NARA conversion staff to quantify costs and quantities of key Pacific Northwest (PNW) candidate feedstocks by region; determine feedstock key quality parameters, variation and impact on conversion processes; perform analyses to select optimum feedstock sourcing strategies, and distill the information and write full reports of all tasks for both Weyerhaeuser portions and NARA year 4 and 5 activities.

The main desired outcome for years 4 and 5 in this area of Feedstocks Logistics is to bring clarity to the economically optimum values for key specifications for the NARA bio-jet fuel production process. In the first 3 years the Logistics team has obtained and quantified a broad range of WA and OR softwood forest residuals feedstocks, demonstrating the extremely high variability in many properties. These results will be documented in final reports for the Weyerhaeuser portions. For years 4 and 5 some additional samples from elsewhere in the NARA region will be sampled, characterized, and reported.

Additional prior year's work has quantified the amount of economic leverage that can be obtained by altering key feedstock production factors in the field. These too will be documented in a written final report.

For year 4, a main task will be to obtain a representative sample of envisioned feedstocks (softwood forest residuals) from across the NARA region in sufficient quantity to prepare 1,000 gallons of bio-jet for a demonstration flight. To be assured of low conversion risk in a pilot facility and to buffer for unforeseen difficulties this means obtaining about 200 bone dried tons (BDT) of prepared feedstock.

Activities and Results

Task FL-1.1.1. Quantify costs and quantities of key PNW candidate feedstocks by region, scale, and year.

Certain feedstock parameters, judged likely to have significant impact on the overall NARA process economics, were entered into the techno-economic analysis (TEA) sensitivity analysis. Feedstock cost through the gate is considered by many to be a likely candidate for strong impact on overall economics. Upper (unfavorable) and lower (favorable) prices were determined by using newly-created sourcing curves developed by Adams and Latta at Oregon State University. Based on Oregon and Washington facility sites tentatively ranked as promising in Integrated Design Experience (IDX) course work, we had feedstock sourcing curves created for Cosmopolis and Longview, WA, and Springfield OR. When the delivered tons per year were chosen at the NARA base case of 850k BDST/yr, the low cost site was Cosmopolis at $61/BDST ($6/BDST less than base case). The high-cost site was Springfield, although it was marginally higher than the NARA base case (Figure FL-1.1). For a high sensitivity value, rather than using the marginally higher Springfield case, we instead assumed an increased market demand for forest residuals which causes the "stumpage" paid to the resource owner to rise from $7/BDST to $20/BDST (pretty arbitrary, but not implausible), leaving the average delivered cost at $81/BDST. This increase or decrease in feedstocks cost was then put in the model and IRR was calculated. The high and low had surprisingly little impact on overall project return, changing the base case V 6.42 IRR from 12.5% to 11.8% or 13.2% respectively—not a very powerful impact compared to many other elements. (Note that all sensitivity analysis elements are shown in more detail in the NARA TEA report; Task SM-TEA-1).

From this analysis, I conclude that, somewhat counter-intuitively, additional investigations at this project stage into feedstock cost reductions via improved logistics are not the key to breakthrough changes in project economics that are likely needed to induce investment in a yet unproven, large capital investment project like biofuels from wood.

Of course if a facility is actually operational, there are significant dollars to be made or lost each year depending upon every dollar per ton change in feedstock cost through the gate, yet this impact is not large enough to move the IRR needle up into the 20 to 30% range considered desirable to induce initial investment.

Task FL-1.1.2. Determine feedstock key quality parameters and variation and impact on conversion process

The chemical composition of feedstocks directly impacts the conversion efficiency and yield to different salable products and thus has a large impact on overall conversion economics. Because our forest residual feedstock consists of the "leftovers" after commercial softwood timber has been removed, the available material has varying tree parts (chunks, small logs, tops, branches) and tree species (main softwood timber crop, invasive non-commercial hardwoods) there is considerable variation in composition of potentially available feedstocks. Thus it follows that there will be measurable differences in overall economics, and selection of feedstock and control of "quality" will be important to process economic feasibility.

It is widely recognized that soil contamination in forest residuals can, if operators are not aware and careful, lead to high inorganic contents (ash) that have negative impacts on conversion. Accordingly all NARA samples were routinely screened in a mill-simulated process, removing the fines that passed a 1/8" wire mesh screen. These Fines were then analyzed

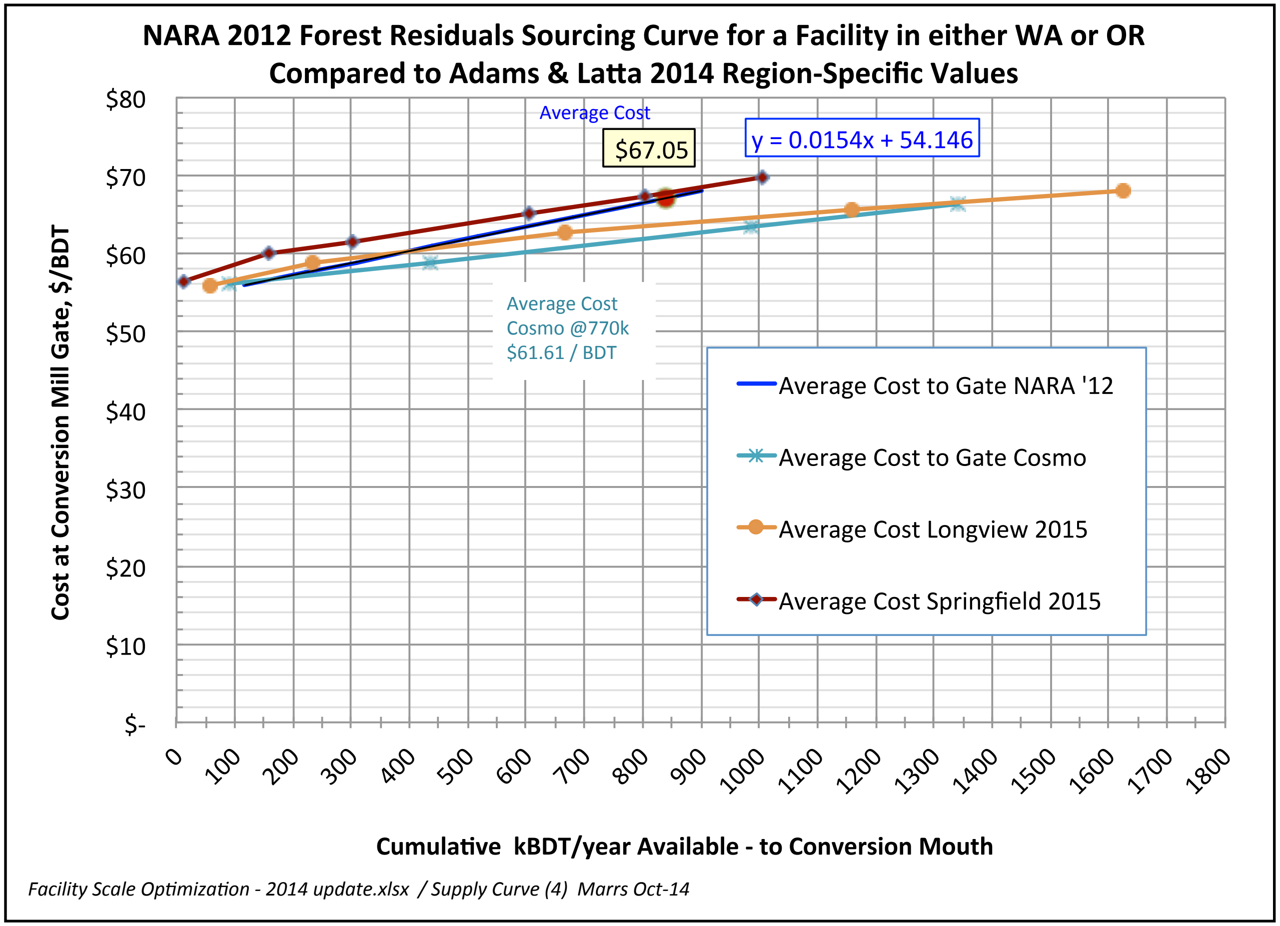


Figure FL-1.1. Comparison of 3 site-specific improved sourcing curves with historic NARA base case assumption. The historic values were very comparable to new improved values.

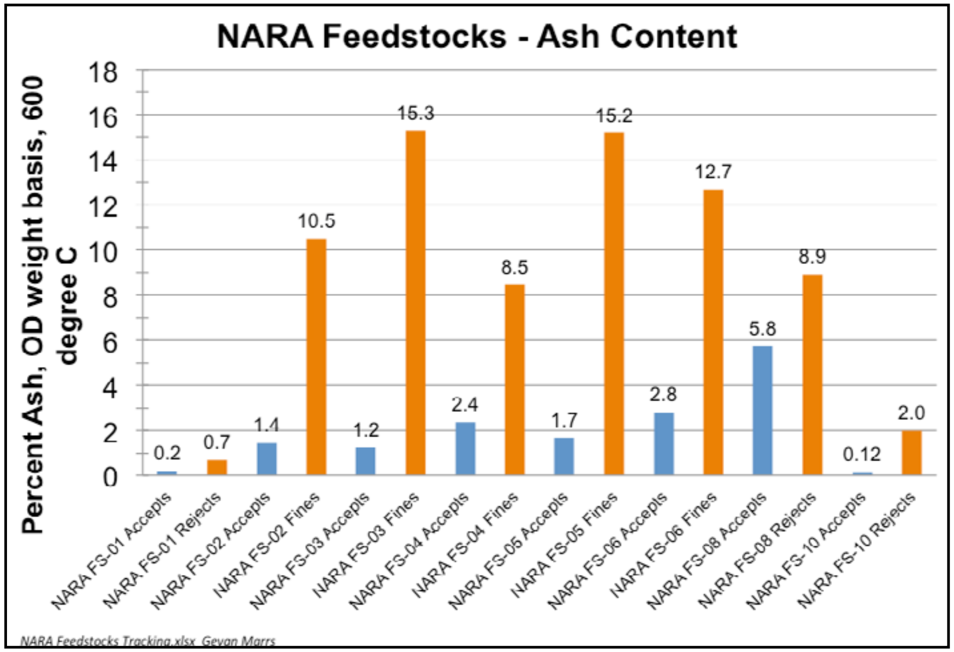
separately from the Accepts, and the difference in ash content is apparent, as shown in Figure FL-1.2. Although we cannot set firm specifications for our as yet un-built facility, current users of forest residuals (for biomass power) have specifications for ash in the range of 1.5 to 2.5%. It can be seen that screening out the -1/8” fines is very helpful in leaving the accept portion poised to meet this type of specification for ash. That is, operational fines screening of about this level is both necessary and (in most cases) sufficient for meeting biofuels feedstock ash specifications. Having accurate and precise measures of feedstock composition are not only important for the economics, they are required to perform a credible Life-Cycle Assessment (LCA), which is required to qualify for the renewability criteria of the Renewable Fuels Standards.

NARA feedstock samples (PNW softwood forest harvest residuals – FHR) have so far been tested for chemical composition by Weyerhaeuser’s analytical group for the major components of chemical composition and the results routinely fall significantly short of summation to 100% (totals range from 89 to 94%). While we are fairly confident that all of the important components of the analysis driving the economics (i.e., sugars and lignin residue) are reasonably accurate, the unidentified “missing pieces” cause difficulties for analyses like the ASPEN modeling, and the attendant LCA analysis (said to require accounting for 99% of the material). If we do not know what is missing, we cannot assign it a fate in the overall material balance for the NARA biofuel process. As a secondary objective, it has been found in the NARA project that analyses by different labs in the NARA project get different results for key components, leaving some uncertainty about the accuracy of WY Analytical and Testing (“A&T”) results. Only with some known reference standard can we assess the accuracy and precision of analytical procedures.

Under the Weyerhaeuser (WY) portion of this task (prior to July, 2014) we implemented a series of tests of the WY Analytical lab implementations of the NREL protocols for summative analysis of lignocellulosic feedstocks (Figure FL-1.3). These exhaustive protocols were developed specifically to achieve accuracy and precision between different labs, as well as resulting in a near-100% accounting for chemical components.

The results of this test, judged by measurements of the two woody reference samples from NIST of certified composition (eastern cottonwood and radiata pine), showed that the WY analytical lab procedures agreed very well with NIST reference values for all measured components and thus the total material accounting. For the previously measured NARA samples, using the NREL protocols, the majority of the missing components in prior WY analytical tests were accounted for by the acetyl content (not measured previously). There was some indication of a bias in early years measurements of glucans for FS-01, and there were still some unexplained missing materials in FS-10, a key reference sample (95.5% accounted for).

It was concluded that using the WY analytical labs, running the NREL analysis protocols would give the most accurate and precise results where all measured NARA samples for the life of the project could be compared most directly. The summary of resulting measurements for samples measured through the end of the WY portion of the Logistics – Sourcing task are summarized in Table FL-1.1 and will be reported in detail in the written final report by mid-2015.



NARA Feedstocks Tracking.xlsx Gevan Marrs

Figure FL-1.2. Ash content (600 degree C) of Accepts and Fines for NARA feedstocks.

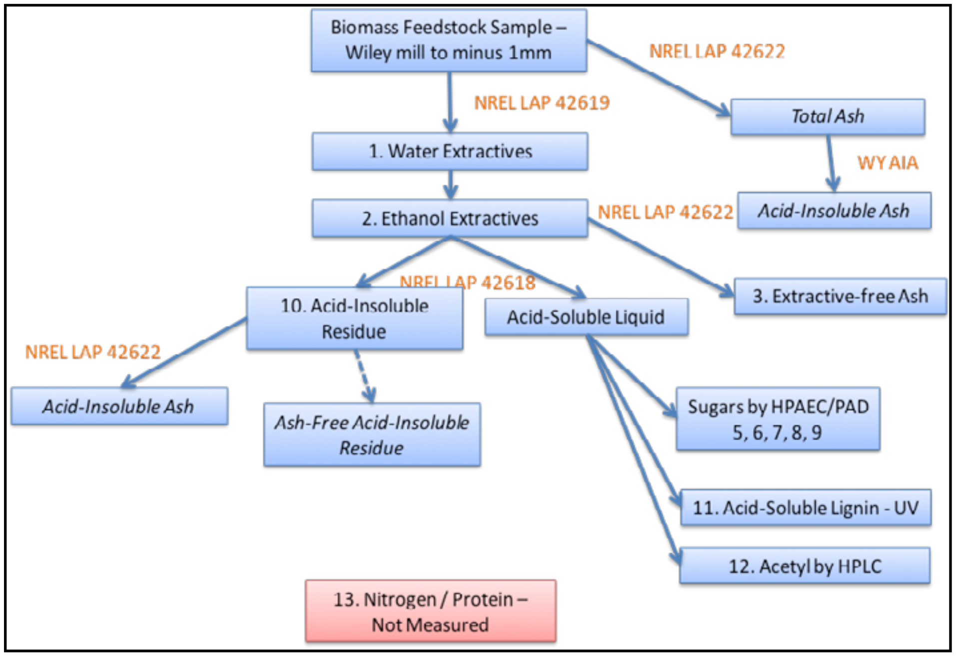


Figure FL-1.3. NREL summative analysis protocols implemented in Weyerhaeuser Analytical Lab.

Note that the common processing step was to include a mill-simulated size screening to remove the "fines", less than 1/8" from the materials since these have a large proportion of the inorganic material (ash, from soil contamination). For most materials the resulting "accepts" and "fines" were analyzed and reported separately in Table FL-1.1.

It should be noted that two of the NARA feedstocks tested and reported were NOT forest residuals. In order to compare to some other possible woody feedstock sources a sample of "clean" Douglas-fir pulp chips was sampled as FS-01. This material is quite pure in species content, very low in bark and fines, and low in ash. Of course it is also in demand and very high-priced—perhaps $120/BDST--compared to forest residuals. The other end of the quality spectrum was "hog fuel" – a mixture of bark, sawdust, and other woody debris that is only suitable for combustion. This material (FS-08) is accordingly very high in bark and fines and ash content. While far less costly than pulp chips—maybe $45/BDST—it is a marketable commodity which will have competing, existing demand, and it is very different in many aspects from forest residuals. It is not considered a viable NARA process feedstock contender and is shown only to demonstrate the extreme properties.

Task FL-1.1.3. Develop and test feedstocks value lift / cost reduction logistics improvements (harvesting, transport, etc.)

Under the WY portion of this task we collaborated with Sessions et.al. at OSU to characterize and process materials produced in their "grinding trials"—which investigated the impact of major controllable grinding variables on final economic impacts in the conversion process. The results (Figure FL-1.4) show that the range of economic impact from best to worst conditions is quite large ($30/BDT range) compared to the assumed base case of about $55/BDT harvest and hauling costs.

Since the potential gain over current practice is not actually worst case to best (since practice has already evolved to a mid-range conditions, shown as the base case above) we can only realistically capture the gains on the cost reduction side against current practice. Additionally, any sorting of materials into categories like those tested above (tops limbs, logs, chunks) will drive up feedstock acquisition costs as it reduces the amount available at each harvesting site if any exclusion of material is practiced. In summary, we might expect to improve logistics about $15/BDT by implementing the best practices as found in this study. This, however, only improves the project IRR by about 0.8%. A discussed in an earlier section, while this is very helpful to an on-going concern, it is far too little to bring a marginal return, unproven project into a desirable IRR range to induce the initial large, risky project investment.

Table FL-1.1. Key chemical composition results for NARA feedstocks tested through April, 2015.

Summary Chemical Analyses NARA Feedstocks

Feedstock	Total Polysaccharides	Hexose Polysaccharides	Pentose Polysaccharides	Ash-free Lignin, Acid-Insoluble (Klason)	Acid-soluble Lignin	Hot Water Extractives	Ethanol Extractives	Ash	Acetyl Groups	**Total**
NARA-FS-01 SW WA Douglas-fir Reference Wood Chips	63.51	59.4	4.10	25.93	1.69	5.64	0.50	0.09	1.64	**99.0**
NARA-FS-02 SW WA Hem/Spruce Forest Residuals Accepts	51.63	45.8	5.82	36.18	0.50	5.22	2.81	1.45	NM	**97.8**
NARA-FS-02 SW WA Hem/Spruce Forest Residuals Fines	32.97	28.9	4.08	37.43	0.87	6.92	4.93	10.48	NM	**93.6**
NARA-FS-03 NW OR Dfir Forest Residuals Accepts	58.28	50.80	7.47	29.96	2.57	4.91	0.97	0.91	1.73	**99.3**
NARA-FS-03 NW OR Dfir Forest Residuals Fines	35.10	30.4	4.73	31.97	0.74	5.55	4.01	15.27	NM	**92.6**
NARA-FS-04 N OR Coast Forest Residuals Accepts	48.55	43.0	5.59	33.55	0.63	4.91	3.09	2.37	NM	**93.1**
NARA-FS-04 N OR Coast Forest Residuals Fines	29.38	24.9	4.50	39.29	1.10	6.07	6.47	8.47		**90.8**
NARA-FS-05 King/Horse Cr Doug-fir / Cedar Accepts	56.56	49.8	6.72	27.62	0.43	5.11	2.49	1.65	NM	**93.9**
NARA-FS-05 King/Horse Cr Doug-fir / Cedar Fines	35.10	29.8	5.30	30.71	0.83	7.49	6.16	15.20	NM	**95.5**
NARA-FS-06 Sisters OR Pine and Spruce Accepts	46.45	37.6	8.89	31.81	0.58	5.43	5.11	2.82	NM	**92.2**
NARA-FS-06 Sisters OR Pine and Spruce Fines	30.12	23.7	6.42	35.39	0.84	7.08	6.29	12.70	NM	**92.4**
NARA-FS-08 Longview Alder / DFir Hog Fuel Accepts	46.48	38.1	8.37	31.03	0.88	5.52	3.14	5.76	NM	**92.8**
NARA-FS-08 Longview Alder / DFir Hog Fuel Fines	44.10	32.8	11.28	31.95	1.20	5.79	2.48	8.92	NM	**94.4**
NARA FS-10 Douglas-fir Forest Residual - Accepts	57.89	52.80	5.10	27.04	1.96	6.10	0.63	0.12	1.76	**95.5**
NARA FS-10 Douglas-fir Forest Residual - Fines	50.60	44.9	5.66	30.66	0.56	4.34	4.33	1.97	NM	**92.5**
NARA FS-11 Douglas-fir Grinding Trials Composite as-received	57.99	51.7	6.31	26.93	0.35	4.81	3.96	0.31	NM	**94.4**
NARA FS-12 Douglas-fir Grinding Trials Tops & Limbs as-received	56.27	49.2	7.10	28.60	0.43	5.92	5.41	0.71	NM	**97.3**
NARA FS-13 Douglas-fir Grinding Trials Pulp Logs as-received	61.79	55.6	6.22	26.80	0.37	3.77	2.59	0.24	NM	**95.6**
NARA FS-14 Douglas-fir Grinding Trials Log Chunks as-received	61.74	57.4	4.30	27.23	0.27	3.89	3.71	0.16	NM	**97.0**
NARA FS-15 Fresh Douglas-fir Grinding Trials Accepts	44.64	37.8	6.88	34.47	0.64	6.60	3.35	10.73	NM	**100.4**

TASKS TO GEVAN MARRS LLC (SINCE 1-JUL-14)

Task FL-1.2.1. Determine feedstock key quality parameters and variation and impact on conversion process

Finding additional sources of forest residuals feedstocks for areas outside the western Oregon and Washington geography has been difficult as there are few, (or no) commercial operating production ventures. Since FHR are highly variable even with a single pile, in order to sample and characterize reliably requires production at realistic scale. We did obtain one east-side (Montana) sample and one far northwest sample (near Enumclaw, WA) in concert with feedstock acquisition for the 1,000 gaillon bio-jet production task. These will be processed and characterized in the same manner as prior NARA feedstocks and results compared in the final task report.

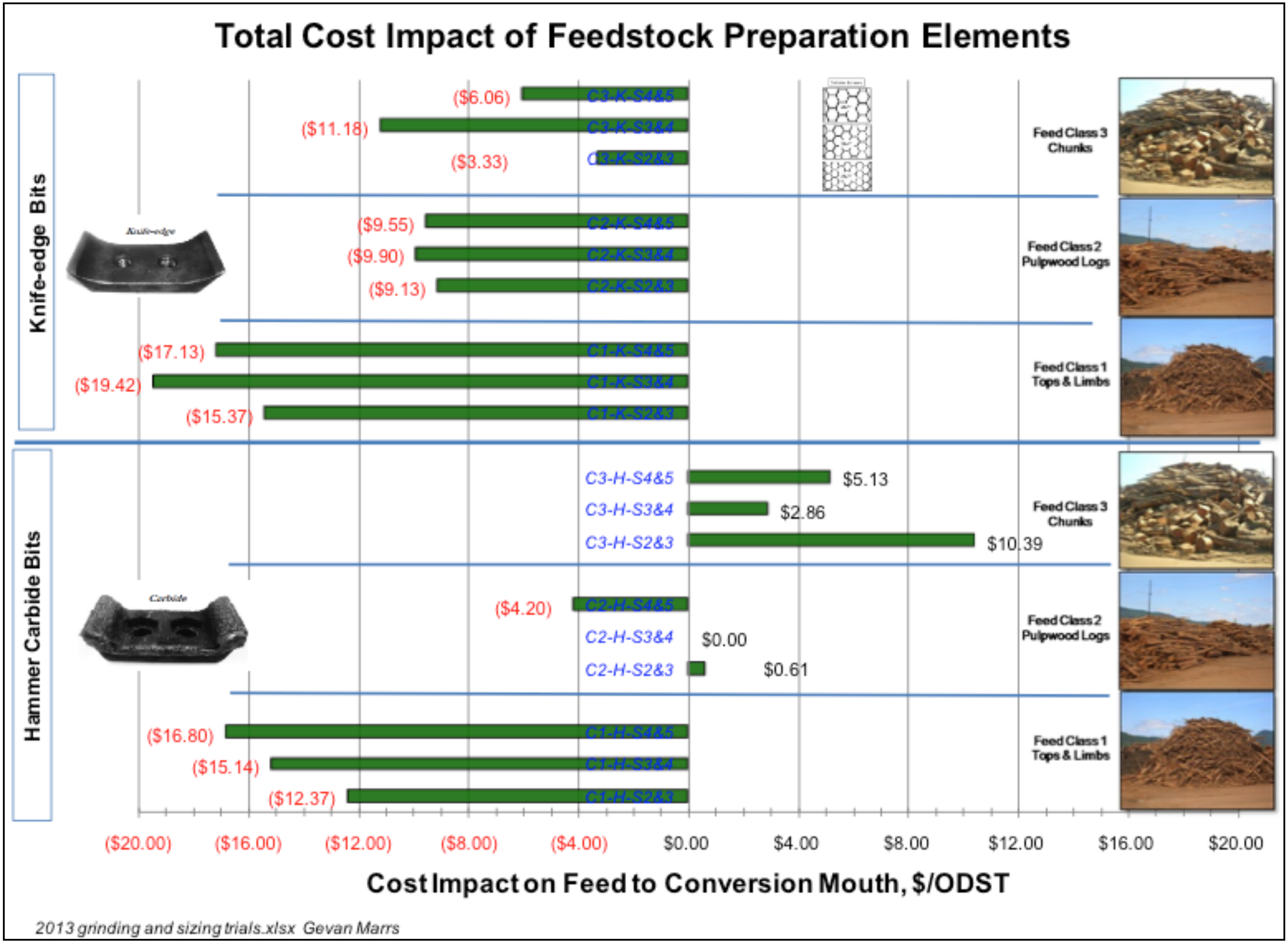
Task FL-1.2.2. Prepare final reports for WY portions of Feedstock Logisitcs - Sourcing

While various key pieces have been reported in a host of formats and forums over the early project years, pulling it all together in a formalized, full final written report has not yet begun.

Task FL-1.2.3. Identify, obtain, prepare, characterize and have delivered to conversion site sufficient feedstock across the NARA region to produce 1,000 gallons NARA bio-jet fuel

An assignment for a new task was created for supplying to a conversion partner sufficient quantity of a suitable feedstock to produce 1,000 gallons of bio-jet (IPK) for a demonstration flight before the NARA project ends in 2016. Considerable effort has been expended to quantify what constitutes “suitable”, as there are both technical and stakeholder criteria, and then identify candidate sources that can produce suitable materials at the needed scale, and a location and facility to process the material to conversion process needs, as well as store and ship to the conversion site.

Broadly speaking, we have narrowed the suitability criteria to be about 100 BDST of primarily Douglas-fir forest harvest residuals with fairly low bark and ash



2013 grinding and sizing trials.xlsx Gevan Marrs

Figure FL-1.4. The net total impact range is about $30/ODST feedstock to conversion mouth.

content. In other words, the material would resemble the current NARA base case feedstock, FS-10. While it is likely that the material would be ground in the woods in a horizontal drum chipper, the resulting typical large particles, with a long aspect ratio (see Figure FL-2.1), may be too large for feeding a lab-to-pilot scale conversion reactor. We will have to identify the pretreatment conversion site before we can pin-point oversize removal and resizing criteria.

In mid-February a suitable amount and type of material was identified on a site belonging to a NARA (Weyerhaeuser) member property—dubbed the Siuslaw 900 site (Figure FL-1.5). This was located in Lane County, OR, west of Eugene. Thirteen truckloads were ground and delivered to a processing yard in Junction City, OR. The total delivered was 317 green tons, with a moisture of about 43%, yielding about 180 BDST starting material. Deliberations are underway to determine what size processing will meet the (as-yet selected) conversion facility equipment criteria.

Recommendations | Conclusions

The softwood forest harvest residuals tested to date, while quite variable, seem to have characteristics that make them suitable for conversion to bio-jet by the NARA process, after suitable woods production and mill-site screening. These steps are both necessary and sufficient to bring the key properties (size distribution and ash content) within reasonable feedstocks specifications.

In the early stages of the project, where iso-paraffinic kerosene (IPK) was the main product focus, much attention was given to factors that change the total polysaccharides content, as that principally determines IPK yield and thus impacts economics. However, as the need for significant revenue contribution from the co-products (derived mainly from the lignin fractions) became apparent and likely co-products were identified (activated carbon, ligno-sulfonates), the overall economic impact due to tradeoffs in polysaccharide and lignin content changed) mostly related to bark content differences.) That is to say, declining IPK production by reduced polysaccharides due to higher bark content are offset by increases in production and sales of activated carbon. Since the two products contribute roughly the same annual revenue in the current base case, this makes bark content a relatively unimportant quality specification—at least over the range of contents we have so-far encountered.


Figure FL-1.5. Main component of 1,000 gallon task feedstock – Siuslaw 900, aka FS-17.

We have additionally demonstrated that there are important incremental cost reduction opportunities in feedstock production—mostly in increasing grinder utilization and decreasing transportation costs through higher bulk density. While these improvements will be important incrementally to an on-going operation, they are not sufficiently large to cause break-through cost reductions that dramatically improve the overall project IRR.

TASK FL-2: LOGISTICS DECISION SUPPORT AND IMPROVEMENT

Key Personnel	Affiliation
John Sessions	Oregon State University
Kevin Boston	Oregon State University

Task Description

Our task is to 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.

TASK 1 REVISION FOR YEAR 3 - EXTENDED SCOPE OF WORK

PI: Kevin Boston

This project will develop a double sampling strategy that will combine both the OSU methods to determine the available recoverable volume of biomass following harvesting operations and the Montana Bureau of Industrial Statistics Method to determine the total volume of biomass that is possible. Harvesting units that were measured by the BERR groups to determine the total volume of biomass will have their piles measured by the OSU group to determine the recoverable biomass. The result will create a ratio that can be used to refine biomass estimates. These ratios will be developed for the two concentration areas, central Oregon and southwestern Washington to further refine the biomass estimates in the woodsheds for the potential sites. Additionally, these differences between these two estimates are useful for other NARA functions as it will be an estimate of the amount of biomass that remains on site for nutrient cycling and potential wildlife habitat.

- Deliverable: Field procedures and model to develop recoverable and residual biomass from TPO data. Draft field procedures to be developed by June 30, 2014. Data has been collected and is currently being analyzed. BEER groups are organizing their data to allow for combining the two approaches into biomass estimates.

Activities and Results

Task FL-2.1. Develop Biomass Recovery Coefficients for OR, WA, ID, MT

A manuscript is being prepared for submission and a white paper is being prepared for internal group use.

Task FL-2.2. Develop Moisture Management Strategies and Models

Live branch moisture data was completed in all four sites and four seasons by PhD candidate Francisca Belart. Data analysis is completed and a manuscript being written. Results show that average branch moisture content is not higher than 50% on any of the sites sampled, and there is statistically significant effect of season in branch average moisture content only in ponderosa pine and valley Douglas-fir. Both species have their lowest moisture content in summer. Western hemlock has almost no variation in moisture content through the year and ponderosa pine the highest variation (Table FL-2.1). This is consistent with the environment these species live in.

Additionally, good correlations were found between tree height, heartwood and average branch moisture content. These functions could be used to predict average branch moisture content with reduced data collection in the future.

The first Douglas-fir logging residue moisture monitoring trial located at the Oregon Coast was deconstructed after one year of monitoring. Most of the sensors were unrecoverable, including the weather station. As residue piles were deconstructed, samples were taken on each height level, corresponding to where sensors were located. Statistical tests show significant differences in moisture content by height in the pile. Moisture content can be as low as 20% in the outer shell and as high as 50% in the residue located in the bottom of the pile after one year of storage.

We installed four logging residue moisture monitoring trials with the new measuring protocol in a drier Willamette Valley Douglas-fir site, a wet Willamette Valley Douglas-fir site an Oregon Coast Western hemlock

Table FL-2.1. Mean seasonal branch moisture content by site

Site	Fall	Winter	Spring	Summer
Valley Douglas fir	0.46 ± 0.02	0.45 ± 0.02	0.46 ± 0.01	0.43 ± 0.02
Ponderosa pine	0.47 ± 0.02	0.50 ± 0.02	0.45 ± 0.02	0.43 ± 0.02
Western hemlock	0.48 ± 0.02	0.48 ± 0.02	0.48 ± 0.02	0.47 ± 0.02
Dry Douglas fir	0.46 ± 0.02	0.48 ± 0.02	0.46 ± 0.02	0.47 ± 0.02

site and a ponderosa pine site in eastern Oregon. Data collection and monitoring has been performed monthly for ten, seven, five and three months on each site respectively. The first pile site is planned to be deconstructed by late May and data collection to be completed by December 2015.

A finite element analysis model (FE) has been developed to simulate environmental conditions and determine the effect of different logging residue storage forms on drying patterns (Figure FL-2.1). The physics model has been implemented with fluid flow, heat transfer and moisture diffusion with the help of Professor Ben Leshchinsky, OSU. Temperature and wind functions were developed from data collected in the field and are already implemented in the model. This model is being calibrated and will be presented at a graduate student seminar in OSU in April by PhD candidate Francisca Belart. Pile and environmental variables such as relative humidity and temperature collected in the field will be used to validate the model.

Task FL-2.3. Refine Collection and Transport Models for regional modeling

A GIS model to determine the area of potential harvest areas by harvest method and distance to road is underway for the NARA region. These results will be used in the NARA feedstock supply model in combination with Kevin Boston's field data and a biomass collection model.

A model comparing double trailers to single trailers was prepared and submitted for review. At low moisture content single trailers are volume limited, but double trailers are not. The model combines simulation with field data to understand under what conditions double trailers are cost effective for transporting dry grindings under the different state regulations in the Pacific Northwest. These results will be integrated into the NARA feedstock supply model.

We worked with the LCA group to produce fuel consumption models for collection, processing and transport of forest residues.

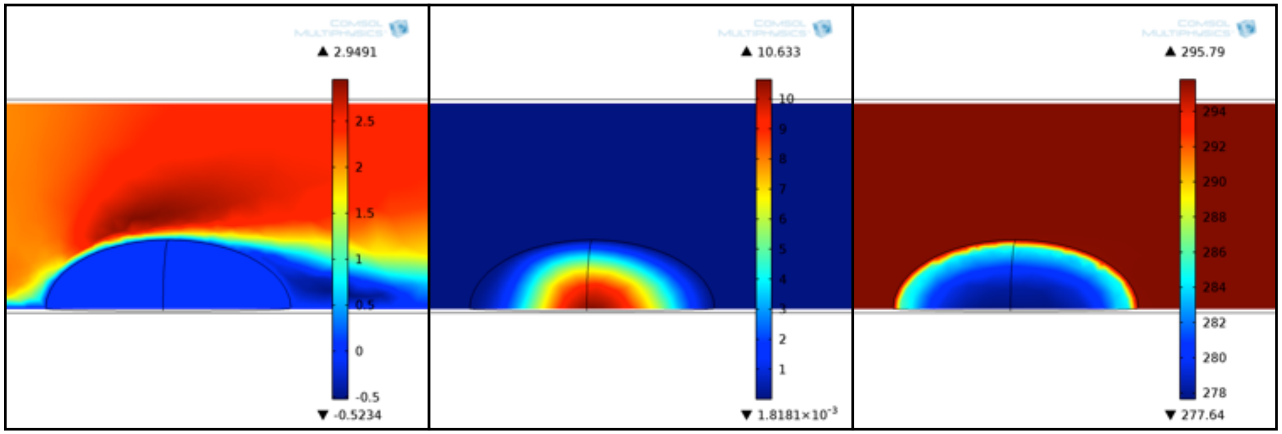


Figure FL-2.1. Wind, moisture content and temperature simulation at a hypothetical slash pile.

A manuscript is under review with the Journal of Forest Policy and Economics exploring biomass supply curves for western juniper in central Oregon under alternative business model and policy assumptions.

Task FL-2.4. Evaluation of chipping and grinding production to meet alternative feedstock specifications.

Chip flinger trials to increase bulk density in dry grindings were completed at the Lane Forest Products yard in Eugene, OR. Twenty trailer loads of dry primarily Douglas-fir grindings were first loaded by conventional gravity loading, then reloaded using a prototype chip flinger under a range of discharge velocities. Laboratory results of grinding samples have been completed. Manual methods of load volume estimation are being compared to aerial drone measurements carried out during the experiment. A manuscript is in preparation.

A manuscript summarizing the economics of grinder parameters on cost was submitted for the special issue on "Biomass-Based Materials and Technologies for Energy," sponsored by Advances in Materials Science and Engineering (Marrs lead author). A manuscript summarizing the high speed blowing tests conducted in Year 3 was reviewed and published. A manuscript comparing supply chain impacts of green versus dry residues is in final preparation and will be submitted in April, 2015. An abstract to the World Forestry Congress in Durban South Africa (7-11 September 2015) describing the economics of forest biomass feedstocks for aviation fuel production was accepted and a final manuscript is being prepared for the proceedings and to be considered for presentation.

Feedstock coordination for the 1000-gallon goal was completed, feedstocks were ground and delivered to Lane Forest Products from the Oregon Coast range, the Flathead reservation (western Montana), and the Muckleshoot tribe (western WA). The residues samples (600-800 lbs) of each will be shipped to Weyerhaeuser (WY). The rest will be mixed, screened, and stored at the Lane Forest Products yard until a pretreatment location is identified.

Task FL-2.5. Demonstrate and evaluate new trailer designs to improve transport efficiency

Preliminary investigation on methods/modifications to permit turning of chip trailers on dead-end landings using log loaders was started. Second generation self-steering trailer technology was reviewed for demonstration potential in year 5.

Task FL-2.6. Evaluate health and safety procedures for any new work processes

No work done this period.

Recommendations | Conclusions

Task FL-2.1. Develop Biomass Recovery Coefficients for OR, WA, ID, MT – The available volume of biomass being recovered is much less than the 70% used in standard analysis. The economically available biomass will be a further reduction with final stages of analysis being completed at the moment.

Task FL-2.2. Develop Moisture Management Strategies and Models – This task had early delays due to field installation redesign, but data collection is now going smoothly and an innovative finite element model is under development.

Task FL-2.3. Refine Collection and Transport Models for regional modeling – This task is well underway. Western Oregon and western Washington GIS analysis to support feedstock group (Adams/Latta) will be complete in June and extensions to remaining region will be done in Year 5.

Task FL-2.4. Evaluation of chipping and grinding production to meet alternative feedstock specifications – This task is about complete, manuscripts need to be followed through peer-review process.

Task FL-2.6. Evaluate health and safety procedures for any new work processes – Have not observed any new work processes where safety protocols are not covered in existing work procedures. The only exception might be steep slope ground-based operations, but these will need to follow any procedures developed for commercial tree operations.

Physical and Intellectual Outputs

PHYSICAL

- Four slash moisture monitoring stations were established, including in-pile sensors, weather stations, and data loggers. Stations are visited monthly.

- Three residue sites (western Oregon, western Washington, western Montana) were selected for 1000 gallon feedstock.

REFEREED PUBLICATIONS

Zamora-Cristales, R. and J. Sessions. A collection model for forest biomass residues. In preparation for Croatian J. of Forest Engineering.

Zamora-Cristales. R., J. Sessions, G. Marrs, and D. Smith. Impacts of green versus dry residues on the liquid fuel supply chain. In preparation for Canadian J. of Forest Res.

Zamora-Cristales, R. and J. Sessions. Economics and system dynamics of double trailers in transporting forest biomass on steep terrain. In review. California Agricultural J.

Lauer, C., J. McCaulau, J. Sessions and S. Capalbo. Biomass supply curves for Western Juniper in central Oregon, USA, under alternative business model and policy assumptions. In review. Journal of Forest Policy and Economics.

Marrs, G., R. Zamora and J. Sessions. Optimizing the Feedstock Value Chain for Bio-Jet Fuel from Pacific Northwest Softwood Harvest Residues. In review for the special issue on “Biomass-Based Materials and Technologies for Energy” sponsored by Advances in Materials Science and Engineering.

Zamora, R., J. Sessions, D. Smith and G. Marrs. Effect of Grinder Parameters on Particle Size and Fuel Consumption. In final review. Biomass and Bioenergy.

Clark, J., Sessions and R. Zamora. Optimizing Knife Change Times for Forest Biomass Chipping Operations. In final review. Forest Products J.

Zamora-Cristales R., J. Sessions, D. Smith, and G. Mars. 2014. Effect of high speed blowing on bulk density of ground residues. (Accepted) Forest Products Journal. http://dx.doi.org/10.13073/FPJ-D-14-00005

Zamora-Cristales, R., J. Sessions, K. Boston and G. Murphy 2014. Economic Optimization of Forest Biomass Processing and Transport. Forest Science. http://dx.doi.org/10.5849/forsci.13-158.

Zamora-Cristales, R., P. Adams, and J. Sessions. 2014. Ground-based thinning on steep slopes in Western Oregon: Soil exposure and strength effects. Forest Science 60(5):1014-1020. doi.org/10.5849/forsci.12-525.

CONFERENCE PROCEEDINGS AND ABSTRACTS FROM PROFESSIONAL MEETINGS (2014)

Zamora-Cristales, R. and J. Sessions. Economics of forest biomass feedstocks for aviation fuel production. In preparation for XIV World Forestry Congress, Durban, South Africa, 7-11 September 2015

J.Y. Zhu, M. Chandra, R. Gleisner, W Gilles, Johnway Gao, G. Marrs, D. Anderson, and J. Sessions. 2014. Reviving sulfite pulping for sugar production from woody biomass. Paper prepared for 2014 TAPPI PEERS conference, Sept 14-17, Tacoma, WA.

Zamora R., and J. Sessions. 2014. Forest harvest residue collection model. In Proceedings: 2014 Council on Forest Engineering (COFE) annual meeting, June 22 – 25, Moline, Illinois, USA.

RESEARCH PRESENTATIONS

Posters:

Zamora-Cristales R., and J. Sessions. 2014. Improving Efficiencies in forest biomass transportation. 2014 Annual NARA Meeting, Seattle, WA, September 15-17.

Belart, F., J. Sessions, G. Murphy, M. Jolly, B. Leshchinsky and K. Tuers. 2014. Moisture Management Model for Optimal Forest Biomass Delivery in the Pacific Northwest. 2014 Annual NARA Meeting, Seattle, WA, September 15-17.

Zamora-Cristales, R. and J. Sessions. 2014 Modeling Forest Harvest Residue Collection. Prepared for Biofuels and Co-products Conference. April 28-30, Red Lion, Seattle, WA.

Belart, F., J. Sessions, G. Murphy, M. Jolly and K. Tuers. 2014. Moisture Management Model for Optimal Forest Biomass Delivery in the Pacific Northwest. Prepared for Biofuels and Co-products Conference. April 28-30, Red Lion, Seattle, WA.

Presentations:

Sessions, J. and R. Zamora-Cristales. 2014. Decision Support Systems for Forest Harvest Residue Collection and Transport in PNW, USA. Norwegian University of Life Sciences, As, Norway, November 13, 2014.

Zamora-Cristales, Rene. 2014 International Union of Forest Research Organizations IUFRO World Congress 2014. “Economics of forest biomass processing and transport on steep terrain” Salt Lake City Utah, USA, October, 2014.

Zamora-Cristales, R. and J. Sessions. 2014. A solution procedure for forest harvest residue collection for bioenergy. Presented at 37th Council on Forest Engineering Annual Meeting. June 22-25 2014. Moline, Illinois, USA.

Marrs, G., J. Sessions, and R. Zamora. 2014. Economic Impacts of Forest Residue Feedstocks. Presented at Bioenergy + Co-products Conference, April 28-30, Red Lion Hotel, Seattle, WA.

Zamora-Cristales, R. and J. Sessions. 2014. Washington Contract Loggers Association, Annual Meeting 2014. “Improving Efficiencies in Forest Biomass in Biomass Collection and Transportation” Spokane, Washington, USA, March 2014

VIDEOS AND WEBINARS

None, although we produced an internal use video on our chip flinger and drone trailer volume measurements

THESIS AND DISSERTATIONS

Loeppky, J. 2015, Energy consumption of grinding unbaled and baled forest harvest residues, Master of Forestry project, Oregon State University, Corvallis, Oregon.

FEEDSTOCK

FEEDSTOCK DEVELOPMENT TEAM

TASK FD-1: POPLAR AND ALDER PRODUCTION

Key Personnel	Affiliation
Norman Lewis	Washington State University

This task was terminated along with all other hardwood activities in NARA project Year-2 to focus efforts on softwood forest residue challenges.

TASK FD-2: PHENOMICS ANALYSIS

Key Personnel	Affiliation
Helmut Kirchhoff	Washington State University

Task Description

Selected plant lines will be subjected to phenomics analyses. This phenomics system 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 individuals 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 a high fidelity of the data. The drought stress response of Douglas-fir trees will be analyzed with this approach.

Activities and Results

The aim was to identify Douglas-fir families out of about 900 tress from the collection of Dr. Jayawickrama (Oregon State) that are either more or less drought-tolerant. Therefore, we used non-invasive, automated optical screening realized by a new Phenomics facility at WSU, Pullman. Since this is the first time that Phenomics was used for Douglas-fir tress, we designed a pilot experiment with only 50 trees to gather information about the optimal design of the experiment (duration of drought stress, optical settings etc). This experiment was performed in the April-July 2014 report phase. Based on the experiences and preliminary results collected from the pilot experiment, we performed the main experiments with 882 plants (nine plants per family, 98 families total) in the second period (August 2014-November 2014). Due to space restrictions in the Phenomics facility, the experiment was divided in two separate runs. The overall arrangement of the plants is shown in Figure FD-2.1.

Measurements of physical conditions in the Phenomics facility reveal that light intensity and temperature fluctuations are below +/- 10% (light) and +/- 3% (temperature). Drought stress was established by stopping the watering of plants. A robust parameter that indicates stress in plants is the maximal photochemical efficiency of photosystem II (PSII) shown in Figure FD-2.2 (ΦII) as a function of days after the last plant watering. A decline in ΦII is indicative for a drought-induced impairment of plant metabolism, i.e. the lower ΦII the stronger the stress response of the plant. Figure FD-2.2 reveals that the drought-induced ΦII decrease is similar for most of the families but some families respond faster or slower to the stress. For better and easier comparison of the different Douglas-fir lines, we calculated the mean ΦII from Figure FD-2.2. A smaller mean ΦII corresponds to earlier drought-induced decline indicating that the plants are more drought-sensitive. The data in Figure FD-2.2 was measured for dark-adapted plants.

We did the same measurement for plants at the middle of the day. Both light and dark mean ΦII values are plotted against each other in Figure FD-2.3. Plants that are on the upper right of this plot have a lower ΦII in the night and in the day. In turn, plants on the lower left respond fast at both times of the day. We use Figure FD-2.3 for screening drought-sensitive and drought tolerant Douglas-fir families. The families given in colors are candidates that are based on ΦII screening are expected to respond differentially to drought stress. Plants indicated as green circles are more drought-tolerant whereas plans in red are more sensitive. Yellow circles represent plants that represent bulk behavior.

Recommendations | Conclusions

The Phenomics screening revealed candidates (Figure FD-2.3) for further in-depth analysis by the gene chip approach developed in the Feedstock development program of NARA. The aim would be identification of differences in gene expression in the selected drought-sensitive and drought-tolerant families. However, to validate the Phenomics data, it would be important to repeat the experiments on the selected lines and increase the number of trees per family to improve statistics. This experiment is planned for Fall 2015. After that, the data should be sufficient to write a summarizing manuscript of our analysis.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS (ACCEPTED OR COMPLETED)

Kirchhoff, H. 2014. Diffusion of molecules and macromolecules in thylakoid membranes. Biochim. Biophys. Acta,1837(4), pp.495-502. DOI: 10.1016/j.bbabio.2013.11.003

RESEARCH PRESENTATIONS

Hoehner, R. (2014) Poster at the Gordon conference on Photosynthesis (West Dover, VT)

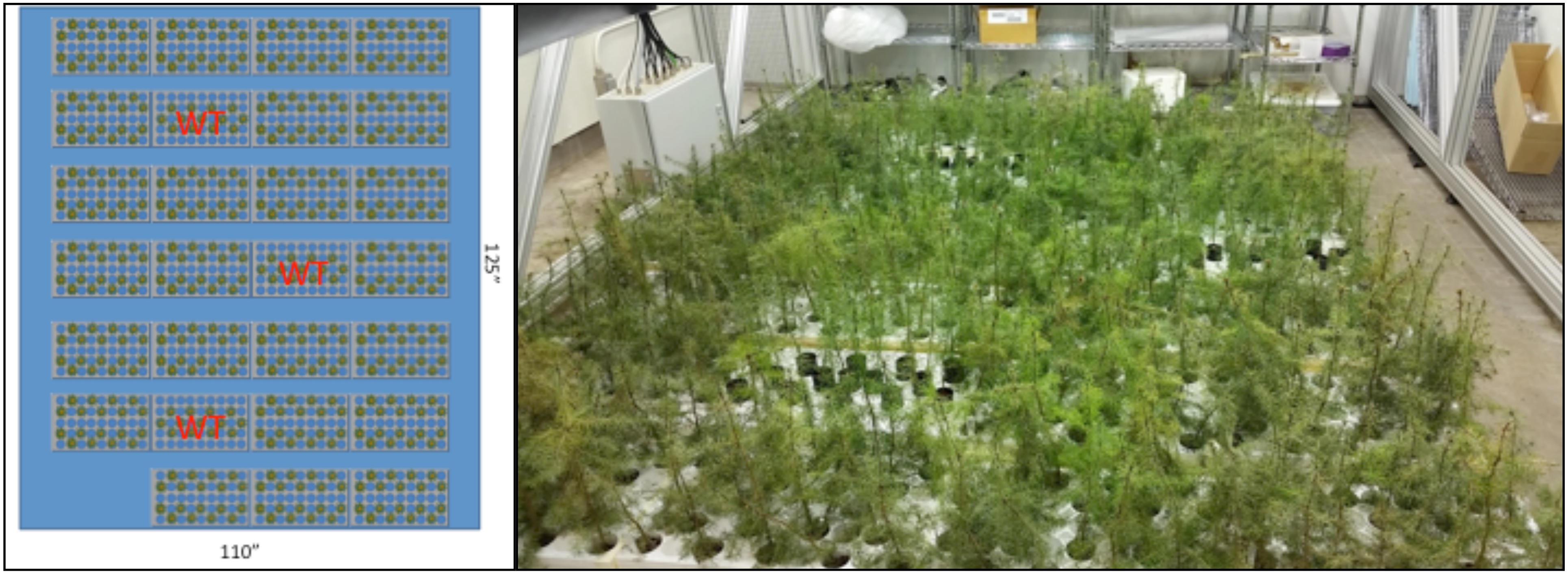


Figure FD-2.1. Left, cartoon showing the arrangement of Douglas-fir seeding's in the WSU Phenomics facility, WT are wildtype control plants. Right, picture of the seedlings in the facility before drought stress.

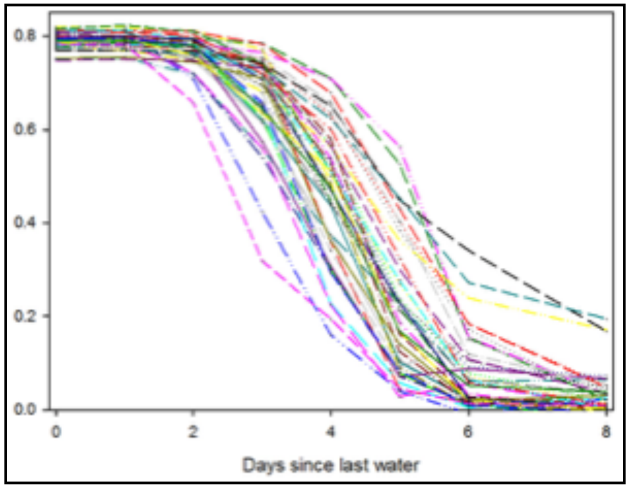


Figure FD-2.2. Photochemical efficiency of PSII (ΦII) as a function of days after the last watering to induce drought stress.

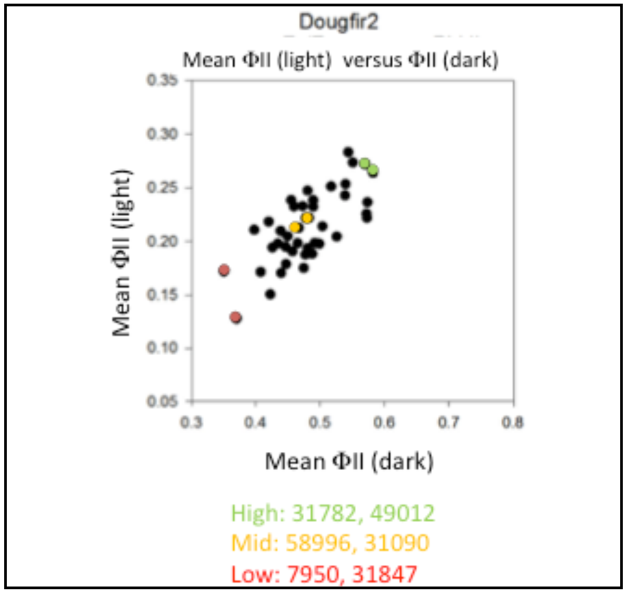


Figure FD-2.3. Mean ΦII (light) versus ΦII (light) to identify drought sensitive and drought insensitive families. Each data point represents the average of nine plants. High performers are located on the top right corner in these graphs.

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, and reduce cost. Recent advances by the Conifer Translational Genomics Network (a multi-institution project for major U.S. 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) (expanded/strengthened Task 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

Task FD-3.1. Collect samples and combine with phenotypic data

Measurement of specific gravity, pretreatment yield, pretreated holocellulose, enzymatic hydrolysis yield and recalcitrance factor were completed for the 2nd cycle CL98 population collected at the Moon Creek test site in SW Oregon. Narrow-sense heritabilities, genetic correlations between traits, and predicted genetic gains for pretreatment yield, pretreated holocellulose, enzymatic hydrolysis yield, and recalcitrance factor were predicted for 284 progeny trees, 30 woodsrun (unimproved) trees, 28 crosses (between 6 and 12 progeny per cross) and 46 parents. Table FD-3-1 shows heritabilities ranging from 0.18 to 0.7. These results compare well to many publications for other wood properties (jet-fuel related heritabilities have not be reported before). While specific gravity was favorably correlated with recalcitrance factor, the genetic correlation (Table FD-3-1) was not high enough to be a very reliable predictor (indirect selection trait).

Table FD-3.1. Narrow-sense individual heritabilities and their standard errors for five wood traits in a Douglas-fir breeding population

	h^2i	s.e.
Density (SG)	0.315	0.219
Pretreatment Yield (PY)	0.767	0.180
Pretreated Holocellulose (PH)	0.185	0.190
Hydrolysis Yield (HY)	0.496	0.142
Recalcitrance Factor (RF)	0.443	0.136

Table FD-3.2. Genetic correlation coefficients (lower triangle) & their standard errors (upper triangle).

	SG	PY	PH	HY	RF
SG		0.251	0.241	0.219	0.212
PY	0.048		0.272	0.189	0.253
PH	0.343	-0.021		0.259	0.273
HY	0.325	-0.497	-0.246		0.015
RF	0.402	-0.111	-0.159	0.972	

One of the forward selections had a 40.6% predicted gain in holocellulose yield and 34.7% predicted gain in recalcitrance factor. If instead we were to select existing seed producing parents, one parent had a 27.0% predicted gain in holocellulose yield and 21.5% predicted gain in recalcitrance factor.

Task FD-3.2. Design and Building of Genotyping Array

The contract for building the array (50K SNPs) using the Affymetrix platform, and for genotyping 1,920 samples, was awarded to GeneSeek Inc., part of NeoGen Corp (http://www.neogen.com/ Genomics/). Rich Cronn and Sanjuro Jogdeo (USDA-USFS Pacific Northwest Research Station) helped develop non-polymorphic sequences that Affymetrix used to design 'control' probes for the genotyping array. These are sequences identical between the Douglas-fir transcriptome and the loblolly pine genome. The control probes were used to calculate a quality control metric (DQC) used to identify samples that have been processed correctly by Affymetrix. We also sent Affymetrix a file of unique transcriptome sequences consisting of all non-redundant contigs and singletons from the Howe et al and Muller et al sequencing projects. These were used to evaluate the uniqueness of the SNP designs that are being generated.

Selecting the SNPs for the array was a major project, involving Glenn Howe of OSU, the Bioinformatics Services team at Affymetrix Inc. (especially Lucy Reynolds and Lakshmi Radhakrishnan), and personnel at GeneSeek. We wrote bioinformatics programs to prepare our SNP database in the format needed by Affymetrix (Axiom myDesign Arrays Design Request Form for Agrigenomics Applications; Affymetrix Technical Note). This SNP database consists of SNPs identified by Muller et al. (2012) and Howe et al. (2013) (see previous NARA reports). The objective of this work was to increase the number of genes that could be assayed, thereby increasing genome coverage for genomic selection.

We originally sent an initial set of 197,200 target SNPs to Affymetrix, and subsequently worked with GeneSeek and Affymetrix to refine the design of the SNP array. This involved multiple rounds of SNP evaluation and prioritization. We sent what we expected to be our final list of high priority SNPs to GeneSeek on December 11, 2014. Just as we were about to finalize the design, a draft Douglas-fir genome sequence became available from Dave Neale, Jill Wegrzyn, and other members of the PineRefSeq Project. Further, we had access to other findings from a similar genotyping effort (ADAPTREE) underway using the Affymetrix platform on spruce and pine by a team based at the University of British Columbia. This gave additional data to improve our design. The team, therefore, ran through several more iterations. Although it postponed the final design, we feel it is now more likely to succeed and give desired results. Finally, we submitted a file of 221,674 target SNPs to GeneSeek/Affymetrix, and obtained information from GeneSeek/Affymetrix indicating the relative quality of the various SNPs (Table FD-3.3).

Table FD-3.3. SNP quality for 221,674 SNPs submitted to GeneSeek/Affymetrix.

15,384	recommended on both strands,
38,392	recommended on the forward strand only
39,388	recommended on the reverse strand only
31,251	neutral in both strands
26,947	neutral in forward strand only, (neutral best result)
27,128	neutral in reverse strand only, (neutral best result)
42,236	not-recommended in both strands
426	not-possible in forward and not-recommended in reverse
521	not-recommended in forward and not-possible in reverse
0	not possible in both strands (This sequence does not have enough non-ambiguous flanking sequence.)

On March 17, 2015, the array was finalized with 55,766 markers and 58,350 probe sets and sent to Singapore for manufacture. This would be most SNPs used for a genotyping array for coastal Douglas-fir. The expected date for completion of manufacture is April 29, 2015 after which genotyping can begin.

DNA Extraction

We collected 1,920 needle samples from selected Douglas-fir trees three progeny sites, four seed orchards, and one container nursery (Table FD-3.4). Each sample consisted of 5-10 green needles. Samples were placed in numbered 14 cm3 vials and 10 cm3 crystalline silicate desiccant added immediately to preserve DNA, and the vials were sealed. All samples were carefully tracked by spreadsheet. Subsamples of three needles were taken from each vial, manually minced to 2-3mm lengths, and each carefully loaded into a well in a 96-well DNA extraction plate (Qiagen DNeasy 96 Plant DNA kit). The location of each sample in each plate was carefully recorded. The loaded plates were transported to the USDA Forest Service National Forest Genetics Electrophoresis Laboratory (NFGEL) in Placerville, CA for extraction.

Table FD-3.4. Foliage samples have been collected from the following sets of trees to be processed through the SNP genotyping array

291	2nd-cycle CL98 progeny trees used in wood chemistry analysis or pilot genomic selection study
28	CL98 parents with wood chemistry data
46	other 1st generation parents or grandparents of 3rd cycle genomic selection crosses
26	2nd cycle parents of 3rd cycle genomic selection crosses
264	other 2nd cycle progeny, full-sibs of genomic selection study 2nd-cycle parents
1,141	3rd cycle progeny (genomic selection study selection population)
124	other parents of future 3rd cycle crosses

Recommendations | Conclusions

The estimates of heritability and predicted genetic gain show that it would be quite feasible to genetically select Douglas-fir for conversion to jet fuel. Given the sample sizes, these estimates should not be taken as the last word in genetic parameter estimates: we would typically want to sample from 100 families, 30 trees per family on at least three sites to increase our confidence in the estimates. However these results show a lot of promise.

From the CL98 test population, it would be possible to collect seed from a group of selected parents and start establishing high jet-fuel plantations in the near future. However for large-scale implementation into breeding programs in the Pacific Northwest it would essential to either (1) identify indirect selection traits that are less expensive to measure or (2) find ways to simplify and accelerate the measurement of the wood chemistry traits so that we could (3) screen many more populations and trees.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Geleynse, S., Alvarez-Vasco, C., Garcia, K., Jayawickrama, K., Trappe, M., & Zhang, X. (2014). A multi-level analysis approach to measuring variations in biomass recalcitrance of Douglas fir tree samples. BioEnerg. Res., 7, 1411-1420. doi:10.1007/s12155-014-9483-z

TASK FD-4: GENETIC VARIATION UNDERLYING AMENABILITY TO PRETREATMENT/BIOCONVERSION

Key Personnel	Affiliation
Callum Bell	National Center for Genome Resources

This task ended on schedule in NARA project Year-2. Portions of this task were incorporated into Task FD-3: Combining Genomic and Field-based Breeding and Testing Methods to Improve Woody Feedstock Production

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 key barrier hindering the development of an economically viable biomass conversion process. Despite the larger abundance, softwood and its forest residues are not still economically viable feedstock for biofuel production. The feedstock collection, transportation and processing all contribute significantly to the overall cost. One effective means of reducing feedstock cost and subsequent conversion cost is to select biomass with high amount of sugars and low recalcitrance toward deconstruction to release sugar.

Our work carried out in the last two years has clearly demonstrated that there is a significant variation in biomass recalcitrance among different Douglas-fir families. A parameter "recalcitrance factor" is introduced to quantify the level of biomass recalcitrance toward sugar production from different Douglas-fir families. The goal of our research is to develop and implement a selective feedstock breeding methodology to identify and produce "ideal" softwood biomass to maximize sugar yield and reduce conversion (pretreatment and hydrolysis) cost.

Activities and Results

A method for screening woody biomass samples for biomass recalcitrance was developed in a previous period. This method focuses on a parameter we call the "recalcitrance factor", which summarizes the ease at which biomass polymers are converted into fermentable sugars. This method was applied to two separate populations of trees sampled in order to test the heritability and genetic correlations associated with the recalcitrance factor. The results from these analyses have been very good, showing high heritabilities and predict high genetic gains for the recalcitrance factor. These results indicated that biomass recalcitrance of woody biomass is influenced by genetic factors, and tree improvement techniques can be applied to improve it for future generations of Douglas-fir. Further investigations of these parameters has been applied to investigate the relative significance and correlations of the different parameters tested to optimize our recommendations for and understand the impact of the selection process for breeding.

The recalcitrance factor tested is composed of three factors: pretreatment yield, holocellulose, and hydrolysis yield. Together, these factors describe the effects of the entire biochemical deconstruction process used in a biorefinery to generate useful carbohydrates to be converted into fuels or chemicals. We have previously found that the hydrolysis yield in particular has high variability in the woody biomass and forms the most important contribution to variation in the recalcitrance factor.

Using the data gathered on the genetic correlations, variability, and heritability of the samples, we have further concluded that the hydrolysis yield is the main driving force behind the variation in sugar yields from different trees. This heritability and predicted gains are summarized in Table FD-5.1; note that positive improvements are desirable for all traits shown here. As is demonstrated by the large potential gains for hydrolysis yield (and thus, recalcitrance factor), the hydrolysis yield demonstrates the largest potential for improvement via genetic selection.

The genetic correlation coefficients generated for these traits are shown in Table FD-5.2. This data represents the amount that these traits share common genes, which control their variation.

Besides the expected relationship between hydrolysis yield and recalcitrance factor, the hydrolysis yield is also associated with density and pretreatment yield. The association with density is a useful (and interesting) result, as it indicates that improvement of these trees targeting biomass recalcitrance may also result in favorable gains in density. In addition, it provides valuable clues into the underlying structural and genetic factors responsible for variations in biomass recalcitrance of Douglas-fir; density is associated with several other physical traits that can be tested for. The association with pretreatment yield is unfortunate, in that trees bred for maximum hydrolysis yield will also return less biomass after pretreatment. However, we have concluded that this effect will result will be negated by the greater gains expected from hydrolysis yield (along with the positive gains predicted for the recalcitrance factor).

Further, these relationships have provided important insights into the underlying factors responsible for the variations we have been observing in biomass recalcitrance. Further investigations have begun into observing the structural differences between selected samples from these populations. This research is expected to provide more complete understanding of how these relationships function. This also serves to further develop a surrogate trait to be measured instead of the direct observation of hydrolysis yield (which is relatively costly and time-consuming). A potential surrogate trait, such as density or other traits associated with it (latewood/earlywood fraction is a main candidate), could pave the way to tree improvement of recalcitrance more economically attractive and feasible.

Table FD-5.1. Heritability and Predicted Genetic Gains for Parameters Tested in Moon Creek Population (second population tested)

Trait	Heritability	Largest Negative Gain	Largest Positive Gain
Density	0.3145166 ± 0.2188238	7.53%	10.49%
Pretreatment Yield	0.7667844 ± 0.1803037	6.14%	17.03%
Pretreated Holocellulose	0.1853049 ± 0.1903503	1.71%	2.10%
Hydrolysis Yield	0.4957738 ± 0.1420026	33.74%	40.63%
Recalcitrance Factor	0.4428915 ± 0.1356903	28.58%	34.72%

Table FD-5.2. Genetic Correlation Coefficients from Moon Creek Population

	Density	Pretreatment Yield	PT Holocellulose	Hydrolysis Yield
Recalcitrance Factor	0.4022 ± 0.2120	-0.1109 ± 0.2526	-0.1596 ± 0.2726	0.9720 ± 0.0147
Hydrolysis Yield	0.3255 ± 0.2186	-0.4972 ± 0.1890	-0.2462 ± 0.2588	
Pretreated Holocellulose	0.3429 ± 0.2415	-0.0207 ± 0.2723		
Pretreatment Yield	0.0478 ± 0.2512			

Recommendations | Conclusions

Along with the significant variation and high values for heritability of the recalcitrance traits of these trees, our analysis of the predicted gains and genetic correlations show strong potential benefits to the application of tree improvement targeting the recalcitrance of Douglas-fir feedstock. Improvement methods aimed to enhance the recalcitrance factor will result in trees demonstrating higher susceptibility to pretreatment processes, an unfortunate effect that will be counteracted by even greater improvements in the hydrolyzability of the feedstock. In addition, this selection may result in the improvement of the density of the wood. This research paves the way for tree improvement initiatives to apply these methods in order to improve the yield of biofuel products from forestry residues. These results also support the use of the genomic screening methods such as the “SNP chips” that are also to be applied by the Feedstock Development Team.

Data collected from this recent screening experiment also continues to lead to further research opportunities to further our understanding of biomass recalcitrance in softwoods. Deeper exploration of these data and the structure of selected samples from these populations are being applied to provide further insights into the underlying factors contributing the biomass recalcitrance. Further, these insights can be utilized to generate a more efficient screening method to better improve the selection of trees for breeding, making the improvement of biomass recalcitrance a more attractive prospect.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Geleynse, S., Alvarez-Vasco, C., Garcia, K., Jayawickrama, K., Trappe, M., & Zhang, X. (2014). A multi-level analysis approach to measuring variations in biomass recalcitrance of Douglas fir tree samples. BioEnerg. Res., 7, 1411-1420. doi:10.1007/s12155-014-9483-z

RESEARCH PRESENTATIONS

Quantifying Variations in the Biomass Recalcitrance of Douglas Fir. American Institute of Chemical Engineers, 2014 Annual Meeting: Biomass Characterization, Pretreatment, and Fractionation Session. November 17, 2014

Investigations into the Chemical and Structural Factors Contributing to Large Differences in the Biomass Recalcitrance of Douglas Fir Trees. American Institute of Chemical Engineers, 2014 Annual Meeting: Recalcitrance of Woody Biomass Session. November 17, 2014

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 (Zhou et al., Ind. Eng. Chem. Res., 52:16057-16065, 2013). The major work for the proposed study is to demonstrate the performance of the SPORL using Douglas-fir softwood forest residue with relatively high lignin contents, and its scalability at two pilot plant facilities for 1000 gallon bio-jet fuel production. 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 10 ton 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 bio-jet fuel production and lignin co-product development form SPORL hydrolysates and lignin fractions.

Activities and Results

Task C-P-1.1. Optimization SPORL and/or other pretreatments for Douglas-fir/Douglas-fir residues at lab bench scale (150 g /2kg)

This task has been completed. For additional related tasks, see Task C-P-4. The optimization study was partially supported by a USDA SBIR research project developed a combined hydrolysis factor (CHF, eq. (1)) that can optimize pretreatment duration for a given temperature at a given chemical loadings (see equation (2) below). Further study indicated that a low pretreatment temperature was favored to reduce sugar degradation to inhibitors (Eq. (3) and Figs. C-P-1.1a and C-P-1.1b).

$$(1) \quad CHF = e^{\left(a - \frac{E}{RT} + \beta C_A + \gamma C_B\right)} (C_A + C_B)\, t$$

$$(2) \quad t^{T145} = \exp\left[-\frac{E}{R}\left(\frac{1}{T_{145}} - \frac{1}{T_{180}}\right)\right] \cdot t^{T180}$$

$$(3) \quad \frac{D_{T1}}{D_{T2}} = \frac{k_d^{T1}}{k_d^{T2}} \cdot \frac{t^{T1}}{t^{T2}} = exp\left[\frac{E-E_d}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

Where C_A and C_B are the concentrations of chemical A (SO_2) and chemical B (hydroxide) used in pretreatment, respectively; α, β and γ are adjustable parameters, E = 100,000 J/mole is the apparent activation energy xylan dissolution for softwoods. Ed is the apparent activation energy of sugar degradation, R is universal gas constant of 8.314 J/mole/K, and T is absolute temperature (K). Defining D as the sum of the concentration of HMF and furfural.

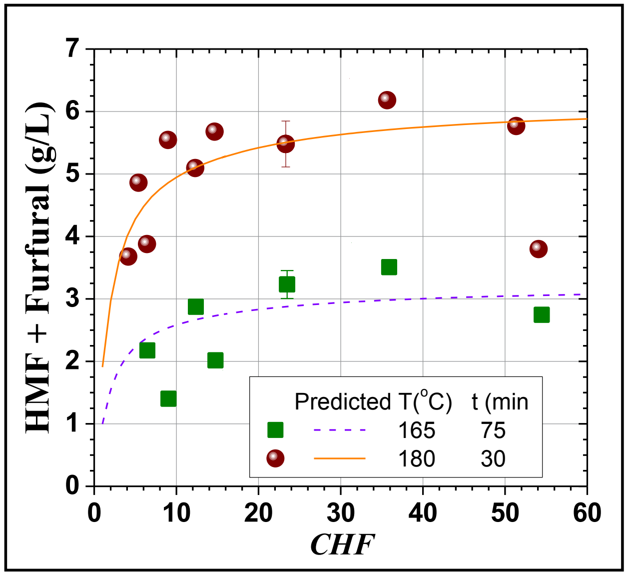


Figure C-P-1.1a. Correlation between the HMF and furfural concentration in the pretreatment hydrolysate with the combined hydrolysis factor (CHF) in comparisons with model predictions at 165°C and 180°C.

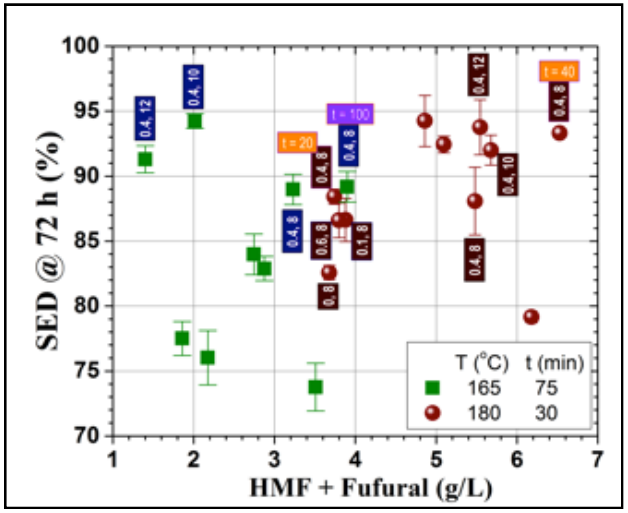


Figure C-P-1.1b. Comparisons of substrate cellulose enzymatic digestibility (SED) and furan (HMF + Furfural) production from SPORL pretreatments at 165°C and 180°C.

Table C-P-1.1. Calculated optimal pretreatment duration and relative inhibitor formation at SO_2 and hydroxide loadings of approximately 6.6 and 6.5 wt% on wood, respectively.

T (°C)	Time (min)	Relative Inhibitor
180	26	1.000
173	39	0.776
170	47	0.694
165	75	0.575
155	123	0.389
145	240	0.258

Table C-P-1.1 lists the optimal pretreatment duration at a given temperature and the corresponding relative inhibitor formation calculated based eq. (2) and (3). The advantage of low T pretreatment is obvious in terms of reducing sugar degradation to inhibitors. However a very long reaction is needed.

We also developed a pH Profiling process for SPORL pretreatment. The purpose of pH profiling run is to reduce sugar degradation to furans by delaying acid application in pretreatment. A U.S. patent has been filed. The basic concept is described in the below diagram (Figure C-P-1.2). Comparing with a control SPORL run, all pretreatment conditions (temperature, chemical loading, reaction time, etc.) were identical to a control run, except the same amount acid as those used in the control run were at a time ti rather at time 0 as in the control run. We did achieved equivalent enzymatic saccharification efficiency and glucose yield but at significantly reduced furan formation as shown in Figure C-P-1.3. This suggest that pH profiling technique can be applied to SPORL pretreatment to reduce furan formation to further facilitate fermentation along with low temperature pretreatment as reported previously. Pilot scale pH-profiling run were conducted. This is very desirable for high temperature pretreatment to reduce pretreatment duration as well as inhibitor formation.

To meet the requirement a sulfite mill operating condition for potential large scale trial run at low temperatures but substantially high SO_2 loading, for example, SO_2 on wood > 25 wt% on wood. Pilot-scale runs (50 kg) were also conducted using $Mg(OH)_2$ with SO_2 at 140C. It was found 60 min pretreatment was sufficient to produce substrate with excellent enzymatic digestibility and ultralow sugar degradation to inhibitor. This indicates increase SO_2 loading can substantially reduce pretreatment time at low temperatures with little sugar degradation to inhibitor. This condition is suitable for using existing pulping facility.

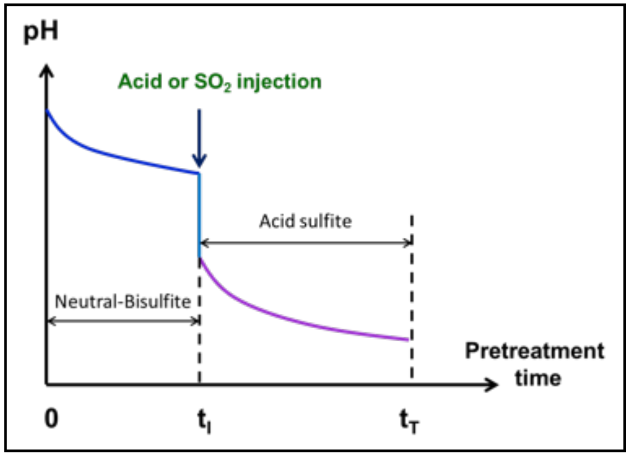


Figure C-P-1.2. Schematic of the SPORL-pH Profiling process

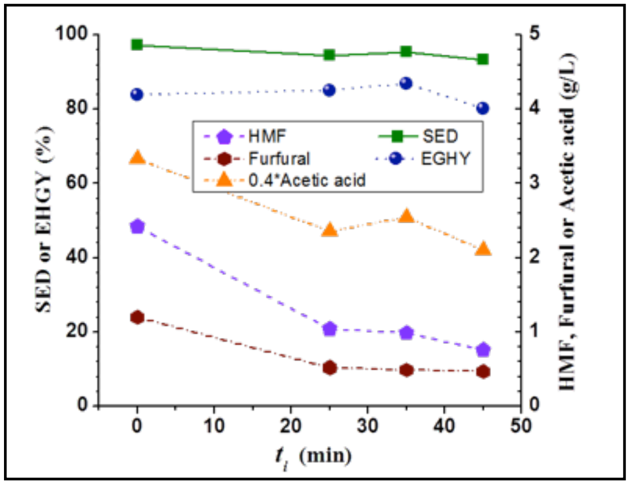


Figure C-P-1.3. Effect of delayed acid application in SPORL pretreatment on substrate enzymatic digestibility (SED), enzymatic hydrolysis glucose yield (EHGY), and furan and acids acid formation

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 their specific needs (Task C-P-3.1). The specific operational conditions for the different biomass materials will be determined initially including temperature, pressure and oxygen level. The pretreatment process is fully instrumented and initial testing under a range of operating conditions will take less than a month per biomass feedstock. During the year of 2013, the pretreatment work has been conducted by a post doc fellow, along with a full time technician under supervision of the pilot plant research manager. This has allowed WSU BSEL to make full mass balances over 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 continually consult with the different 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. Conversion results from the fermentation and co-product experiments will be reported back to WSU BSEL and used to adjust the pretreatment process to optimize the pretreatment process (Task C-P-3.2). In NARA Year 3, the results will be evaluated against other pretreatment methods used in the project. If our pretreatment method shows most successful, further activities will be planned at that time and a new budget will be determined for further work in the NARA project.

Activities and Results

Task C-P-3.2. Evaluate data from partners and adjust pretreatment systems

This task is completed. A final report for task C-P-3 will be issued in 2016. This report describes work done between April and July 2014. Most of the work done in this quarter was with FS-10 (Forest Slush material with Douglas-fir as the majority portion). The mass balance for the optimized wet explosion conditions for FS-10 treatment is shown in Figure C-P-3.1. The initial FS-10 was found to have around 33.79% glucan and 6.15% xylan with almost 46.47% present in the form of lignin. After optimization of the wet explosion pretreatment conditions, it was found that soluble solids in the biomass hydrolysate contained majority of the xylan sugars with 18% conversion of glucan to glucose monomer while most of the lignin and available cellulose was obtained in the insoluble solids, which were treated with Cellic Ctec2 and Cellic Htec2 enzymes. At optimum enzyme loading, it was found that we were able to recover close to 99.9% glucan and 78.6% xylans from FS-10 with minimal adverse effects from the high lignin content in the biomass feedstock. We are currently studying the biomass lignin portion left behind to understand its characteristics and have invested this biomass lignin after wet explosion pretreatment in co-products research. Initial characterization studies have indicated that the biomass lignin does not undergo any major structural transformation as is the case with traditional sulfuric acid or sulfite based pretreatments making the lignin ideal for co-products research. Literature studies have indicated that the biomass lignin structure opens up during traditional dilute acid pretreatment processes and re-condenses and re-distributes itself after the pretreatment over the outer cell wall making it difficult to activate it and convert into high value co-products. These literature studies also indicate that the re-condensation and re-polymerization of the lignin compounds over the cell wall adversely affects the cellulose enzyme activity, thereby, eventually affecting process kinetics and yields. However, such problems were not found with wet explosion pretreatment of the biomass lignin. These characterization studies have also revealed that hydroxyphenyl- or H-form of lignin was converted to syringyl- or S-form of lignin after wet explosion pretreatment making the process more amenable for co-product production from the biomass lignin.

From the discussions shown above, it is evident that wet explosion pretreatment at its optimized conditions can effectively breakdown lignocellulosic biomass (as dirty as forest slush) with effective C5 and C6 sugar conversions while providing a good and clean biomass lignin for valuable co-product production. We are currently working on further optimization of the lignocellulosic biomass and understanding the chemistry behind effective sugar conversion while characterizing the biomass lignin for co-products production. Further improvements in this area will be the main goal of the next quarter.

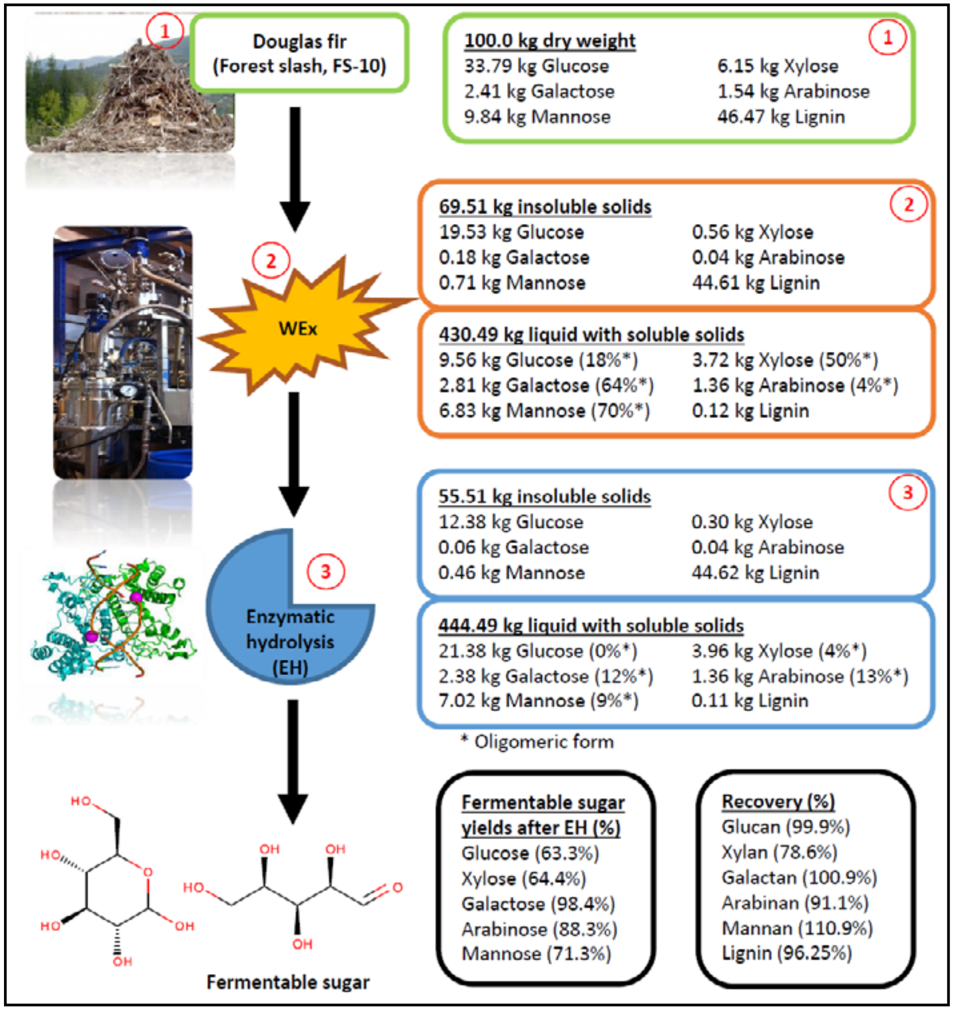


Figure C-P-3.1. Mass Balance for the optimized wet explosion of FS-10 to produce sugar monomers

Recommendations | Conclusions

The following parameters were found to give the highest digestibility of FS-10:

PRETREATMENT:
Dry content = 25% (not optimized)
Temp = 190C (optimized)
Time = 30min (optimized)
Oxygen loading = 7.5% of DM (optimized)

ENZYME HYDROLYSIS:
20% DM (not optimized)
40 mg EP/ g Cellulose (70% CTec2, 30% HTec2) (optimized)
50°C (optimized)
96h
pH = 5.3 (optimized)

A major study was done on FS-10 to determine the “sweet spot” where sugar yield and enzyme load is optimized for cost and biomass lignin is studied in detail for co-product production (papers in preparation/submitted).

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Biswas, R., Teller, P.J., and Ahring, B.K. 2014, Mass balance of pilot-scale pretreatment of forest residues by wet explosion, In Preparation, To be Submitted to Biotechnology for biofuels.

Oliveira, F. D-C., Srinivas, K., Teller, P., Goncalves, A.R. and Ahring, B.K. 2014, Wet oxidation of pretreated biorefinery lignin for production of aromatic compounds, In Preparation, To be Submitted to Bioresource Technology.

TASK C-P-4: MILD BISULFITE PRETREATMENT OF FOREST RESIDUALS

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., Bioresour. Technol., 179:390-397, 2015). The major work for the proposed study is to demonstrate the performance of the SPORL using Douglas-fir softwood forest residue with relatively high lignin contents, and its scalability at pilot plant facilities for 1000 gallon biojet fuel production. 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) Evaluate SPORL performance under different operating conditions required by potential industrial scale demonstration sites for large scale demonstration; (4) Conduct large scale, approximately 10 ton 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; (5) to work with Washington State University and Gevo for large scale bio-jet fuel production and lignin co-product development form SPORL hydrolysates and lignin fractions.

Activities and Results

Task C-P-4.4.1. Optimization SPORL and/or other pretreatments at FPL pilot plant facility (50 kg/run)

Pilot scale of 50 kg FS-10 Douglas-fir forest residue was conducted using Calcium bisulfite at 145°C using the FPL pilot scale digester. The technical issues addressed in this study are: (1) demonstrating SPORL process using commercial pulp mill chemistry i.e., bubbling SO_2 into a hydroxide solution to produce the sulfite solution, rather than using H_2SO_4 and sodium bisulfite as reported previously for ease of pretreatment experiments in the laboratory; (2) using a low pretreatment temperature of 145°C to accommodate facility limitations at pulp mills without reducing cellulose saccharification efficiency; (3) direct enzymatic saccharification and fermentation of the pretreated whole slurry at high solids without solids washing or slurry detoxification to simplify process integration. The pretreatment time was determined by maintaining the same pretreatment severity measured using Combined hydrolysis factor (CHF) reported previously, according to Eq. (2) described in Task C-P-1: Pretreatment to Overcome Recalcitrance of Lignocellulose.

$$(2) \qquad t^{T145} = \exp\left[-\frac{E}{R}\left(\frac{1}{T_{145}} - \frac{1}{T_{180}}\right)\right] \cdot t^{T180}$$

Using the optimal pretreatment time of 25-30 min at 180ºC for softwood determined at the 0.15 kg lab scale reported previously, Eq. (2) indicates the required reaction time, tT145, for the pilot-scale pretreatment at 145°C to be 230 – 275 min.

A dilute sulfite solution, at approximately pH 2.0 and containing 2.28 wt% $Ca(HSO_3)_2$ and 0.87 wt% true free SO_2 was produced in a stirred barrel by bubbling SO_2 regulated at a gauge pressure of 34.5 kPa into a hydroxide solution of 139 L containing 1.25 kg (95% purity) of $Ca(OH)_2$. After 37 minutes bubbling, a solution weight gain of 3.3 kg was achieved while a small amount of calcium hydroxide remained at the outer edge of the barrel. Complete reaction of $Ca(OH)_2$ was achieved by manually stirring the solution 3 times. A cover was clamped and sealed with tape to the barrel and then stored at 4°C overnight.

As schematically show in Figure C-P-4.1, the digester was heated by a steam jacket and rotated at 2 rpm during pretreatment for mixing of chemicals with woody materials. The digester was first loaded with 61.75 kg FS-10 with solid content of 81.4% (50.26 kg in oven dry (OD) weight). At the current test condition, this required a total liquor volume of 150 L, total SO_2 mass concentration in the sulfite solution of 2.3 wt%, and free SO_2 and $Ca(HSO_3)_2$ charge on wood 2.48 and 6.46 wt%, respectively. This translates to a total SO_2 loading of 6.6 wt% on oven dry wood residue. Before calcium sulfite was added, the upper lid was lightly closed with the discharge valve open and low-pressure steam was injected into the top of the digester. This steaming was continued for 5 minutes after steam flow was observed at the discharge valve. The steam was stopped, the discharge valve closed and the lid quickly opened to obtain a sample. The amount of steam injected was determined to be 27.85 kg based on the moisture content of 44.18% of the steamed FS-10 in the digester. The actual liquor to wood ratio (L/W) for the pretreatment was therefore 3.55 (L/kg). The lid was then quickly sealed and a vacuum applied to the digester. The vacuum was applied for approximately 20 min at which time the vacuum valve was closed and a hose connection was made between the bottom of the digester and a centrifugal chemical transfer pump. The pump was used in case the vacuum was inadequate to pull all of the sulfite solution into the digester. After approximately 6 min all the sulfite solution was pulled into the digester. Two 50 mL samples of the liquor were collected just prior to injection for verification of sulfite concentration. The measured concentrations of $Ca(SHO_3)_2$ was

2.01 wt% and true free SO_2 was 0.43 wt% compared with calculated values of 1.93 wt% and 0.74 wt%, respectively, based on the amounts of $Ca(OH)_2$, SO_2, and steam applied. The lower measured SO_2 concentration could be due to losses during transit to Weyerhaeuser Company (Federal Way, WA). Rotation of the digester was started immediately. It took approximately 37 min to heat the digester from 30ºC to a terminal temperature of 145ºC. The temperature was maintained for 240 min. The digester contents were discharged into a blow tank through a stainless steel pipe. An additional air blow was applied to ensure all contents were discharged. Volatiles including SO_2 were vented to a wet scrubber (Figure C-P-4.1). The freely drainable portion of the pretreatment spent liquor of 42 kg was collected from the blow tank shortly after discharging from the digester. The remaining liquor stayed with the pretreated solids. After venting in the blow tank for two days to let the remaining small amount of SO_2 escape, the solids were collected and weighed.

The freely drainable spent liquor were neutralized and then proportionally fed with the pretreated solids to a laboratory disk refiner (Andritz Sprout-Bauer Atmospheric Refiner, Springfield, OH) to produce pretreated whole slurry of FS-10 (Fig. C-P-4.1). The whole slurry had a solids content of 24.49% (including the dissolved solids from pretreatment) and was directly used for subsequent saccharification and fermentation. A small sample of the whole slurry was separated into wet solids and liquor by pressing in a screen box. The moisture of the solid fraction was determined gravimetrically by oven drying the collected wet sample. An aliquot of the wet solid sample was thoroughly washed to remove soluble solids. Both the washed and unwashed solids were used to conduct enzymatic hydrolysis after neutralization using lime.

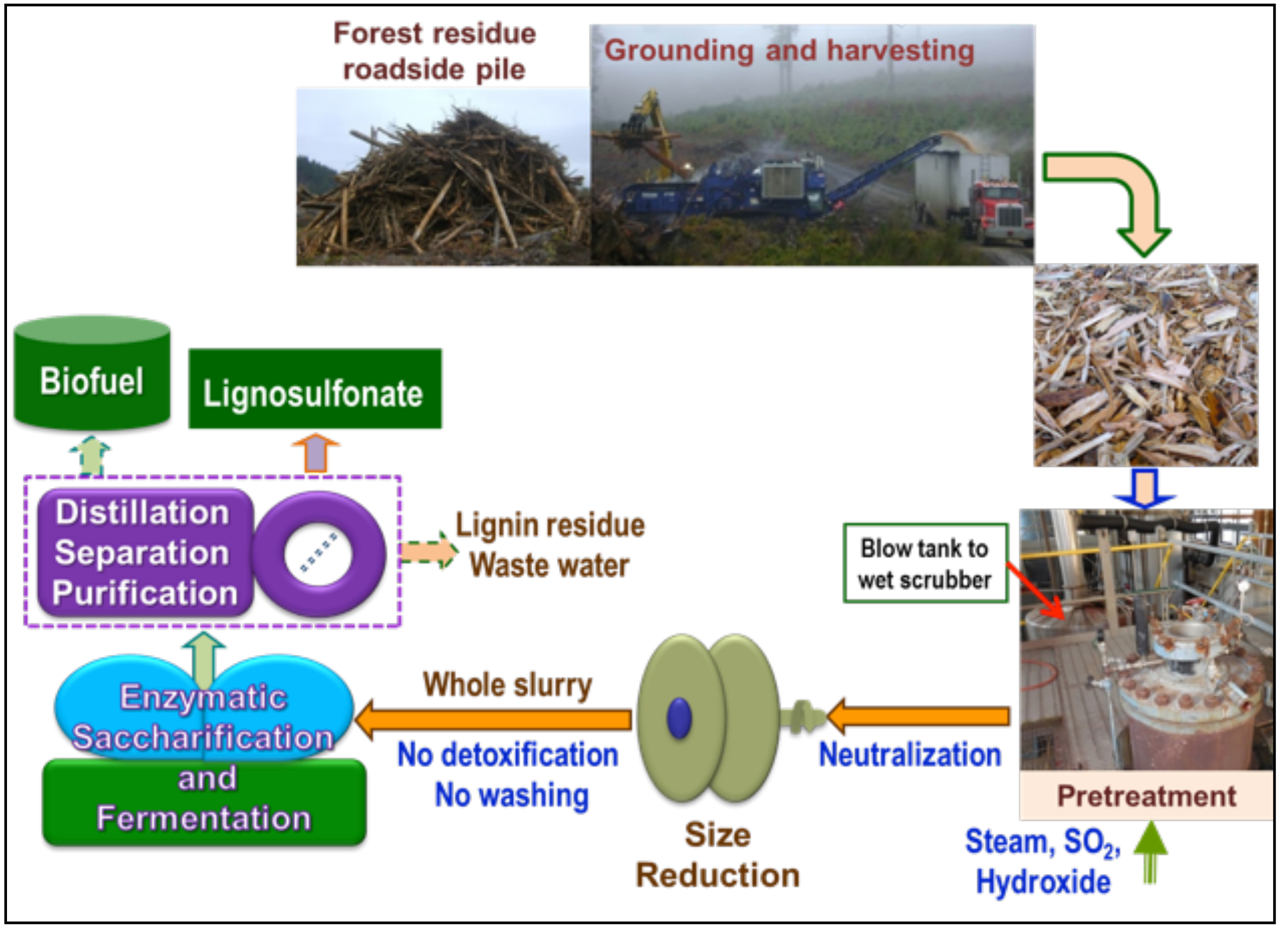


Figure C-P-4.1. A schematic process flow diagram shows Douglas-fir forest residue harvesting, transportation, pretreatment and downstream saccharification and fermentation.

Enzymatic saccharification of the washed solids was conducted to evaluate the effectiveness of SPORL pretreatment in removing the recalcitrance of Douglas-fir forest residue FS-10. Substrate enzymatic digestibility (SED), defined as the percentage of washed solids glucan enzymatically saccharified to glucose, reached 84% in 48 h with titer of 80 g/L at a washed solids loading of 15% (Fig. C-P-4.2). Saccharification efficiency increased to over 90% at 10% solids loading in 24 h. The dissolved lignin or lignosulfonate from sulfite spent liquor was found to have less affinity to cellulase and can act as a surfactant to enhance enzymatic saccharification. When enzymatic saccharification was conducted using unwashed solid substrates that containing dissolved lignin at 18.5% solids, SED reached 92% with a glucose titer of 97 g/L. This indicates more glucose will be available in Q-SSF of the SPORL pretreated whole slurry that contains lignosulfonate than using washed solids alone.

The pretreated liquor had very low fermentation inhibitors and was found it can be directly fermented at 16.7wt% total solids loading without detoxification using Saccharomyces cerevisiae YRH-400 (A strain developed by USDA-ARS). The ethanol yield of 284 L/tonne at 41.9 g/L were obtained. It is expected that the sample should be fermentable by GEVO strain without detoxification.

We have developed a pilot-scale membrane system for purify lignosulfonate. The spent liquor was first centrifuged to remove particulates. Any remaining particulates were further separated by passing through the 200 kDa membrane. The liquor was then sent to a 4 kDa membrane to remove small molecular impurities such as sugars. Each fraction was collected and weighed to determine spent liquor mass distribution and for mass balance analysis. After UF through the two membranes, 69.6% of Ca-LS and 7.6% of total sugar were retained in the purified sample (fraction of 4 k-200 kDa), as shown in Table C-P-4.1. The lignin purity was only 44.5% in the original spent liquor and was increased to 86.8% after UF in the purified sample. Table 2 indicated that Ca-LS could be extracted with high recovery and purity by UF. The purified Ca-LS had a similar molecular weight and polydispersity to the commercial lignosulfonate D748 (Borregaard LignoTech, Rothschild, WI, USA) based on GPC MALS measurements. However, GPC UV measurements indicate that the purified Ca-LS had a smaller molecular weight with lower polydispersity than D-748 (Table C-P-4.1).

The Ca-LS is highly sulfonated with sulfur content of 69.2 ± 0.9 mg/g which is higher than the commercial LS D-748 of 60.1 ± 3.9 mg/g. The sulfur content along with the molecular weight information suggests that the Ca-LS from SPORL can be directly marketed with comparable properties of commercial lignosulfonate.

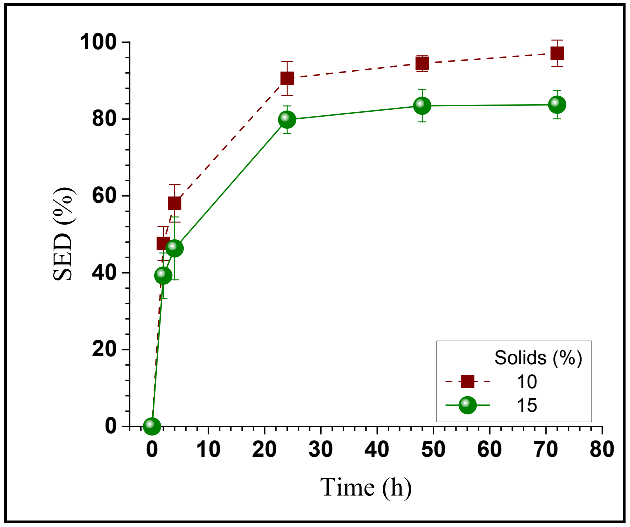


Figure C-P-4.2. Time-dependent enzymatic saccharification efficiency of washed SPORL pretreated FS-10 at pilot-scale at two solids loadings with CTec3 dosage of 15 FPU/g glucan.

Table C-P-4.1. Characterization of purified calcium lignosulfonate solution

Ultrafiltration experiment				
Sample	LS-Ca (%)	Sugar (%)	Mass (%)	Lignin Purity (%)
Original	100	100	100	44.5
> 200 kDa	3.9	n/a	2.4	89.1
4-200 kDa[a]	69.6	7.6	43.2	86.8
< 4 kDa	24.9	84.3	41.5	19.3
GPC (MALS) analysis				
Sample	Mw[b]	Mn[c]	Mw/Mn[d]	
4-200 kDa	23430	12910	1.8	
D748	24660	14190	1.7	
GPC (UV) analysis				
4-200 kDa	2704	1092	2.5	
D-748	13113	3293	4.0	

a) The fraction of 4-200 kDa is the purified calcium lignosulfonate sample
b) Number-average molecular weight
c) Weight-average molecular weight
d) Polydispersity

Task C-P-4.4.2. Identification and experimental verification of operating conditions that are suitable for industrial trial runs

Previous study $Ca(HSO_3)_2$ pretreatment of Douglas-fir harvest forest residue FS-10 at 145°C for 240 min with very low SO_2 loadings of approximately 18 g/L (or 6.6wt% on wood) in the pretreatment liquor. Excellent results were obtained when evaluated using ethanol and iso-buthanol production. Several industrial facilities were identified for potential 50 tonne FS-10 pretreatment. The first facility is a sulfite pulp mill using $Mg(HSO_3)_2$ with very high SO_2 loading of approximately 60-80 g/L (or >25 wt% on wood) in the pulping liquor at 140C. Mill stated that chemical formulation cannot be modified for pretreating 50 tonne FS-10. The second facility is has limited SO_2 handling capabilities, so a low SO_2 loading is desired, however, 240 min is too long for the facility to handle, a high temperature of 170°C is required, based on the scaling factor CHF reported in the previous quarter, to meet the 45 min longest residence time of the facility. The third facility has too low a capacity of 1 ton/day though has excellent capability for SO_2 handling and sugar concentration, therefore not serious consideration.

Our laboratory study in this quarter has been concentrated on using the operating conditions at the two potential industry sites to evaluate SPORL performance. Specifically, Mg was chosen for its substantially high iso-buthanol productivity based on a fermentation study at Gevo. The first set of conditions is to meet the requirements of sulfite mill, low temperature 140°C and high SO_2 loading of 60-80 g/L. We have identified that a pretreatment time of 60 min is sufficient to obtain good substrate enzymatic digestibility with very low inhibitors with this condition. We also conducted pretreatment at 170°C for 45 min using $Mg(HSO_3)_2$ plus sulfuric acid as the second industry facility has limited capability to handle SO_2. All pretreated samples have been shipped to Gevo for iso-buthanol production evaluation. Mass balance data of these pretreatments are in progress.

We also evaluate the potential of eliminate size reduction for fermentation. We used a laboratory high shear mixing devise to conduct enzymatic saccharification of a $Mg(HSO_3)_2$ pretreated sample without size reduction. Different size fractions were used. The results will be reported in the next reporting period.

Task C-P-4.4.3. Industrial scale-up of SPORL technology

We have visited three industry sites and conducting laboratory evaluation of technical feasibilities as discussed above. A pretrial at Andritz spring field facility is scheduled in May 27.

Recommendations | Conclusions

The robust of the SPORL process lies in the fact that it can be carried out at several sets of conditions that can provide excellent sugar yield and low inhibitor formation. An industrial site can be chosen after the isobutanol fermentation evaluation completed using the SPORL pretreated samples produced in this quarter.

Physical and Intellectual Outputs

PHYSICAL

- Many pilot-scale (50 kg) SPORL pretreatments of FS-10 were conducted
- Sample analyses were in progress
- Shipped the lignosulfonate to the lignin-co-product team
- Three potential demonstration site were visited

REFEREED PUBLICATIONS

Zhu, J.Y., Chandra, M.S., Gu, F., Gleisner, R., Reiner, R., Sessions, J., Marrs, G., Gao, J. & Anderson, D. (2015). Using sulfite chemistry for robust bioconversion of Douglas-fir forest residue to high titer bioethanol and lignosulfonate: A pilot-scale demonstration. Bioresource Technology , 179, 390-397 doi: 10.1016/j.biortech.2014.12.052.

Cheng, J., Leu, S.Y., Zhu, J.Y. & Gleisner, R. (2015). High titer and yield ethanol production from undetoxified whole slurry of Douglas-fir forest residue using pH-profiling in SPORL. Biotechnol. Biofuels, 8, 22. doi:10.1186/s13068-015-205-3.

Zhang, J., Gu, F., Zhu, J.Y. & Zalesny, Jr. R.S. (2015). Using a combined hydrolysis factor to optimize high titer ethanol production from sulfite pretreated poplar without detoxification. Bioresource Technology, 186, 223–231 doi: 10.1016/j.biortech.2015.03.080

Cheng, J., Leu, S.-Y., Gleisner, R., Pan, X.J. & Zhu, J.Y. (2015). High solids quasi-simultaneous enzymatic saccharification and fermentation of un-detoxified whole slurry of SPORL pretreated Douglas-fir forest residue. Cellulose Chem. Technol., 48 (9-10), 849-854.

Zhang, J., Laguna, A., Clemons, C., Wolcott, M.P., Gleisner, R. & Zhu, J.Y. (2015). Effect of hot-pressing temperature on the subsequent enzymatic saccharification and fermentation SPORL of pretreated forest biomass. BioEnergy Res. 8 ,464-470. doi:10.1007/s12155-014-9530-9

Lou, H, Zhou, H, Li, X., Wang, M., Zhu, J.Y., and Qiu, X., (2014), "Understanding the Effects of Lignosulfonate on Enzymatic Saccharification of Pure Cellulose", Cellulose 21:1351-1359, DOI: 10.1007/s10570-014-0237-z

Zhang, C., Houtman, C.J. & Zhu, J.Y. (2014). Using low temperature to balance enzymatic saccharification and furan formation during SPORL pretreatment of Douglas-fir. Process Biochemistry, 49, 466-473. doi: 10.1016/j.procbio.2013.12.017

Zhang, C., Lei, X., Scott, C.T., Zhu, J.Y. & K. Li. (2014). Comparison of dilute acid and sulfite pretreatment for enzymatic saccharification of earlywood and latewood of Douglas-fir. BioEnergy Research, 7, 362-370. doi: 10.1007/s12155-013-9376-6

RESEARCH PRESENTATIONS

Zhu, J.Y., M.S. Chandra, F. Gu, R. Gleisner, R. Reiner, J. Sessions, G. Marrs, J. Gao, D. Anderson, (2015), "SPORL for robust bioconversion of Douglas-fir forest residue: Pilot scale-up design, lignin co-product, and high solids fermentation without detoxification" presented at the 249th ACS National Spring Meeting, Denver, CO, March 22-26.

Zhu, J.Y. Liheng Chen, Qianqian Wang, Kolby Hirth, Carlos Baez, Umesh Agarwal, (2015), "Tailoring the

Properties and Yield of Wood Cellulose Nanocrystals (CNC) using Concentrated Acid Hydrolysis" presented at the 249th ACS National Spring Meeting, Denver, CO, March 22-26.

Zhu, J.Y. (invited) "Recent Progress in Biofuel Fuel Production form Woody Biomass", Invited Panel presentation at the Second Generation Ethanol Workshop-2014, Brazilian National Center for Ethanol Science and Technology (CTBE), Campinas, Sao Paulo, Brazil, November, 2014.

Zhu J.Y., M. Subhosh Chandra, Roland Gleisner, William Gilles, Johnway Gao, Gevan Marrs, Dwight Anderson, John Sessions, (2014) "Reviving Sulfite Pulping from Sugar Production from Woody Biomass" 2014 TAPPI PEERS Conference, Tacoma, WA, Sep, 2014

Zhu, J.Y., (2014), "Role of Lignin on Enzymatic Saccharification of Lignocellulose", 2014 TAPP IBBC, Tacoma, WA, Sep, 2014

Zhu, J.Y. (2014) "Bioconversion of Forest Residue using SPORL: Process Scale-up Design, Lignin-Coproducts, High Solids Fermentation without Detoxification", 36th Symposium on Biotechnology for Fuels and Chemicals, Clearwater Beach, FL, April 28 - May 1

Zhu, J.Y. (2014), "Bioconversion of Forest Residue using SPORL: Process Scale-up Design, Lignin-Coproducts, High Solids Fermentation without Detoxification", Nordic Wood Biorefinery Conf, Stockholm, Sweden, March 24-27

Zhu, J.Y. (2014) "Why enzymatic hydrolysis of lignocelluloses should be conducted at elevated pH 5.2-6.2", presented at the 247th ACS National Spring Meeting, Dallas, TX, March 15-21

Zhu, J.Y. (2014) "Role of lignin on enzymatic saccharification of lignocelluloses", presented at the 247th ACS National Spring Meeting, Dallas, TX, March 15-21

Zhu J.Y. (2014), "Using low temperature to balance enzymatic saccharification and furan formation during SPORL pretreatment of Douglas-fir", presented at the 247th ACS National Spring Meeting, Dallas, TX, March 15-21

OTHER PUBLICATIONS

Zhu, J.Y., (2015), "The pulp and paper industry in 2040" TAPPI Journal (TAPPI Centennial Editorial), 14(3):S19-S20

AWARDS AND RECOGNITION

1. J.Y. Zhu, US Forest Service Deputy Chief's Distinguished Science Award

2. J.Y. Zhu, TAPPI R&D International Technical Award and William Aiken Prize

3. J.Y. Zhu, Greater Madison Area Federal Agency Association Employee of the year - Technical

4. J.Y. Zhu, the Grantee of the Fulbright-Aalto University Distinguished Chair (scholarship) in Energy and Sustainable Use of Natural Resources, Helsinki, Finland, for the 2015-2016 Academic year.

5. J.Y. Zhu, Invited panel speaker and International Expert at the Second Generation Ethanol Workshop-2014, Brazilian National Center for Ethanol Science and Technology (CTBE), Campinas, Sao Paulo, Brazil

INTELLECTUAL PROPERTY

Zhu, J.Y., Gleisner, R., "Methods of Pretreating Lignocellulosic Biomass with Reduced Formation of Fermentation Inhibitors", U.S. Utility Patent Application No 14/299,926, 06/09/2014

TASK C-P-5: CLEAN SUGAR AND LIGNIN PRETREATMENT TECHNOLOGY

Key Personnel	Affiliation
Johnway Gao	Weyerhauser

This task has been combined with the E-8 Distributed Sugar Depot task in NARA project Year-4.

CONVERSION

AVIATION TEAM

TASK C-AF-1: PRODUCTION OF LIGNOCELLULOSIC ISOBUTANOL BY FERMENTATION AND CONVERSION TO BIOJET

Key Personnel	Affiliation
Andrew Hawkins	Gevo, Inc
Glenn Johnson	Gevo, Inc
Bob Wooley	Gevo, Inc
Christopher Ryan	Gevo, Inc.
Joseph Ley	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 1,000 gallons 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® fermentation from pretreated biomass; (8) Produce ≥1,000 gallons isobutanol from GIFT® fermentations at a suitable demonstration scale. Convert lignocellulosic isobutanol to ≥1,000 gallons biojet for further testing.

Activities and Results

Over the past year, Gevo received hemlock reject fibers pretreated by Cosmo Specialty Fibers (Cosmo) and milled by Dr. Junyong Zhu (J.Y.) at the USDA Forest Products Laboratory (FPL). Preliminary growth and fermentation experiments were carried out with Gevo biocatalysts using the clarified Cosmo reject fiber hydrolyzate. FS-10 concentrated milled wood (CMW) hydrolyzate as well as FS-10 SPORL pretreated using magnesium was also received and tested in Gevo GIFT® fermentation systems. A small fraction of the FS-10 SPORL-Mg^{2+} pretreated material received from J.Y. was pressed on-site to separate as much of the liquor from the combined material as possible for further analysis. The new pressed material was hydrolyzed, at a similar solids percentage as the combined material, then clarified (FS-10 SPORL-Mg^{2+} pretreated solids hydrolyzate). The liquor stream was clarified (FS-10 SPORL-Mg^{2+} pretreated liquor) for further comparison to both FS-10 SPORL-Ca^{2+} and FS-10 SPORL-Mg^{2+} combined pretreated hydrolyzate. A sample of concentrated FS-10 SPORL-Mg^{2+} pretreated hydrolyzate (EHS$$FS10-SPO601401.05-M022615-01), processed using conditions similar to what a potential scale-up partner for pretreatment, American Process, Inc. (API) is capable of creating, was received from J.Y. and analyzed. Gevo also received FS-01 (PSU$$-FS01-DM04012000EW-J050114) and EW-01 (80 minute grind = PSU$$-EW01-DM08001050L-P102214 and 120 minute grind = PSU$$-EW01-DM12001050L-P102214) Milled Wood feedstocks from Dr. Jinwu Wang of Washington State University (WSU) to compare the effectiveness of a ball mill using a Japanese milling process to the SPORL pretreatment process. This material was analyzed on a high throughput scale and benchtop scale to further assess the optimal ball mill parameters and pretreatment method for scale-up purposes.

Work progressed to further define process conditions (operating pH, hydrolyzate loading during growth, and nutrient package development) now that a feedstock/pretreatment selection has been made. The Gevo evolutionary improvement project using first and second generation Gevo yeast biocatalysts continue to yield strains with improved growth in FS-10 SPORL-Mg^{2+} pretreated hydrolyzate material. Over the past year, Gevo has continued to refine the process box, which includes material flows and capital/operating costs. It still remains imperative that sufficient quantities of a single feedstock pretreated using a single method be provided to Gevo to continue process development work toward scale up and the ~1,000 gal biojet project.

Task C-AF-1.1. Characterize toxicity of a representative sample of pre-treated woody biomass (Douglas-fir) for fermentation

Sugar and inhibitor concentrations were determined by high performance liquid chromatography (HPLC) analysis for each feedstock and pretreatment method received (Table C-AF-1.1). To date, Gevo has received and characterized the following: FS-01, FS-03, and FS-10 SPORL. Characterization work of FS-10 SPORL has involved several varieties of SPORL pretreatment. Included in the characterization work was sodium pretreated FS-10 SPORL material, which was previously denoted as FS-10 mild bisulfite. Washed and unwashed solids variations of SPORL material have been characterized and the spent sulfite liquor has also been characterized. Calcium and

Table CAF-1.1. Sugar and inhibitor concentrations in FS-01, FS-03, FS-10, and Hemlock feedstocks from various pretreatment methods. Concentrations of sugars and inhibitors were determined using HPLC at Gevo. (n.d. = not detected, underlined samples indicate recent additions to this table)

	% solids in hydrolysis	Glucose (g/L)	Xylose (g/L)	Galactose (g/L)	Arabinose (g/L)	Mannose (g/L)	Acetate (g/L)	HMF (g/L)	Furfural (g/L)	Total Hexose (g/L)
FS-01 Wet Oxidation Hydrolyzate		57.20	6.67	5.12	1.58	20.87	7.27	3.90	0.99	83.19
FS-03 Wet Oxidation Hydrolyzate (Batch A)	19.9	87.54	4.67	5.14	0.76	10.06	12.46	3.66	0.81	102.74
FS-03 Wet Oxidation Hydrolyzate (Batch B)	23.19	89.58	5.25	3.00	n.d.	7.66	7.00	n.d.	n.d.	100.24
FS-10 Wet Oxidation Hydrolyzate (Batch A)	15.09	44.76	6.61	4.18	6.00	16.84	7.94	2.42	0.56	65.78
FS-10 Wet Oxidation Hydrolyzate (Batch B)	24.99	67.22	4.57	2.37	n.d.	9.04	3.90	n.d.	n.d.	78.63
FS-10 Wet Oxidation Hydrolyzate (Batch C)	21.78	54.79	12.01	5.38	4.43	9.59	7.99	3.53	0.26	69.76
FS-01 SPORL Hydrolyzate		93.65	6.89	4.94	1.24	23.01	4.56	0.79	0.10	121.60
FS-03 SPORL Hydrolyzate	36.43	81.81	5.79	3.82	0.40	7.02	5.78	1.84	0.63	92.65
FS-10 SPORL-Na^+ Pretreated SSL		7.83	7.32	5.29	2.21	18.06	3.61	n.d.	n.d.	31.18
FS-10 SPORL-Na^+ Pretreated Washed Solids Hydrolyzate	24.48	63.88	3.77	2.07	0.68	7.52	1.65	n.d.	n.d.	73.47
FS-10 SPORL-Na^+ Pretreated Unwashed Solids Hydrolyzate	29.19	84.22	10.14	5.26	2.02	20.93	3.44	n.d.	n.d.	110.41
FS-10 SPORL-Ca^{2+} Pretreated Hydrolyzate	26.29	62.74	6.84	5.07	n.d.	11.83	0.62	n.d.	n.d.	79.64
FS-10 SPORL-Mg^{2+} Pretreated Hydrolyzate	24%	71.59	8.89	4.23	14.39	0.61	3.00	n.d.	n.d.	76.43
FS-10 SPORL-Mg^{2+} Pretreated Solids Hydrolyzate	27.29	88.56	8.39	3.47	12.68	0.66	2.71	n.d.	n.d.	92.70
FS-10 SPORL-Mg^{2+} Pretreated Liquor	As rec'd	7.11	12.38	7.82	24.09	0.00	4.57	n.d.	n.d.	14.94

Table CAF-1.1. continued

FS-03 Catchlight Combined Hydrolyzate	19.27	164.12	8.56	5.24	0.94	13.34	3.45	0.15	0.14	182.70
FS-03 Catchlight Clean Hydrolyzate	28.81	130.89	1.84	0.49	n.d.	1.34	0.26	0.14	0.01	132.72
FS-10 Unconcentrated Milled Wood Hydrolyzate	12.9%	39.84	7.61	1.87	2.04	11.40	0.74	n.d.	n.d.	53.11
FS-10 Concentrated Milled Wood Hydrolyzate	As rec'd	61.84	9.21	0.46	1.36	12.76	0.77	n.d.	n.d.	75.06
FS-01 Milled Wood (40 min. Grind)	~25%	90.34	9.77	0.61	2.12	10.67	1.58	n.d.	n.d	101.61
EW-01 Milled Wood (80 min. Grind)	~25%	28.83	3.54	0.63	1.22	6.09	0.99	0.05	n.d.	35.55
EW-01 Milled Wood (120 min. Grind)	~25%	92.30	10.86	1.25	2.60	15.01	2.27	0.06	n.d.	108.57
Cosmo Reject Solids Hydrolyzate	24.86	111.35	2.02	0.15	1.45	0.79	0.27	n.d.	n.d.	112.29
FS-10 SPORL-Mg^{2+} Pretreated Concentrate	As rec'd	282.63	44.05	18.25	7.18	75.28	10.39	n.d.	n.d.	376.2

magnesium pretreated SPORL material has also been included in the characterization work conducted by GEVO. SPORL pretreated materials were obtained from Dr. Junyong Zhu at the USDA Forest Products Laboratory (Madison, WI). FS-01, FS-03, and FS-10 wet oxidation pretreated materials were obtained from Dr. Birgitte Ahring at Washington State University – Tricities (Richland, WA). FS-03 pretreated material (Clean and Combined) was obtained from Catchlight Energy (Federal Way, WA). FS-10 milled wood pretreated material (Concentrated and Unconcentrated) was obtained from Dr. Johnway Gao at Catchlight Energy. Hemlock reject fibers that were washed solids produced by Cosmo and milled by Dr. Junyong Zhu and FS-01 (40 minute grind time) and EW-01 (80 and 120 minute grind time) Milled Wood (MW) samples from Jinwu Wang at Washington State University (Pullman, WA). Gevo has also worked to optimize the hydrolysis efficiency of the various pretreated feedstocks that have been received. Various solids loading and enzyme addition rates have been explored in order to optimize hydrolysis efficiency.

Task C-AF-1.2. Adapt yeast biocatalyst to pretreated biomass hydrolyzates

Inhibitor concentrations in SPORL pretreated material can vary widely depending on the pretreatment conditions. In order to generate a biocatalyst capable of maximized growth and production, adaptation to pretreated hydrolyzate is required. First generation hydrolyzate adapted biocatalysts with improved growth and isobutanol production performance have been isolated previously in both FS-03 (LB4) and FS-03 SPORL (LB21). A second generation biocatalyst and the current best corn starch biocatalyst (LB23), was also selected for hydrolyzate adaptation after it demonstrated maximum growth rates similar to LB21 in FS-10 SPORL-Ca^{2+} and Mg^{2+} pretreated hydrolyzate (Figure C-AF-1.1).

Both LB21 and LB23 adaptation in FS-10 SPORL-Mg^{2+} pretreated hydrolyzate is currently being conducted. Most recently, an LB23 evolution was examined using high throughput analysis to compare growth rates of the LB23 parent to various evolved LB23 isolates (Figure C-AF-1.2). Multiple LB23 evolved isolates had an improved maximum growth rate in 20% (v/v) FS-10 SPORL-Ca^{2+} pretreated hydrolyzate compared to the parent strain. In the coming year LB23 evolved isolates will be examined further at the bench scale to investigate growth in FS-17 pretreated hydrolyzate as well as to establish the fermentation performance of each promising isolate.

Task C-AF-1.3. Produce isobutanol in a 1L batch fermentation from pretreated biomass sugars using the adapted yeast biocatalyst.

No additional 1L batch fermentations were run from April 2014 to March 2015. The focus instead has shifted to 1L (baby) GIFT® runs.

Task C-AF-1.4. Economic assessment of wood to isobutanol, jet

Gevo performed various ASPEN modeling work based on Douglas-fir biomass hydrolyzate from the mild bisulfite process, supplied by the NARA project, to determine the mass and energy balance and CapEx cost for that portion of the process involving Gevo Proprietary Technology. Gevo has supplied sufficient information to the NARA process team to enable them to complete a mass and energy balance for the portions of the process not included in the Gevo Process Box. Gevo also supplied the CapEx for the Gevo portion of the process. Figure C-AF-1.3 illustrates the information (streams 2 through 8 and CapEx) supplied to the NARA process team.

In summary, the saccharified biomass sugars are fermented and isobutanol recovered in a process essentially identical to the corn mash process being used currently at Gevo's plant in Luverne, MN. The process modelled here accommodates two feeds from the NARA mild bisulfite pretreatment, a liquid only stream separated from the Mild Bisulfite Pretreatment by the NARA team and a solids containing stream where the cellulose has been enzymatically saccharified. Gevo discharges two whole stillage streams containing all the unreacted solids, insoluble and soluble, back to NARA for processing and recycling the water to pretreatment. Only a small amount of clean water,

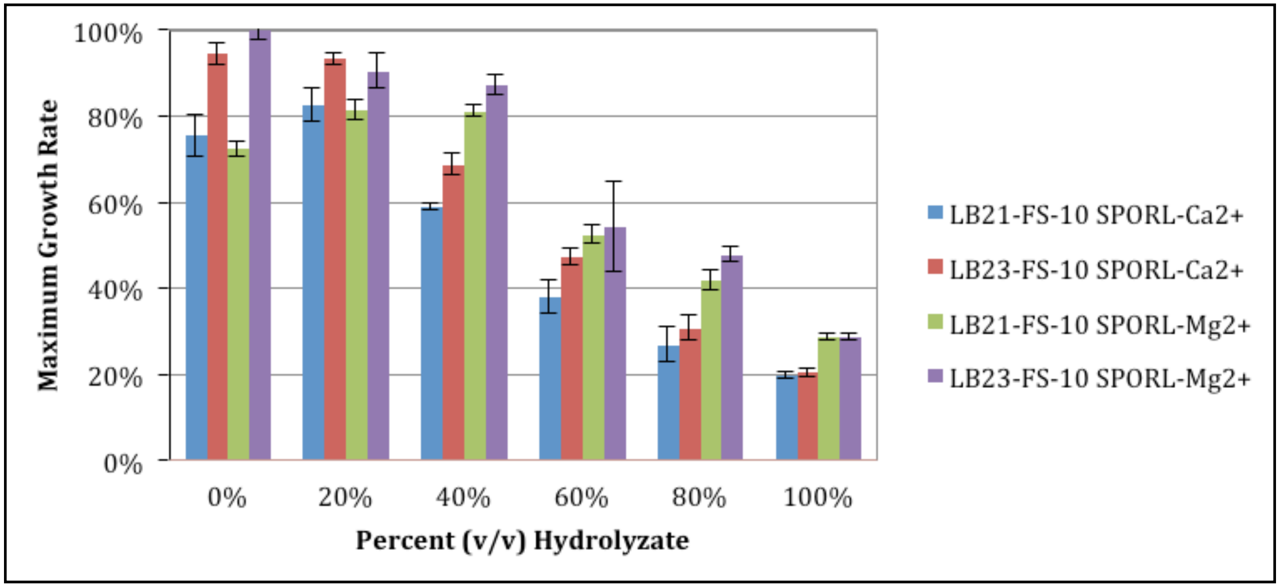


Figure C-AF-1.1. Maximum growth rate of LB21 and LB23 in FS-10 SPORL-Ca^{2+} and Mg^{2+} pretreated hydrolyzate with NP 2.0. Mock medium made for each hydrolyzate is a combination of hexoses, pentoses and acetate at the same concentrations outlined in Table C-AF-1.1 supplemented with NP 2.0. Dilutions (volume/volume) of hydrolyzate were created using mock media. Growth carried out at 33°C and maximum growth rate measured for each percent (v/v) hydrolyzate.

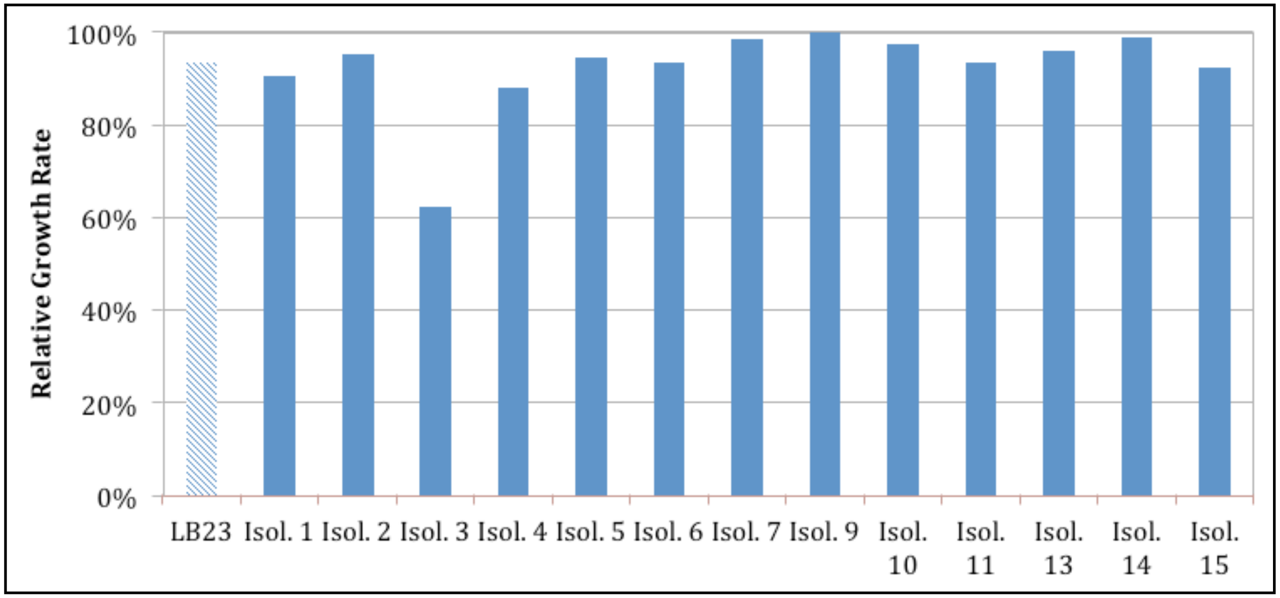


Figure C-AF-1.2. Maximum growth rate of LB23 parent strain compared to LB23 evolved isolates in 20% v/v FS-10 SPORL-Ca2+ pretreated hydrolyzate with NP 2.0. 20% v/v mixture created by diluting FS-10 SPORL-Ca2+ using buffered water. Growth carried out at 33°C under high aeration conditions and maximum growth rate measured for each isolate. Isolates 7,9, and 14 shown in figure 2 above warrant further characterization and potentially characterization of isobutanol production in 1L GIFT® fermentations in order to demonstrate improved performance compared to LB23 for vent scrubbers, is required by Gevo over what is present already in the hydrolyzate. Utility requirements include city water, steam, natural gas (for fired heaters and hydrogen production), cooling water, and electricity. No steam boilers or cooling towers have been assumed inside the Gevo box. Combined atmospheric vents (fermentation, fired heaters, etc.) were specified. Waste water was also specified as to flow and composition. Minor raw materials (other than biomass hydrolyzate) utilized in the process were specified as an operating cost amount. The material quantities are insignificant to the material balance. Hydrocarbon vents from the biojet (IPK) process are burned in the fired heaters and the combustion products included in the combined vent along with the hydrogen reformer vent and fermentation vent. No other hydrocarbon products besides biojet (IPK) are produced in the process. All lower molecular weight materials (e.g., isobutylene and isooctane) are recycled and incorporated in jet range molecules. Byproducts from isobutanol fermentation are generally discharged in the whole stillage. Some lower molecular weight alcohols can be recycled to the fermentation.

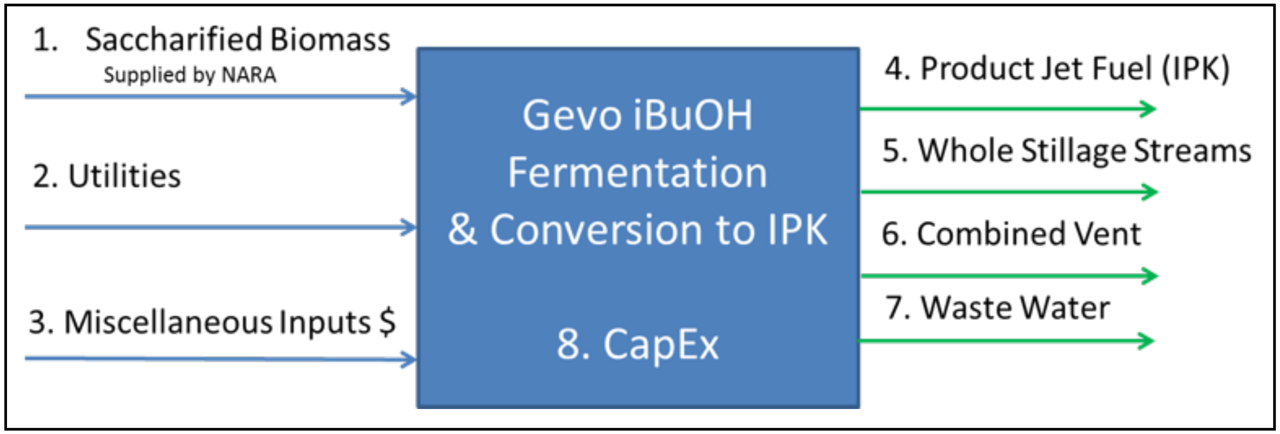


Figure C-AF-1.3. Gevo approach to modeling material flows and capital and operating costs.

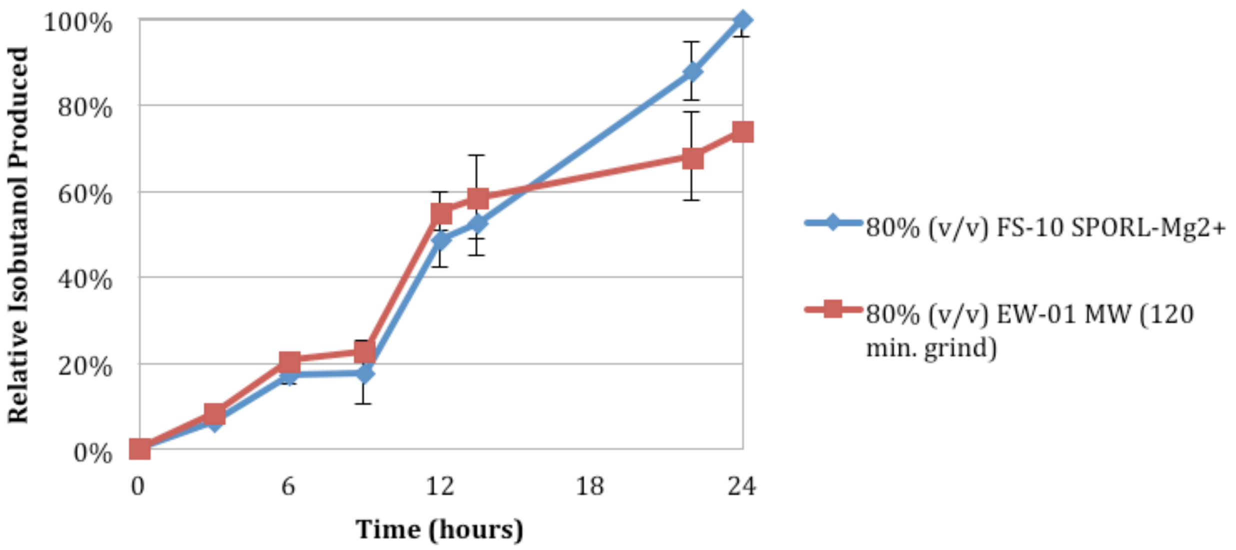


Figure C-AF-1.4. . Isobutanol produced by LB21 in 80% v/v FS-10 SPORL-Mg2+ pretreated and EW-01 MW (120 min. grind) hydrolyzate. Production of isobutanol was conducted in 1L fermentation vessels equipped with GIFT®, held at 33°C and pH controlled. Media was created using the corresponding mock media. Error bars represent the standard deviation.

Task C-AF-1.5. Produce isobutanol in 1L GIFT® fermentation from pretreated biomass sugars using the adapted yeast biocatalyst

A 1L GIFT® fermentation was performed using 100% (v/v) FS-10 concentrated milled wood (CMW) to further characterize the pretreatment and hydrolysis method used by Catchlight Energy. The volumetric rate of isobutanol production as well as the isobutanol titer achieved was comparable to 60% (v/v) FS-10 SPORL-Ca^{2+} pretreated hydrolyzate. In order to compare the milled wood process and SPORL pretreatment process, shipments of EW-01 and FS-01 MW samples were received from WSU and hydrolyzed at Gevo at similar solids percentages as previously hydrolyzed FS-10 SPORL-Mg^{2+} pretreated hydrolyzate. EW-01 MW (120 min. grind) hydrolyzed (23% solids, 108.6 g/L hexose sugars) under similar conditions as FS-10 SPORL-Mg^{2+} pretreated hydrolyzate (24% solids, 76.4 g/L hexose sugars) was the closest comparison in terms of hexose sugar concentration.

Growth of LB21 was nearly identical in 20% (v/v) FS-10 SPORL-Mg^{2+} pretreated hydrolyzate and 20% (v/v) EW-01 MW (120 min. grind) hydrolyzate using their corresponding mock media. The seed culture of LB21 from each condition was then used to inoculate 80% (v/v) of corresponding hydrolyzate using mock medium as the balance and allowed to ferment for 24 hours when both hydrolyzates were depleted of hexose sugars. Volumetric isobutanol production of LB21 in 80% (v/v) FS-10 SPORL-Mg^{2+} pretreated hydrolyzate was an average of 26.4% higher than LB21 in 80% (v/v) EW-01 MW (120 min. grind) hydrolyzate after 24 hours. LB21 continued to produce isobutanol at similar rates in both hydrolyzates up to 12 hours before plateauing in EW-01 MW (120 min. grind) hydrolyzate (Figure C-AF-1.4). The theoretical isobutanol yield of LB21 was 8.6% higher in 80% (v/v) FS-10 SPORL-Mg^{2+} pretreated hydrolyzate compared to the EW-10 MW (120 min. grind) hydrolyzate equivalent. Under the current pretreatment conditions, LB21 ferments better in FS-10 SPORL-Mg^{2+} pretreated hydrolyzate compared to EW-01 MW (120 min. grind) hydrolyzate under similar fermentation conditions.

Task C-AF-1.6. Analysis of isobutanol produced to close mass balance and determine potential low-level impurities.

Isobutanol collected from FS-10 (CMW) hydrolyzate lab-scale GIFT® fermentations were analyzed by gas chromatography for impurities. Table C-AF-1.2 shows very similar profiles for isobutanol produced from the mock hydrolyzate (pure sugars) medium and FS-10 CMW hydrolyzate. Consultation with the Gevo biojet conversion team did not identify any impurities that would be detrimental to the biojet conversion process. Work in this area will continue when the FS-17 feedstock using a single pretreatment method is fermented using GIFT® technology for process development work, scale-up, and production of ~1,000 gal biojet.

Task C-AF-1.7. Optimize process parameters for isobutanol fermentation from pretreated biomass

Over the past year, effort was put towards defining process conditions such as hydrolyzate loading during growth and production, and nutrient package development. This process information will be applicable to scale up from the 1L GIFT® scale and could be applied to producing isobutanol in the 20L GIFT® fermentation system as well as producing 1,000 gallons of biojet. Gevo, in consultation with NARA (Dr. Robert Wooley) no longer believes a step up to the 20L scale is required. Gevo has successfully scaled from 1L to hundreds of thousands of L directly. This, scaling from 1L GIFT® to ~23,000 L demonstration scale fermentations is directly feasible. Upon receiving a large pretreated FS-17 sample (15-20 kg) which resembles the conditions expected during the 1,000 gallon biojet production process, a 20L GIFT® fermentation experiment could be conducted if deemed necessary. Process development (including nutrient package development) will continue at the 1L scale.

Nitrogen supplementation using a variety of inorganic and organic (complex) nitrogen sources as well as supplemented with vitamins and minerals were tested using the LB21 biocatalyst. Based on the previously reported isobutanol productivity results, nutrient package (NP) 2.0 supplemented with a nitrogen source during propagation/growth and fermented in hydrolyzate containing NP 2.0 will create optimal conditions for isobutanol titer and volumetric isobutanol productivity (Figure C-AF-1.5).

In April/May 2014, three various industrially relevant operating pH ranges for growth of LB21 were also tested using 40% (v/v) FS-10 SPORL-Na^{+} pretreated hydrolyzate (previously labeled unwashed mild bisulfite solids, UMBS). Growth

Table CAF-1.2. Impurity profile of isobutanol produced in FS-10 CMW mock and 100% v/v FS-10 CMW hydrolyzate. Materials were analyzed by gas chromatography.

	FS-10 CMW Mock Media (Weight %)	FS-10 CMW Hydrolyzate (Weight %)
Methanol	0.0	0.0
Ethanol	3.0±0.2	3.9±0.7
Acetone	0.0	0.0
Isopropanol	0.0	0.0
1-Propanol	0.1	0.1
Isobutyraldehyde	0.2	0.1±0.1
2,3-Butanedione	0.0	0.0
2-Butanone	0.0	0.0
2-Butanol	0.0	0.0
Isobutanol	76.8±0.2	75.6±1.0
1-Butanol	0.0	0.0
Acetoin (3-Hydroxy-2-butanone)	0.0	0.0
3-Methyl-1-Butanol	1.1±0.1	1.0±0.1
2-Methyl-1-Butanol	0.6	0.5±0.1
Isobutyl Acetate	0.0	0.0
Isopentyl Acetate	0.0	0.0
Isobutyl Isobutyrate	0.0	0.0
2,3,5-Trimethylpyrazine	0.0	0.0
2,3,5,6-Tetramethylpyrazine	0.0	0.0
2-Phenylethanol	0.1	0.1
Phenethyl Acetate	0.0	0.0
All Unknown Peaks	0.1	0.2±0.1
Density	82.0±0.2	81.6±0.3
Water (weight %)	18.1±0.2	18.6±0.4
Water (Vol %)	21.4±0.5	21.8±0.3

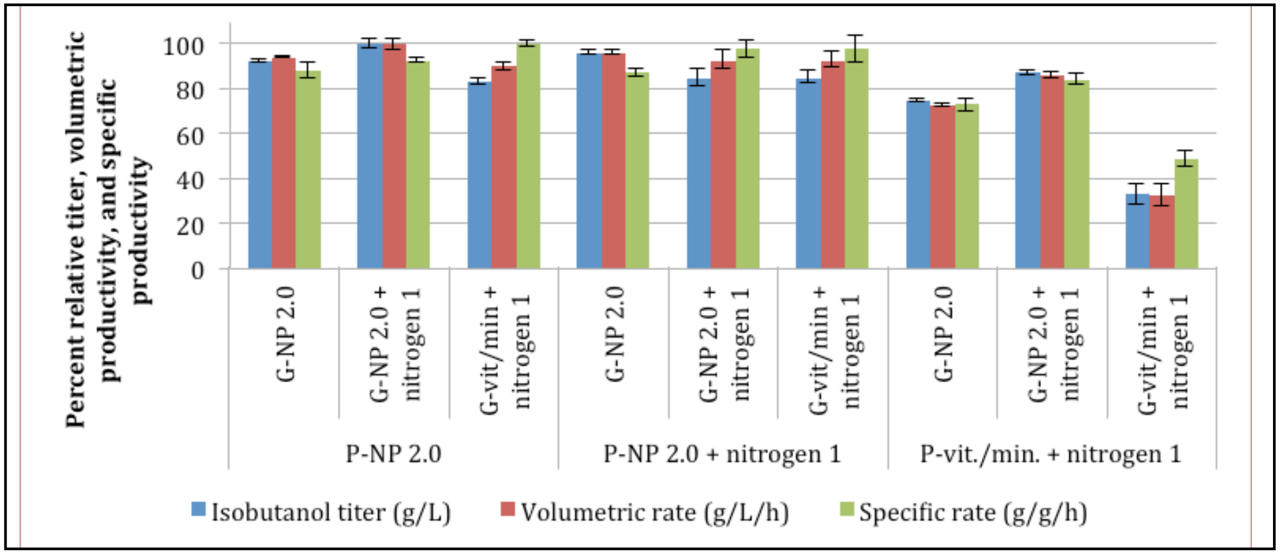


Figure C-AF-1.5. LB21 isobutanol metrics during nitrogen source optimization for isobutanol production. LB21 was grown (G) under high aeration conditions for 23 hours in shake flasks in either NP 2.0, NP 2.0 + nitrogen 1, or vit/min + nitrogen 1. After 23 hours of growth, production (P) was started with LB21 by transferring 1:4 volumetrically into shake flasks containing NP 2.0, NP 2.0 + nitrogen 1, or vit/min + nitrogen 1. All permutations of growth and production were tested for the different nitrogen media. The fermentation occurred under low aeration conditions for 24 hours. All media contained the same buffering agent Growth was carried out at 33ºC. Cell density was measured using a spectrophotometer. Error bars represent the standard deviation. Abbreviations: NP 2.0, yeast nutrient package containing complex nitrogen source; nitrogen 1, inorganic nitrogen source; vit/min, yeast vitamin and mineral mix essential for growth.

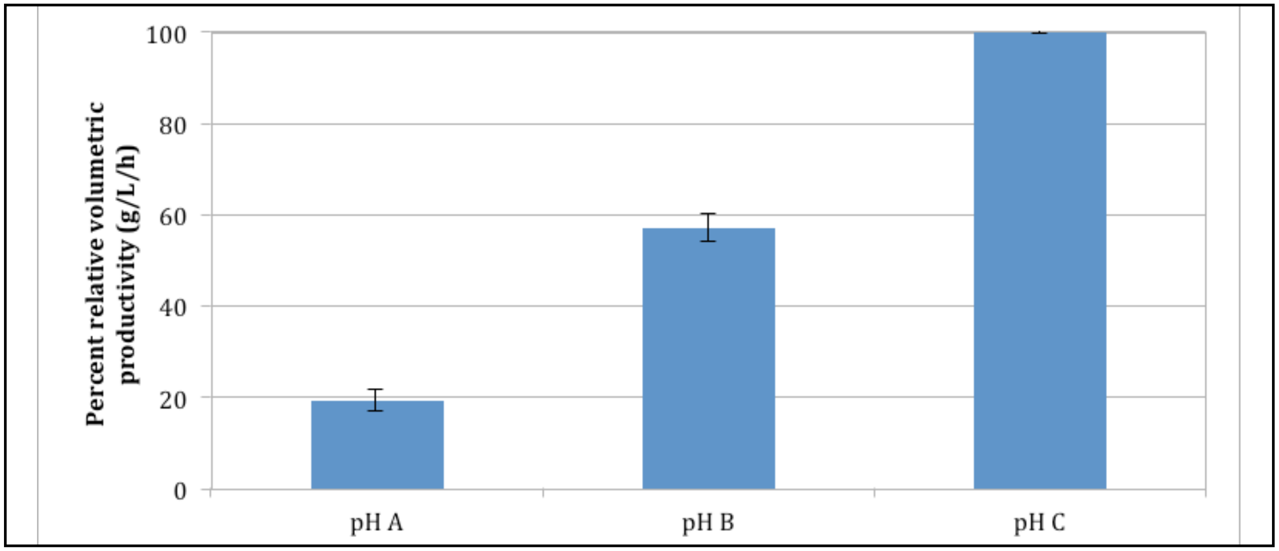


Figure C-AF-1.6. LB21 volumetric isobutanol productivity during fermentation at different industrially relevant pH conditions in 85% v/v FS-10 SPORL-Na+ pretreated unwashed solids hydrolyzate. To replicate potential commercial production conditions a 1:4 volumetric transfer from the 40% v/v FS-10 SPORL-Na+ pretreated unwashed solids hydrolyzate growth flask at pH A, B, and C into 100% v/v FS-10 SPORL-Na+ pretreated unwashed solids hydrolyzate fermentation flask at pH A, B, and C was carried out to yield an 85% v/v FS-10 SPORL-Na+ pretreated unwashed solids hydrolyzate medium. All media contained nutrient package 2.0 (NP 2.0). All conditions contained a buffering agent. Growth was carried out at 33ºC. Cell density was measured using a spectrophotometer. Error bars represent the standard deviation of 3replicates.

at pH C resulted in 40% and 22% higher biomass yield compared to pH A and B, respectively. After 23 hours of growth/propagation at the pH A/B/C the cultures were transferred into 100% (v/v) FS-10 SPORL-Na^+ pretreated hydrolyzate held at the same pH. Volumetric isobutanol productivity was 80% and 40% higher at pH C compared to pH A and pH B, respectively (Figure C-AF-1.6).

Task C-AF-1.8. Produce ≥1,000 gallons of isobutanol from GIFT® fermentations at 40,000L demonstration scale. Convert lignocellulosic isobutanol to ≥1000 gallons biojet for further testing.

The scale-up process for this task will begin as soon as the FS-17 pretreated material arrives in sufficient quantities at Gevo in Year 4 or 5. In an effort to determine if a direct pitch of LB23 into a production vessel was feasible, a 1L GIFT® fermentation using 85% (v/v) FS-10 SPORL-Mg^{2+} pretreated hydrolyzate (32% solids) containing NP 2.0 was performed. The initial inoculation cell density of LB23 was identical to a similar LB21 1L GIFT® fermentation run but unlike the LB21 fermentation, the LB23 inoculum was not pre-conditioned to the hydrolyzate and a slight lag in growth and isobutanol production was noted. The amount of isobutanol produced by LB23 compared to LB21 in FS-10 SPORL-Mg^{2+} pretreated hydrolyzate (Figure C-AF-1.7) was greater in large part because of the nearly 50% higher hexose sugar concentration in the LB23 fermentation (89 g/L vs. 172 g/L). Also, LB23 has a 17% higher theoretical isobutanol production yield compared to LB21 meaning that more hexose sugar is being converted to isobutanol compared to other metabolic co-products. Finally, under the direct pitch conditions, LB23 had a 20% higher volumetric isobutanol productivity compared to LB21.

LB23 is the current best NARA and Gevo biocatalyst. Therefore, LB23 will be utilized going forward in the 1,000 gallon biojet production. Process optimization will be pursued aggressively in the time remaining in year 4 and into year 5 to maximize the performance of the LB23, or LB23 hydrolyzate evolved strains, yeast biocatalyst in FS-17 SPORL pretreated hydrolyzate.

Recommendations | Conclusions

Work continues to proceed according to the project plan. Optimization of fermentation conditions and characterization of fermentation performance has progressed now that pretreatment options have been narrowed down. Further optimization and characterization will be carried out as feedstock and pretreatment options continue to become representative of actual materials that will be used in process scale-up work. Currently, fermentation performance meets or exceeds target volumetric rates and yields. The adaptation program has continued to provide improved biocatalyst strains and has recently been used to adapt Gevo's second-generation biocatalyst. Gevo will continue to refine process model. Process development work has begun and will continue in order to support a demonstration scale-up trial targeted for later in the year.

Physical and Intellectual Outputs

PHYSICAL

- Demonstration site for hydrolysis and fermentation was established
- Demonstration site for conversion of isobutanol to iso-paraffinic kerosene was established
- Isobutanol recovered from 2L GIFT scale fermentations on various substrates

RESEARCH PRESENTATIONS

IHawkins, A.C. (2015). Development and commercialization of fermentative isobutanol production. American Chemical Society Division of Biochemical Technology. 249th ACS National Meeting. March 2015. Presentation number BIOT 144.

Parker, A.C., G.J. Balzer, L.T. Robinson, M.H. Schmalisch and A.C. Hawkins. 2014. Fermentative Conversion of Hydrolyzed Douglas fir Biomass into Isobutanol. 2014 Annual NARA Meeting, Seattle, WA, September 15-17.

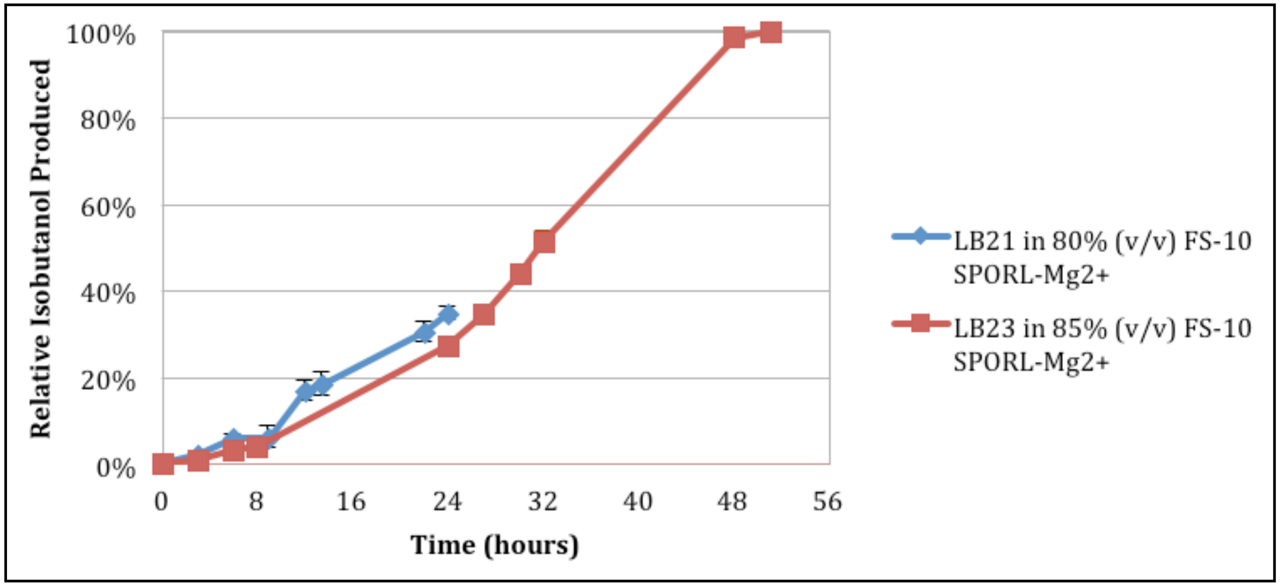


Figure C-AF-1.7. Isobutanol produced by LB21 in 80% v/v FS-10 SPORL-Mg2+ pretreated and LB23 in 85% v/v FS-10 SPORL-Mg2+ pretreated hydrolyzate. Production of isobutanol was conducted in 1L fermentation vessels equipped with GIFT®, held at 33°C and pH controlled. Medium was created using the corresponding mock media as the balance of 100%. LB21 was pre-conditioned in 20% v/v FS-10 SPORL-Mg2+ pretreated hydrolyzate before inoculating 80% v/v hydrolyzate compared to LB23 which was directly pitched into 85% v/v hydrolyzate. Error bars represent the standard deviation of two replicates. LB21 in 80% FS_10 SPORL-Mg2+ fermentation was run until all consumable sugars were exhausted.

TASK 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. In the project we will concentrate effort on the following two areas: Task 1: Co-culture optimization for high production yield and productivity of platform molecules (VFA) from pretreated biomass hydrolysate. Task 2: Catalysis of platform molecules into jet fuel. WSU BSEL will work with PNNL using the PNNL combinatorial catalysis computational laboratory platform.

The BioChemCat process is a new way to produce more biofuels from biomass for significant lower cost. The cost reductions will come from: 1) the process will have no need for enzymes, a significant cost reduction; 2) the mixed culture fermentations used is non-sterile and robust; 3) no special seed culture needs to be grown and the culture needs no expensive additives; 4) simple low-cost reactors as used for anaerobic digestion can be used; 5) only a fraction of the biomass material needs to be pretreated and at low retention times which considerably lowers the cost of pretreatment; 6) a large part of the lignin can be converted to biofuels along with the carbohydrates in the biomass material.

Activities and Results

Task C-AF-2.1. Optimizing fermentation for making platform molecules

Based on results obtained from the previous quarter, the wet explosion pretreatment for woody biomass were made less severe to effectively obtain greater amount of cello-oligosaccharides available for the anaerobic fermentation. The mixed culture was used to ferment the pretreated biomass at 37°C and pH of 6.5. Under these mesophilic conditions, our maximum yield was found to be 72g of VFA as acetic acid equivalents per 100 g of sugar equivalents in the pretreated biomass. On an average, we obtained around 54g of VFA (acetic acid equivalents) per 100g of biomass sugar or 33g VFA per 100g of woody materials. The main VFAs obtained in the fermentation were C2-4 and C7 acids. It was found that greater amount of C7 acid was produced by pretreated biomass when compared with similar fermentation done using non-pretreated biomass as feed. It can be seen from Figure C-AF-2.1 that under optimized conditions, the anaerobic fermentation was capable of producing more than 0.5 wt% of VFA per gram of biomass sugars or 0.35 wt% VFA per gram of biomass. The VFAs produced in this process are currently being separated using different separation methodologies discussed in the previous quarterly reports such as supercritical carbon dioxide extraction and ion exchange resin. The mass balance and the techno-economic analysis for this optimized process are currently being done together CleanVantage to complete the work associated with this part of the project.

Task C-AF-2.2. Catalysis of Platform Molecules into Jet Fuel

Initial studies on the catalytic hydrogenation of VFAs were done using cobalt catalyst impregnated in silica as catalyst. Preliminary investigation indicates that in the conversion reaction scheme where dehydration mechanisms are important, silica may not be

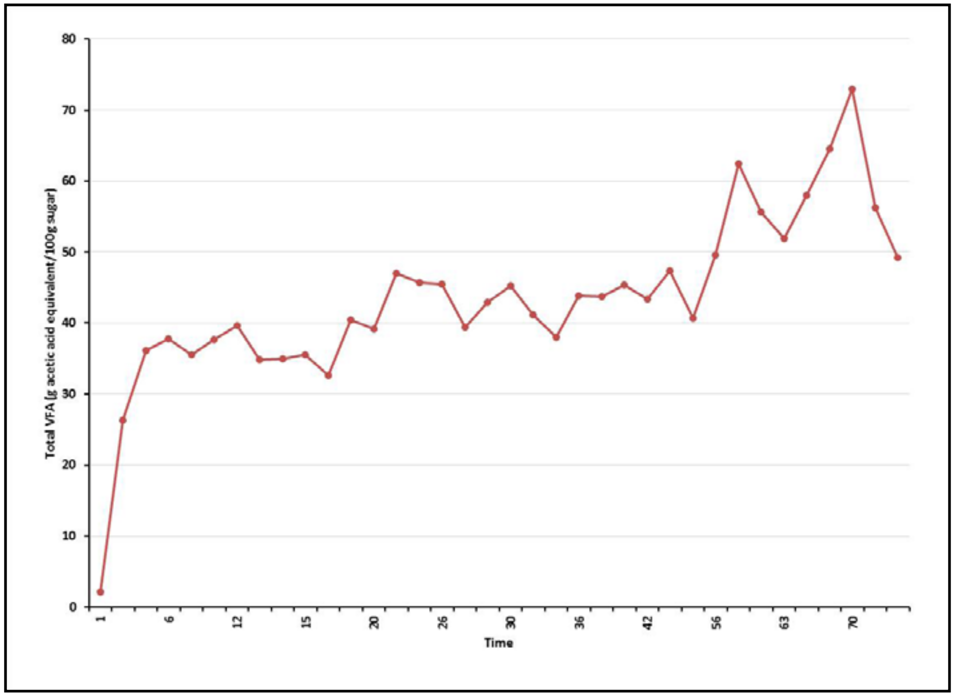


Figure C-AF-2.1. Total VFA as acetic acid equivalents as a function of time(days) obtained in a continuous mesophilic anaerobic fermentation of wet-exploded woody material using a mixed bacterial culture.

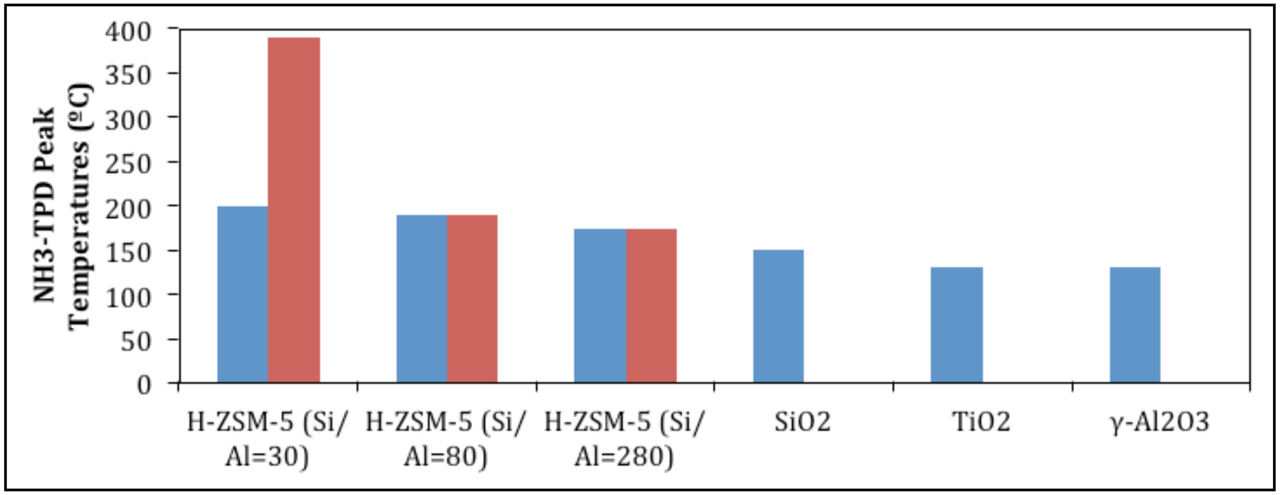
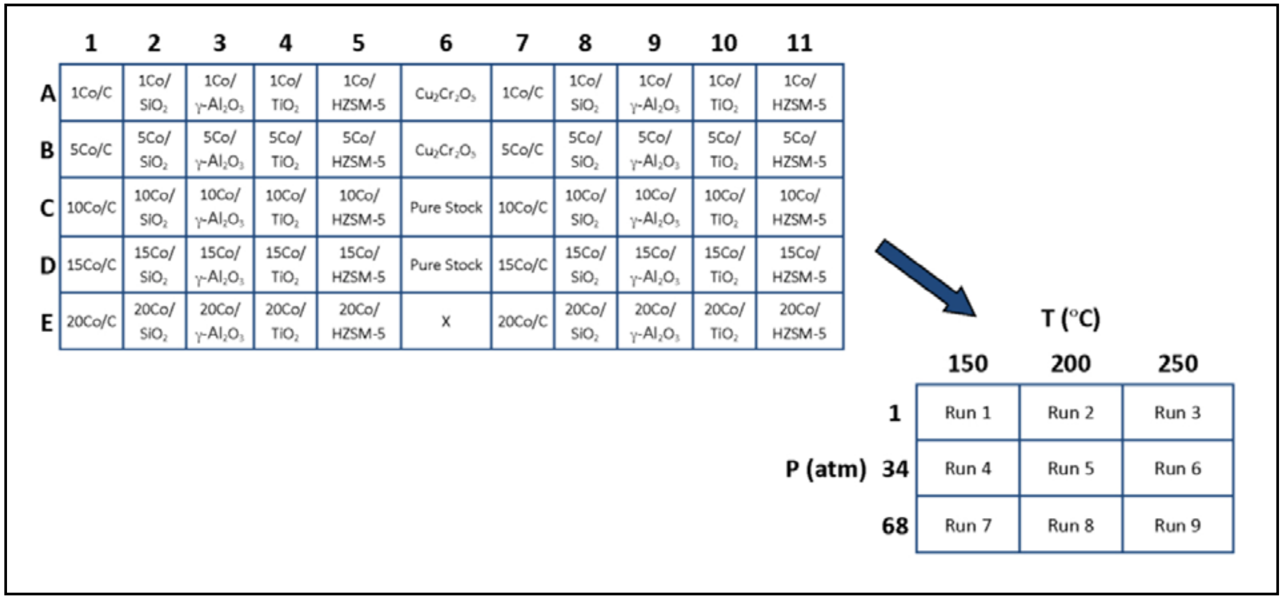


Figure C-AF-2.2. Average desorption temperatures for ammonia bound to various acidity catalysts supports.



	1	2	3	4	5	6	7	8	9	10	11
A	1Co/C	1Co/ SiO_2	1Co/ γ-Al_2O_3	1Co/ TiO_2	1Co/ HZSM-5	$Cu_2Cr_2O_5$	1Co/C	1Co/ SiO_2	1Co/ γ-Al_2O_3	1Co/ TiO_2	1Co/ HZSM-5
B	5Co/C	5Co/ SiO_2	5Co/ γ-Al_2O_3	5Co/ TiO_2	5Co/ HZSM-5	$Cu_2Cr_2O_5$	5Co/C	5Co/ SiO_2	5Co/ γ-Al_2O_3	5Co/ TiO_2	5Co/ HZSM-5
C	10Co/C	10Co/ SiO_2	10Co/ γ-Al_2O_3	10Co/ TiO_2	10Co/ HZSM-5	Pure Stock	10Co/C	10Co/ SiO_2	10Co/ γ-Al_2O_3	10Co/ TiO_2	10Co/ HZSM-5
D	15Co/C	15Co/ SiO_2	15Co/ γ-Al_2O_3	15Co/ TiO_2	15Co/ HZSM-5	Pure Stock	15Co/C	15Co/ SiO_2	15Co/ γ-Al_2O_3	15Co/ TiO_2	15Co/ HZSM-5
E	20Co/C	20Co/ SiO_2	20Co/ γ-Al_2O_3	20Co/ TiO_2	20Co/ HZSM-5	X	20Co/C	20Co/ SiO_2	20Co/ γ-Al_2O_3	20Co/ TiO_2	20Co/ HZSM-5

		T (°C)		
		150	200	250
P (atm)	1	Run 1	Run 2	Run 3
	34	Run 4	Run 5	Run 6
	68	Run 7	Run 8	Run 9

Figure C-AF-2.3. Execution plan for high-throughput batch testing using CombiCat well plate reactor available at PNNL. This process will be run 9 different times to account for the desired changes in operating temperature and pressure. The value next to cobalt stands for metal loading percentage. Ex. 10Co/C denotes 10 wt% cobalt on carbon catalyst.

the most effective support, as there are many other much more acidic supports available with comparable surface area shown to be appropriate for propylene glycol dehydration. According to the ammonia temperature programmed desorption (TPD) results from investigation of various supports (Figure C-AF-2.2), a high Si/Al ratio HZSM-5 support is highly capable of dehydration reactions due to a strong affinity for protons (stronger acid-base bonds). An issue with selection of a support based solely on these values is that if a support is too acidic, coke will form, deactivating catalyst. Therefore, a combination of effective hydrogenation/hydrogenolysis metal must be combined with an appropriately acidic support in order to catalyze the one-pot synthesis of VFAs to alcohols. From these investigations, the main aim of our work is to investigate the production of mixed alcohols from VFAs by understanding the role of catalyst support acidity in the conversion reaction.

In order to gather data to understand and optimize dehydrations reactions in this conversion scheme, we plan to first study the conversion and yield of using VFA methyl and ethyl esters (specifically C2 and C3 acids which were predominantly produced in the mesophilic anaerobic fermentation discussed in the previous section) with a 10 wt% cobalt on fumed silica catalyst at the to-date reported best conditions for propanol production, as well as different weight loading of this catalyst on varying acidity of supports such as cobalt on carbon black, amorphous silica, γ-alumina, acidic zeolite (HZSM-5, varying Si/Al ratios), and titania to promote changes in catalyst dehydration ability. To screen all of these catalysts, small batch reactions will be used. The set of studies that are still planned to be executed to complete this study is listed in Figure C-AF-2.3. The best catalysts determined from batch studies will be characterized using a multitude of different physical and spectroscopy techniques to determine catalyst stability along with its effect on the conversion of alkyl VFA's to their corresponding alcohols at varying operating conditions.

Recommendations | Conclusions

The mesophilic fermentation was studied in this quarter and compared to the thermophilic fermentation previously discussed in the other quarterly reports. It was found that using the mesophilic fermentation at 37˚C and pH 6.5, we obtained a greater amount of C-2 acids than C-3 acids, which indicated greater overall conversion when compared to thermophilic conditions of 50˚C and pH 5.5 where a greater amount of C-3 acids were produced. Also, we found the presence of C-4 and C-7 organic acids in this fermentation process when compared to that previously discussed. This change in the type of VFA yield can be attributed to the different microbial organisms present in the mixed culture that are activated at the different conditions. This tuning of the fermentation conditions to obtained desirable VFA concentrations and yields at non-sterile conditions using the mixed bacterial culture adds to the significance of the discussed technique. With respect to VFA yields, comparison with literature studies has indicated that our process produces almost similar acid yields when compared to different pure bacterial culture. However, this process does not required high sterility conditions which significantly reduce process costs when compared to the current state-or-art.

The separation process for a mixed VFA concentration from the fermentation broth has been done previously and the work right now is being concentrated on the mesophilic culture. While ion exchange resins are better suited for C-3 and above acids, supercritical fluid extraction has been found to be better suited for C-2 acids. However, other stronger ion exchange resins are being tested with the mixed VFA feed. Esterification of the VFAs has been strongly recommended as indicated in the previous quarterly report. Preliminary experiments done using liquid phase hydrogenation of acetic acid using Pt-Rh catalyst on silica had indicated a catalyst conversion of not higher than 50% for a maximum selectivity greater than 90% towards ethanol production. This decreased conversion was found to be due to the conversion of acetic acid to ethyl acetate at higher concentrations of ethanol produced. This work was not a part of the USDA-NARA initiative and was primarily used to justify our decision to consider vapor phase hydrogenation of the methyl or ethyl ester of the VFAs to produce mixed alcohols. Further studies are currently being done to optimize and characterize the catalyst for effective vapor-phase hydrogenation to produce alcohols. Preliminary studies have indicated that temperatures above 200˚C and pressures below 1 MPa are best conditions to test and optimized effective catalytic hydrogenation of VFAs to alcohols which can be further dehydrated and oligomerized in the presence of a zeolite catalyst to produce jet fuels.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

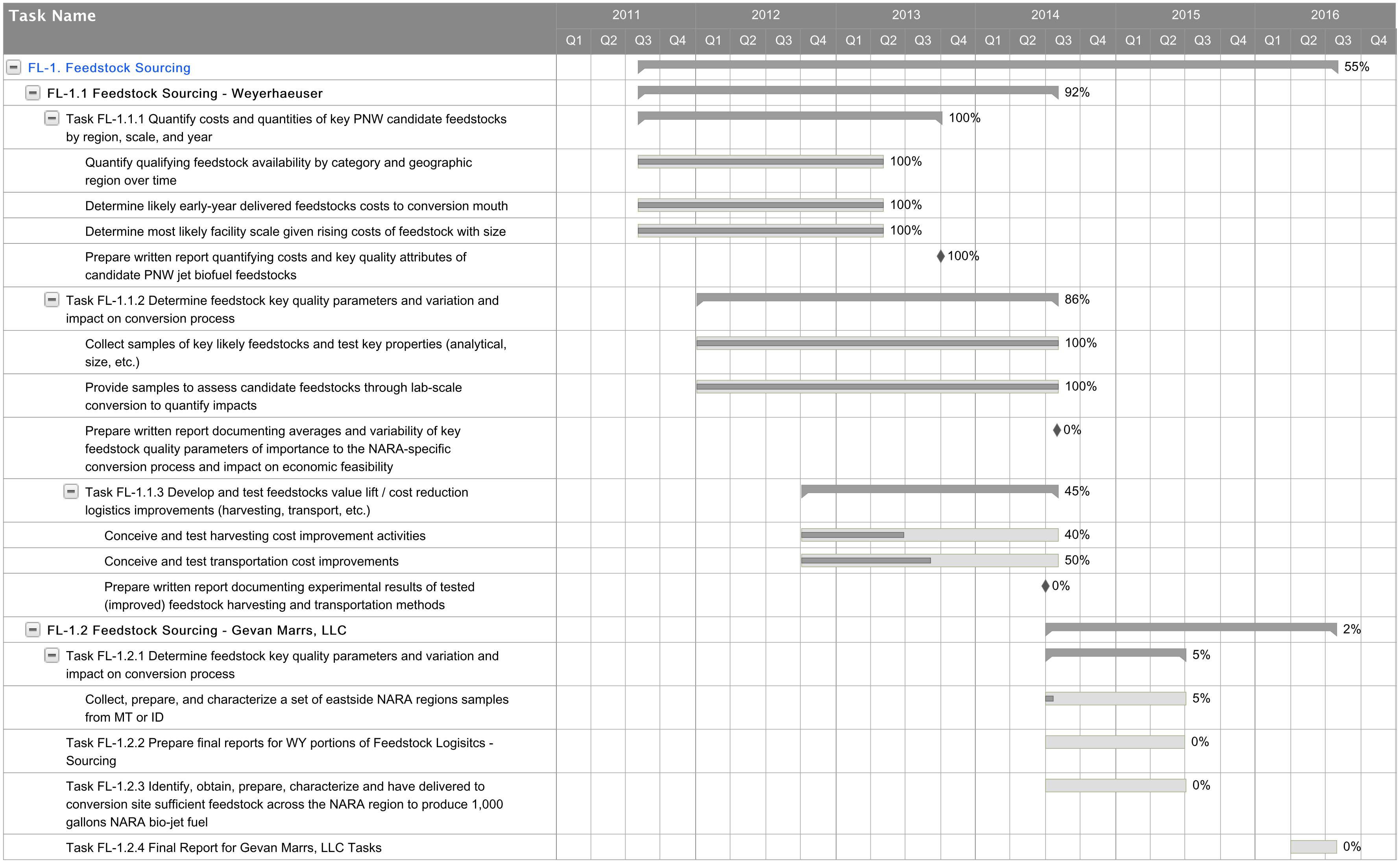
Fernandez, S., Murali, N. and Ahring, B. K., 2014, Effect of methanogens on VFA yield using anaerobic fermentation of biomass using mixed culture, Submitted to Biochemical Engineering Journal

Murali, N. and Ahring, B. K., 2014, Comparison between wet-exploded and non-pretreated corn stover as feedstocks for VFA production using anaerobic fermentation, Submitted to Bioresource Technology

Garrett, B.G., Srinivas, K., & Ahring, B.K. (2014). Design and optimization of a semi-continuous high pressure carbon dioxide extraction system for acetic acid. J.of Supercritical Fluids, 95, 243-251. doi:10.1016/j.supflu.2014.08.029

Garrett, G.B., Srinivas, K., & Ahring, B.K. (2015). Performance and stability of Amberlite TM IRA-67 ion exchange resin for product extraction and pH control during homolactic fermentation of corn stover sugars. Biochemical Engineering Journal, 94,1-8. doi:10.1016/j.bej.2014.11.004

FeedstockLogistics_Marrs

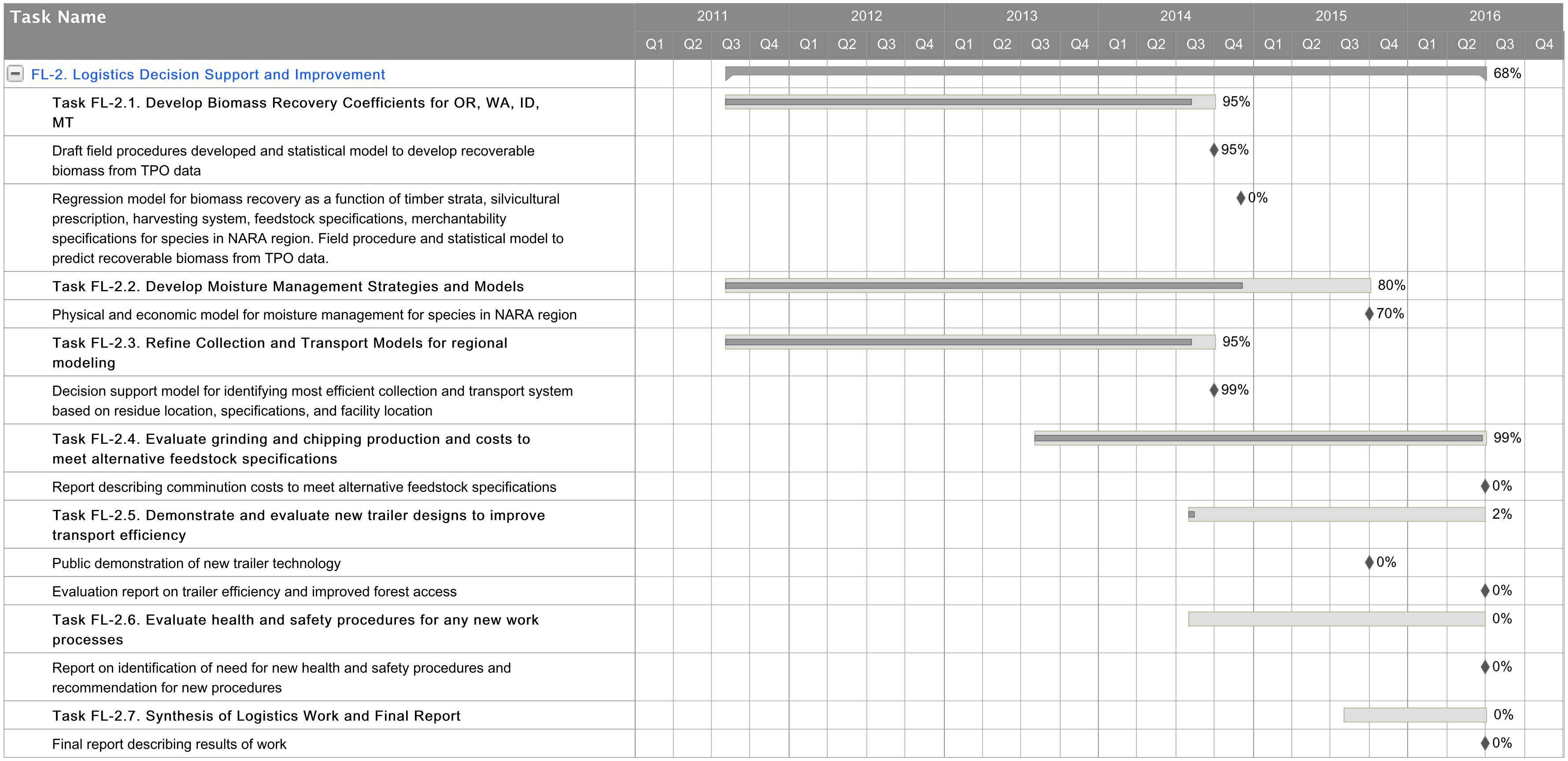


	Task Name	
1	FL-1. Feedstock Sourcing	55%
2	FL-1.1 Feedstock Sourcing - Weyerhaeuser	92%
3	Task FL-1.1.1 Quantify costs and quantities of key PNW candidate feedstocks by region, scale, and year	100%
4	Quantify qualifying feedstock availability by category and geographic region over time	100%
5	Determine likely early-year delivered feedstocks costs to conversion mouth	100%
6	Determine most likely facility scale given rising costs of feedstock with size	100%
7	Prepare written report quantifying costs and key quality attributes of candidate PNW jet biofuel feedstocks	100%
8	Task FL-1.1.2 Determine feedstock key quality parameters and variation and impact on conversion process	86%
9	Collect samples of key likely feedstocks and test key properties (analytical, size, etc.)	100%
10	Provide samples to assess candidate feedstocks through lab-scale conversion to quantify impacts	100%
11	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%
12	Task FL-1.1.3 Develop and test feedstocks value lift / cost reduction logistics improvements (harvesting, transport, etc.)	45%
13	Conceive and test harvesting cost improvement activities	40%
14	Conceive and test transportation cost improvements	50%
15	Prepare written report documenting experimental results of tested (improved) feedstock harvesting and transportation methods	0%
16	FL-1.2 Feedstock Sourcing - Gevan Marrs, LLC	2%
17	Task FL-1.2.1 Determine feedstock key quality parameters and variation and impact on conversion process	5%
18	Collect, prepare, and characterize a set of eastside NARA regions samples from MT or ID	5%
19	Task FL-1.2.2 Prepare final reports for WY portions of Feedstock Logisitcs - Sourcing	0%
20	Task FL-1.2.3 Identify, obtain, prepare, characterize and have delivered to conversion site sufficient feedstock across the NARA region to produce 1,000 gallons NARA bio-jet fuel	0%
21	Task FL-1.2.4 Final Report for Gevan Marrs, LLC Tasks	0%

Exported on April 8, 2015 8:09:39 AM PDT

Page 1 of 1

FeedstockLogistics_Sessions

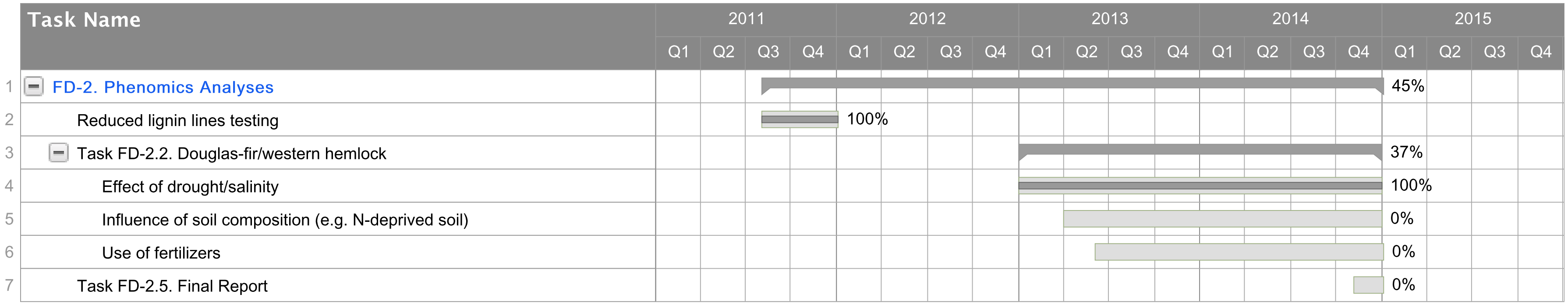


	Task Name	
1	FL-2. Logistics Decision Support and Improvement	68%
2	Task FL-2.1. Develop Biomass Recovery Coefficients for OR, WA, ID, MT	95%
3	Draft field procedures developed and statistical model to develop recoverable biomass from TPO data	95%
4	Regression model for biomass recovery as a function of timber strata, silvicultural prescription, harvesting system, feedstock specifications, merchantability specifications for species in NARA region. Field procedure and statistical model to predict recoverable biomass from TPO data.	0%
5	Task FL-2.2. Develop Moisture Management Strategies and Models	80%
6	Physical and economic model for moisture management for species in NARA region	70%
7	Task FL-2.3. Refine Collection and Transport Models for regional modeling	95%
8	Decision support model for identifying most efficient collection and transport system based on residue location, specifications, and facility location	99%
9	Task FL-2.4. Evaluate grinding and chipping production and costs to meet alternative feedstock specifications	99%
10	Report describing comminution costs to meet alternative feedstock specifications	0%
11	Task FL-2.5. Demonstrate and evaluate new trailer designs to improve transport efficiency	2%
12	Public demonstration of new trailer technology	0%
13	Evaluation report on trailer efficiency and improved forest access	0%
14	Task FL-2.6. Evaluate health and safety procedures for any new work processes	0%
15	Report on identification of need for new health and safety procedures and recommendation for new procedures	0%
16	Task FL-2.7. Synthesis of Logistics Work and Final Report	0%
17	Final report describing results of work	0%

Exported on April 14, 2015 9:23:02 AM PDT

Page 1 of 1

FeedstockDevelopment_Kirchhoff

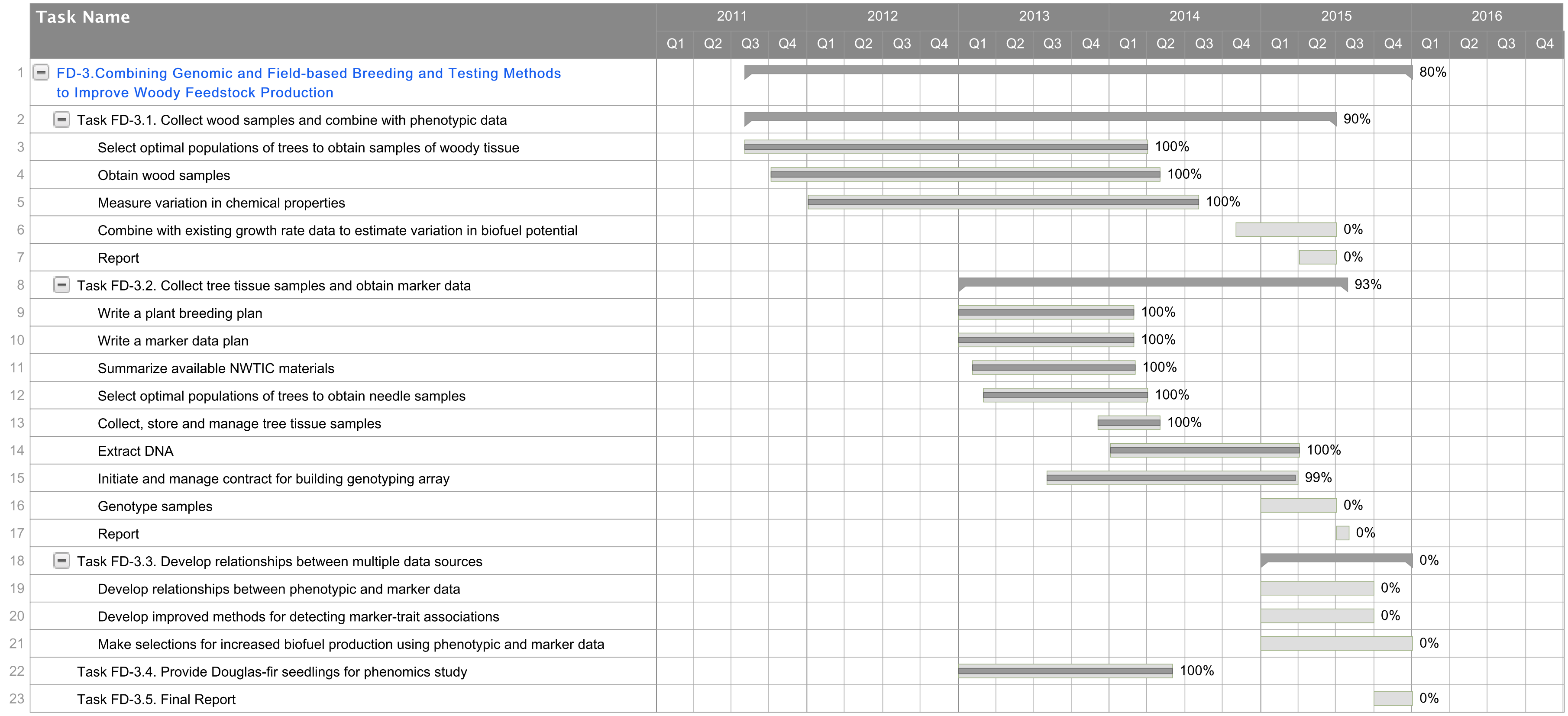


	Task Name	
1	FD-2. Phenomics Analyses	45%
2	Reduced lignin lines testing	100%
3	Task FD-2.2. Douglas-fir/western hemlock	37%
4	Effect of drought/salinity	100%
5	Influence of soil composition (e.g. N-deprived soil)	0%
6	Use of fertilizers	0%
7	Task FD-2.5. Final Report	0%

Exported on April 24, 2015 9:13:10 AM PDT

Page 1 of 1

FeedstockDevelopment_Jayawickrama



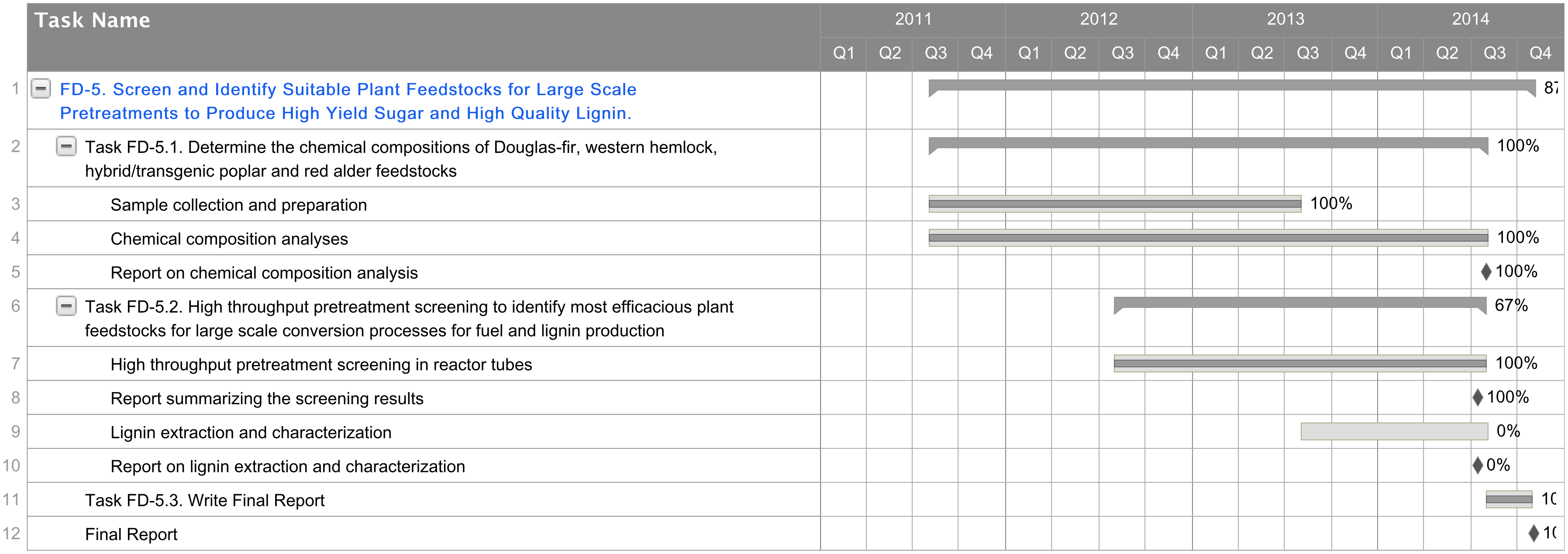
	Task Name	
1	FD-3.Combining Genomic and Field-based Breeding and Testing Methods to Improve Woody Feedstock Production	80%
2	Task FD-3.1. Collect wood samples and combine with phenotypic data	90%
3	Select optimal populations of trees to obtain samples of woody tissue	100%
4	Obtain wood samples	100%
5	Measure variation in chemical properties	100%
6	Combine with existing growth rate data to estimate variation in biofuel potential	0%
7	Report	0%
8	Task FD-3.2. Collect tree tissue samples and obtain marker data	93%
9	Write a plant breeding plan	100%
10	Write a marker data plan	100%
11	Summarize available NWTIC materials	100%
12	Select optimal populations of trees to obtain needle samples	100%
13	Collect, store and manage tree tissue samples	100%
14	Extract DNA	100%
15	Initiate and manage contract for building genotyping array	99%
16	Genotype samples	0%
17	Report	0%
18	Task FD-3.3. Develop relationships between multiple data sources	0%
19	Develop relationships between phenotypic and marker data	0%
20	Develop improved methods for detecting marker-trait associations	0%
21	Make selections for increased biofuel production using phenotypic and marker data	0%
22	Task FD-3.4. Provide Douglas-fir seedlings for phenomics study	100%
23	Task FD-3.5. Final Report	0%

Exported on April 24, 2015 9:53:43 AM PDT

Page 1 of 1

FeedstockDevelopment_XZhang

NARA



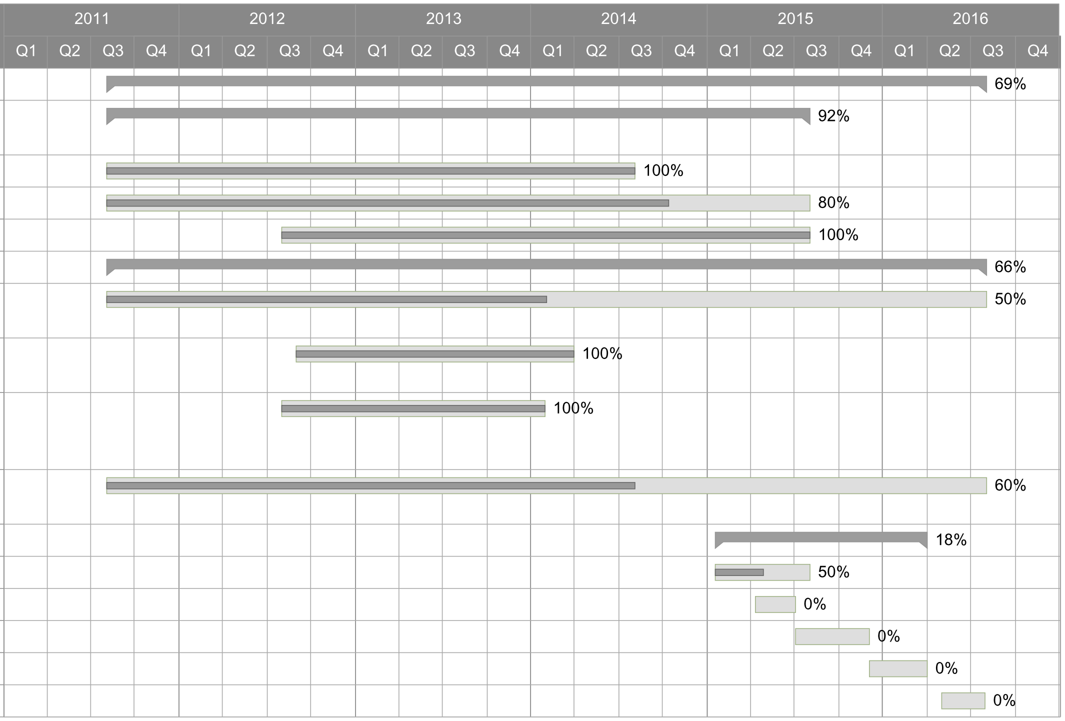
	Task Name	
1	FD-5. Screen and Identify Suitable Plant Feedstocks for Large Scale Pretreatments to Produce High Yield Sugar and High Quality Lignin.	87
2	Task FD-5.1. Determine the chemical compositions of Douglas-fir, western hemlock, hybrid/transgenic poplar and red alder feedstocks	100%
3	Sample collection and preparation	100%
4	Chemical composition analyses	100%
5	Report on chemical composition analysis	♦ 100%
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	67%
7	High throughput pretreatment screening in reactor tubes	100%
8	Report summarizing the screening results	♦ 100%
9	Lignin extraction and characterization	0%
10	Report on lignin extraction and characterization	♦ 0%
11	Task FD-5.3. Write Final Report	1
12	Final Report	♦ 1

Exported on May 12, 2015 1:03:59 PM PDT

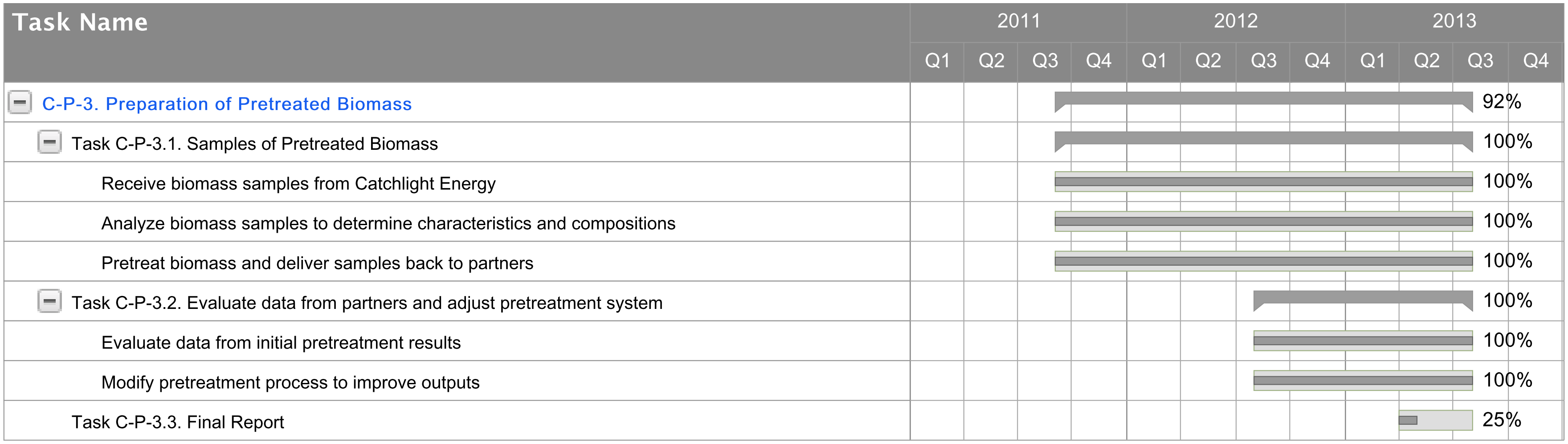
Page 1 of 1

Pretreatment_Zhu

	Task Name
1	C-P-4. Mild Bisulfite Pretreatment of Forest Residuals
2	Task C-P-4.4.1. Optimization SPORL and/or other pretreatments at FPL pilot plant facility (50 kg/run)
3	Experiment design based on Task 1, pretreatment
4	Sample analysis, high solids (~20%) enzymatic saccharification
5	Material and energy balance, correlate data between Task 1 and Task 2
6	Task C-P-4.4.2. Scale-up of SPORL technology
7	Identification and experimental verification of operating conditions that are suitable for industrial trial runs
8	Scale up from 2-3 to 50 kg feedstock. Integrate downstream processes of defibering, hydrolysis, and concentration of sugar
9	Hydrolyze and concentrate a sample of waste fiber from a commercial sulfite mill and compare the resulting sugar to the sugar produced in the Mild Bisulfite Pretreatment
10	Work with Washington State University, Weyerhaeuser and Gevo for jet fuel/lignin products production, data analysis, reporting
11	Task C-P-4.4.3. Industrial scale-up of SPORL technology
12	Identify operating conditions for industrial scale trial run
13	Evaluation runs at an industry facility for designing industrial trail runs
14	Industrial scale trial run
15	Sample analyses and data analyses
16	Task C-P-4.4.4. Final Report



Pretreatment_Ahring

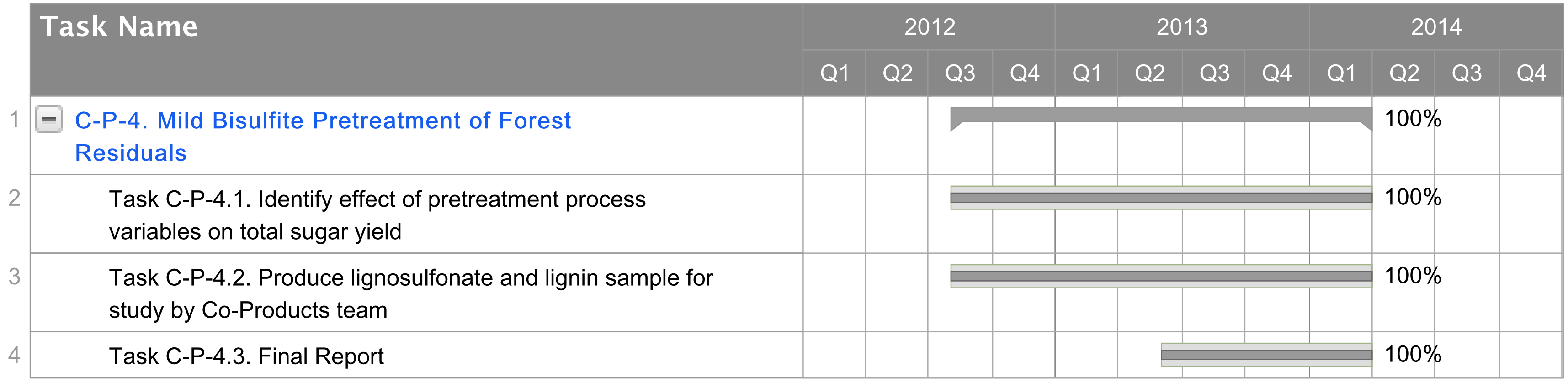


	Task Name	
1	C-P-3. Preparation of Pretreated Biomass	92%
2	Task C-P-3.1. Samples of Pretreated Biomass	100%
3	Receive biomass samples from Catchlight Energy	100%
4	Analyze biomass samples to determine characteristics and compositions	100%
5	Pretreat biomass and deliver samples back to partners	100%
6	Task C-P-3.2. Evaluate data from partners and adjust pretreatment system	100%
7	Evaluate data from initial pretreatment results	100%
8	Modify pretreatment process to improve outputs	100%
9	Task C-P-3.3. Final Report	25%

Exported on November 13, 2014 10:21:31 AM PST

Page 1 of 1

Pretreatment_Catchlight



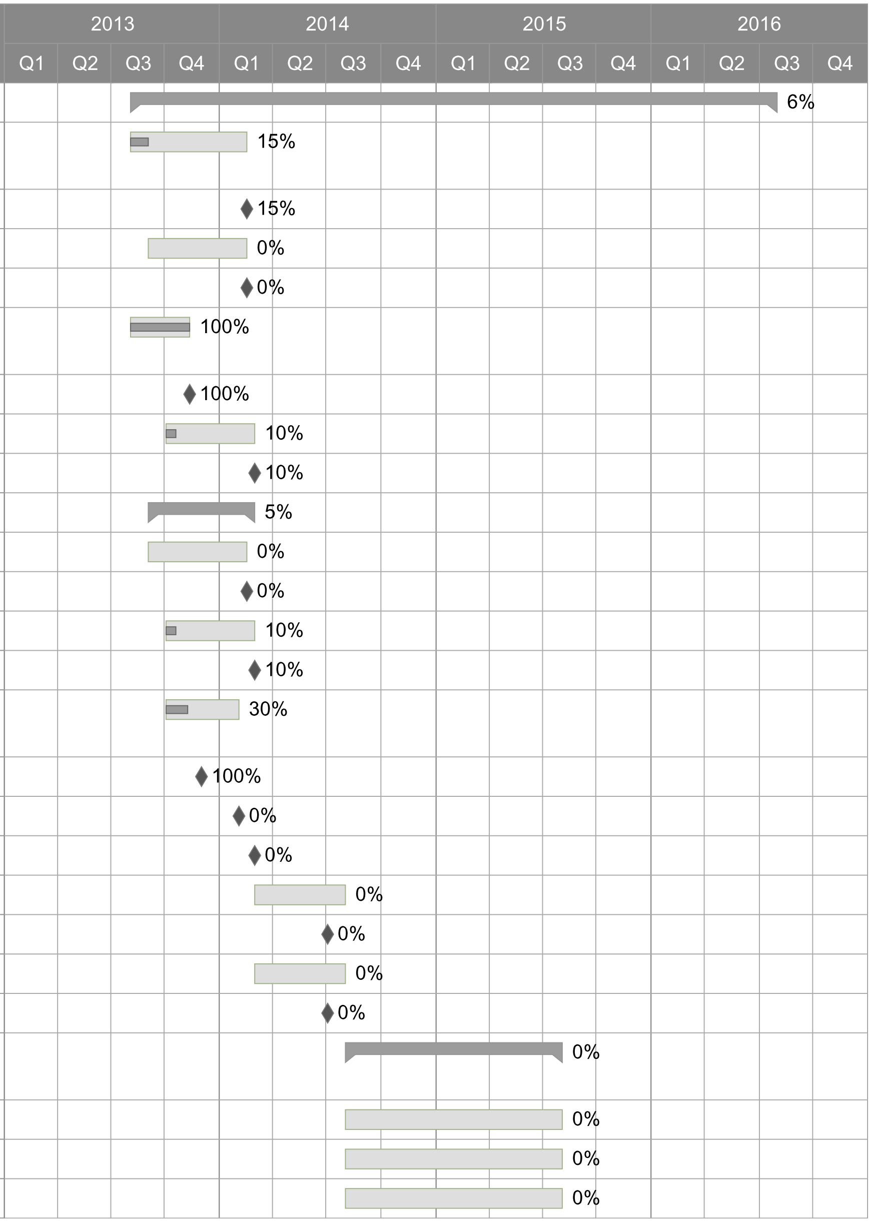
	Task Name	
1	C-P-4. Mild Bisulfite Pretreatment of Forest Residuals	100%
2	Task C-P-4.1. Identify effect of pretreatment process variables on total sugar yield	100%
3	Task C-P-4.2. Produce lignosulfonate and lignin sample for study by Co-Products team	100%
4	Task C-P-4.3. Final Report	100%

Exported on April 10, 2014 1:24:44 PM PDT

Page 1 of 1

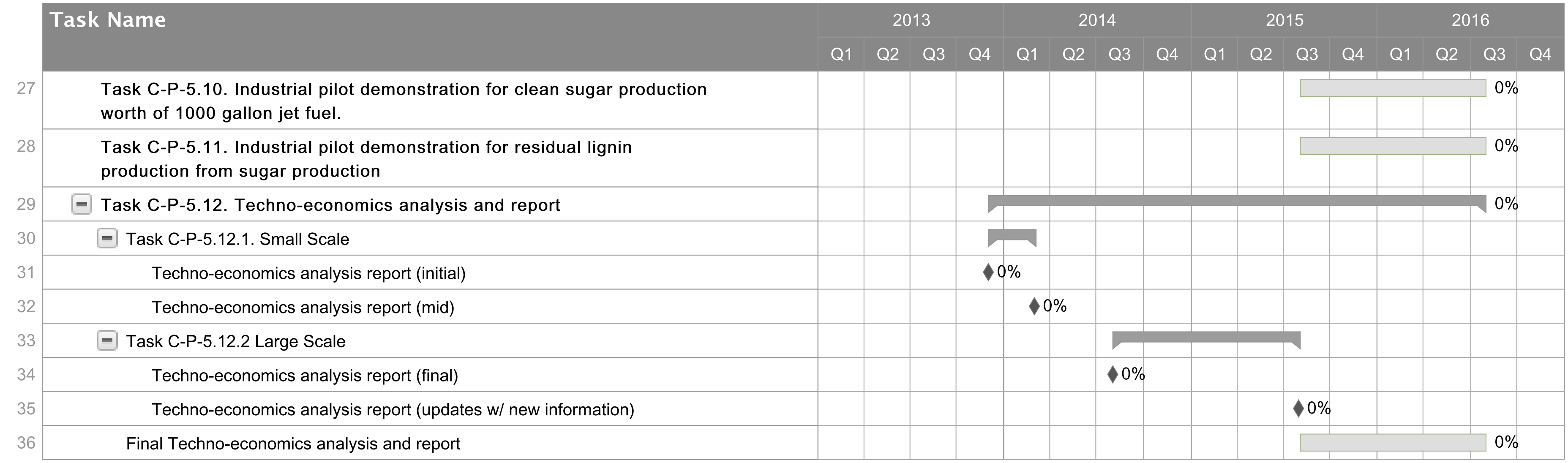
Pretreatment_Gao

	Task Name	
1	C-P-5. Clean Sugar and Lignin Pretreatment Technology	6%
2	Task C-P-5.1. Comprehensive literature study of wood milling technologies	15%
3	Wood milling technology review report	15%
4	Task C-P-5.2. Conduct life cycle analysis LCA of wood milling	0%
5	Life cycle analysis report on wood milling	0%
6	Task C-P-5.3. Verify energy consumption in tandem mill at Akita University	100%
7	Energy consumption verification report on tandem milling	100%
8	Task C-P-5.4. Small scale milling screening	10%
9	Small scale milling screening report	10%
10	Task C-P-5.5. Hydrolysis Optimization	5%
11	Milling equipment (small unit for optimization), order and installation	0%
12	Milling equipment (small unit for optimization) installed	0%
13	Optimize hydrolysis	10%
14	Hydrolysis optimization report	10%
15	Task C-P-5.6. Small-scale clean sugar and lignin production for Gevo fermentation and lignin co-product evaluation	30%
16	Small scale clean sugar to Gevo and lignin sample to co-product	100%
17	Small scale clean sugar to Gevo and lignin sample to co-product	0%
18	Gate Analysis and Review - Decision to proceed with Large Scale	0%
19	Task C-P-5.7. Large scale production of clean sugar	0%
20	Clean sugar sample delivered to Gevo	0%
21	Task C-P-5.8. Large scale production of residual lignin	0%
22	Lignin residuals production completion	0%
23	Task C-P-5.9. Large scale production optimization and engineering analysis	0%
24	Further optimize large scale clean sugar production	0%
25	Provide more samples to Gevo and co-product team	0%
26	Engineering assessment for pilot demonstration	0%



Exported on December 5, 2013 2:39:21 PM PST

Page 1 of 2

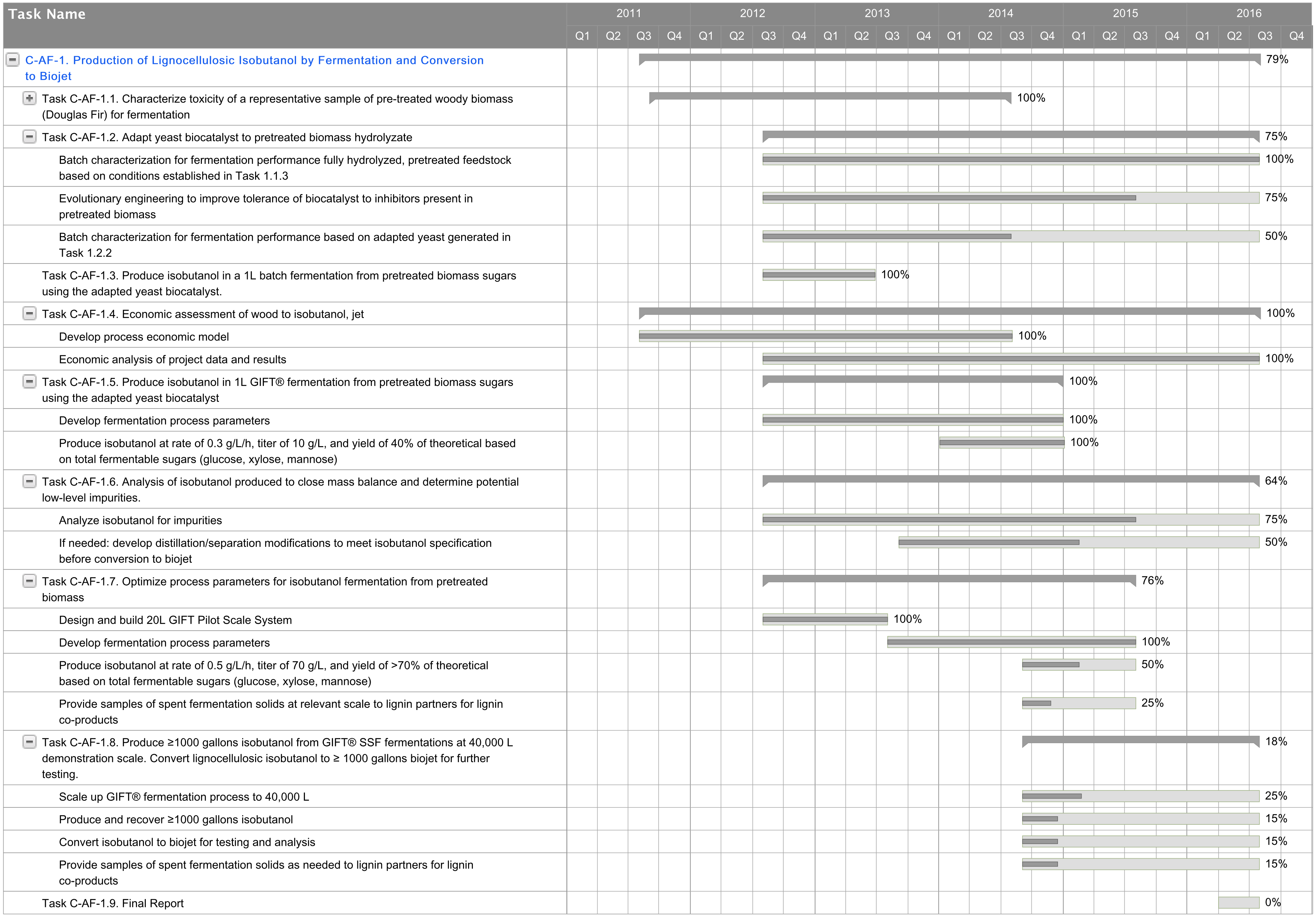


	Task Name	
27	Task C-P-5.10. Industrial pilot demonstration for clean sugar production worth of 1000 gallon jet fuel.	0%
28	Task C-P-5.11. Industrial pilot demonstration for residual lignin production from sugar production	0%
29	Task C-P-5.12. Techno-economics analysis and report	0%
30	Task C-P-5.12.1. Small Scale	
31	Techno-economics analysis report (initial)	0%
32	Techno-economics analysis report (mid)	0%
33	Task C-P-5.12.2 Large Scale	
34	Techno-economics analysis report (final)	0%
35	Techno-economics analysis report (updates w/ new information)	0%
36	Final Techno-economics analysis and report	0%

Exported on December 5, 2013 2:39:21 PM PST

Page 2 of 2

Conversion-AF_Gevo

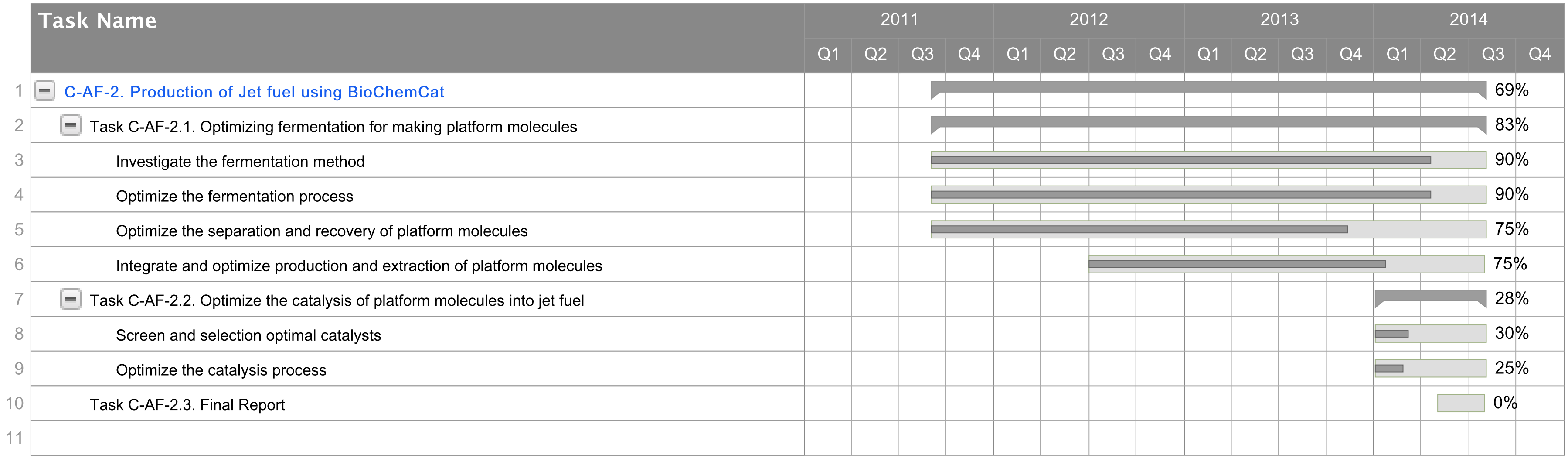


	Task Name	
1	C-AF-1. Production of Lignocellulosic Isobutanol by Fermentation and Conversion to Biojet	79%
2	Task C-AF-1.1. Characterize toxicity of a representative sample of pre-treated woody biomass (Douglas Fir) for fermentation	100%
6	Task C-AF-1.2. Adapt yeast biocatalyst to pretreated biomass hydrolyzate	75%
7	Batch characterization for fermentation performance fully hydrolyzed, pretreated feedstock based on conditions established in Task 1.1.3	100%
8	Evolutionary engineering to improve tolerance of biocatalyst to inhibitors present in pretreated biomass	75%
9	Batch characterization for fermentation performance based on adapted yeast generated in Task 1.2.2	50%
10	Task C-AF-1.3. Produce isobutanol in a 1L batch fermentation from pretreated biomass sugars using the adapted yeast biocatalyst.	100%
11	Task C-AF-1.4. Economic assessment of wood to isobutanol, jet	100%
12	Develop process economic model	100%
13	Economic analysis of project data and results	100%
14	Task C-AF-1.5. Produce isobutanol in 1L GIFT® fermentation from pretreated biomass sugars using the adapted yeast biocatalyst	100%
15	Develop fermentation process parameters	100%
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)	100%
17	Task C-AF-1.6. Analysis of isobutanol produced to close mass balance and determine potential low-level impurities.	64%
18	Analyze isobutanol for impurities	75%
19	If needed: develop distillation/separation modifications to meet isobutanol specification before conversion to biojet	50%
20	Task C-AF-1.7. Optimize process parameters for isobutanol fermentation from pretreated biomass	76%
21	Design and build 20L GIFT Pilot Scale System	100%
22	Develop fermentation process parameters	100%
23	Produce isobutanol at rate of 0.5 g/L/h, titer of 70 g/L, and yield of >70% of theoretical based on total fermentable sugars (glucose, xylose, mannose)	50%
24	Provide samples of spent fermentation solids at relevant scale to lignin partners for lignin co-products	25%
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.	18%
26	Scale up GIFT® fermentation process to 40,000 L	25%
27	Produce and recover ≥1000 gallons isobutanol	15%
28	Convert isobutanol to biojet for testing and analysis	15%
29	Provide samples of spent fermentation solids as needed to lignin partners for lignin co-products	15%
30	Task C-AF-1.9. Final Report	0%

Exported on April 24, 2015 12:31:09 PM PDT

Page 1 of 1

Conversion-AF_Ahring



	Task Name	
1	C-AF-2. Production of Jet fuel using BioChemCat	69%
2	Task C-AF-2.1. Optimizing fermentation for making platform molecules	83%
3	Investigate the fermentation method	90%
4	Optimize the fermentation process	90%
5	Optimize the separation and recovery of platform molecules	75%
6	Integrate and optimize production and extraction of platform molecules	75%
7	Task C-AF-2.2. Optimize the catalysis of platform molecules into jet fuel	28%
8	Screen and selection optimal catalysts	30%
9	Optimize the catalysis process	25%
10	Task C-AF-2.3. Final Report	0%
11		

Exported on November 13, 2014 9:11:15 AM PST

Page 1 of 1

NARA Goal Two

3RD Cumulative Report

April 2014 - March 2015

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. The most common strategy for dealing with these residual solids is to recover their fuel value to assist in heating and providing electrical power for facilities. While this strategy remains as a potentially valid one, NARA researchers are developing new products such as (1) activated carbon products, (2) cement additives, (3) thermosetting resins, and (4) thermoplastic polymers from the residual solids to provide a higher value than current use for energy. Creating high-value products from the residual solids produced in the pretreatment and hydrolysis production stages is essential to establish a value-chain for improved bio-refinery profitability. In addition, NARA is exploring methods to modify the lignin-rich material to produce platform molecules used to make an even broader array of valued products.

Freeze dried lignin residues from Douglas-fir after various mechanical and chemical pretreatments. NARA image

RESIDUAL SOLIDS AS MATERIAL FOR ACTIVATED CARBON AND SUPERCAPACITORS

In the previous NARA Year-3 reporting period, activated carbon (AC) materials were made from fermentation residual solids (FRS) derived from the mild bisulfite and wet oxidation pretreatment procedures and initially characterized for structure and their ability to absorb vapor phase mercury from coal power plant flue gas. In this reporting period, the activated carbon products were modified, by increasing the activation time, and again tested for vapor mercury absorption. The tests showed that the increase in activation time improved vapor mercury saturation, however, equilibrium capacity for both AC products was less that offered by commercially available AC products.

Experimental results suggest that the improved capacity of the commercial product is due to a greater proportion of large mesopores and macropores; consequently, further experimentation is underway to establish an AC production process that extends the pore size of the FRS AC. In addition, the lignin-rich residuals derived from modified pretreatment protocols like milled wood (MW; Task E-8) will be evaluated and could potential produce AC with superior absorption capacity (Task C-CP-2).

LIGNIN USE AS THERMOPLASTIC MATERIAL

In the previous NARA Year-3 reporting period, methylated ball-milled softwood lignin (MBML), was used to develop protocols that could be applied to lignosulfonates generated from Douglas-fir residues after sulfite-based pretreatment and enzymatic hydrolysis. Polymeric material exhibiting ~50% tensile strength and elongations at break around 8% were generated from the MBML material.

During this reporting period, improved protocols were applied to methylated lignosulfonate (MLS) from

Douglas-fir residues, and polymeric materials were produced for the first time that are comparable in strength to those formed from methylated softwood ball-milled lignin. The plastics formed from MLS verses MBML are different, however, at a molecular level. Research is in progress to estimate and reduce the cost of producing plastic material from MLS feedstock (Task C-CP-1).

PARTIALLY DEPOLYMERIZED LIGNIN AS A BUILDING BLOCK FOR CHEMICAL SYNTHESIS

The goal of producing partially depolymerized lignin (PDL) is to create building blocks used to engineer high value polymers. In the previous NARA Year-3 reporting period, the mild hydrogenolysis and BCD depolymerization protocols were applied to the lignin derived from forest residuals pretreated by the mild bisulfite (MBS) and wet oxidation (WOX) process. For this reporting period, partial hydrogenolysis protocols using MBS lignin were further developed, and a PDL-based epoxy was produced with yields of 86.6% at 70 °C and 100% at 117 °C. The molecular structure for the PDL-epoxy was evaluated.

The PDL-epoxy was cured and compared with a similarly cured commercially available epoxy. The PDL-epoxy exhibited a lower curing temperature and a higher activation energy compared to the commercial epoxy. The comparison results indicate that the PDL-epoxy possessed a similar thermal stability to the commercial epoxy. Additional curing agents are being investigated for use with the PDL-epoxy.

Additional depolymerization protocols to generate organosolv (OL) and oleated organosolv lignins were developed by mechanochemical reaction ball milling with the intent to produce PDL-lignin under milder conditions compared to the mild hydrogenolysis and BCD depolymerization protocols. The molecular structures for the resulting modified lignins were determined. The OLs were blended with polylactic acid (PLA) and exhibited good processability (Task C-CP-3).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR THE CO-PRODUCT DEVELOPMENT TEAMS

- An international patent application titled “Compositions Including Lignin” was filed March 13, 2015 (Task C-CP-1).

- For the first time, lignosulfonate-based plastics have been successfully produced from sulfite-based pretreated Douglas-fir residuals (Task C-CP-1).

- A partially depolymerized lignin-epoxy was produced that, when cured, shares similar properties to commercially available epoxies (Task C-CP-3).

- A peer-reviewed manuscript (Ma et al) was published titled “Catalytic Oxidation of Biorefinery Lignin to Value-added Chemicals to Support Sustainable Biofuel Production” doi: 10.1002/cssc.201402503 (Task CP-2).

- A peer-reviewed manuscript (Alvarez-Vasco et al) was published titled “Dilute acid pretreatment of Douglas fir forest residues: pretreatment yield, hemicellulose degradation, and enzymatic hydrolysability” doi: 10.1007/s12155-014-9496-7 (Task CP-2).

SIGNIFICANT OUTCOMES

- None reported

TRAINING

Name	Affiliation	Role	Contribution
Yi-ru Chen	Univ of Minnesota	Graduate Student	Lignin-based plastic formulations
Yun-Yan Wang	Univ of Minnesota	Graduate Student	NARA ligninsulfonate-based plastics formulations
Junna Xin	WSU, CMEC	Post-doc	Lignin depolymerization and epoxy asphalt
Xiaojie Guo	WSU, CMEC	PhD Student	Lignin modifications and blends
Mei Li	WSU, CMEC	Visiting PhD Student	Lignin modification and epoxies
Alvarez Vasco, C	WSU, BSEL	PhD Student	
Cassandra Sanders	WSU, BSEL	NARA SURE Undergraduate	
Ruoshui Ma	WSU, BSEL	PhD Student	

RESOURCE LEVERAGING

Resource Type	Resource Citation	Amount	Relationship or Importance to NARA
Scholarship			Funding for C. Alvarez Vasco
NARA SURE		$5,000	Cassandra Sanders

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

As a result of the work carried out during Years 1–3, promising formulations have been developed for converting softwood lignins into plastics with the highest attainable lignin contents. These unprecedented achievements have paved the way for converting NARA ligninsulfonates into useful polymeric materials. A positive outcome will enable productive communication with Borregaard to explore translation from laboratory practice to industrial applications. The emphases given to the various components of the tasks listed below will depend upon the outcomes from the inter-related studies that are carried out.

Context:
For the first time in 40 years, simple native softwood lignin derivatives (namely, methylated ball-milled lignins) have been converted into plastics without the need for additional blend components. The new biodegradable polymeric materials possess mechanical properties that are better than those of polystyrene. This represents the most important development in the history of lignin-based plastics.

Task 1.
(a) NARA ligninsulfonate derivatives will be created that alone, or in formulations with cheap commercially available blend components, can be transformed into polymeric materials with promising mechanical properties.
(b) Inchoate NARA ligninsulfonate-based plastics will be characterized using X-ray powder diffraction and atomic-force microscopy to establish trends that identify how new formulations may be efficiently optimized.
(c) The compatibility of ligninsulfonate-based plastics with flame-retardants will be determined.
(d) Conditions will be devised for converting ligninsulfonate-based plastics into foams with reasonable compressive strengths.
(e) The impact of molecular weight on the properties of ligninsulfonate-based plastics will be examined.

Task 2.
(a) The effects of incomplete derivatization on the properties of ligninsulfonate-based plastics will be explored.
(b) The effectiveness of additives that neutralize small quantities of acid liberated during casting of ligninsulfonate-based plastics will be investigated.
(c) Industrial conditions proposed by Borregaard to derivatize ligninsulfonates for incorporation into plastics formulations will be evaluated.
(d) Impact of polysaccharides (cellulose and hemicelluloses) on the mechanical properties of ligninsulfonate-based plastics will be determined.
(e) Efficacy of chemical foaming agents at different temperatures for producing ligninsulfonate-based plastic foams will be documented.
(f) In collaboration with Borregaard, production costs for the most promising ligninsulfonate-based plastics will be estimated.

Activities and Results

Methylated NARA ligninsulfonate-based polymeric materials have been reliably made. Technical proficiency in producing plastics from ligninsulfonates had necessitated extensive preliminary studies with ball-milled lignins. Hereby, the foundations created by the intrinsic lignin substructures can be differentiated from effects caused by the sulfonic acid groups.

Plastics composed exclusively of methylated ball-milled softwood lignins (MBMLs) can exhibit ~50 MPa tensile strengths with elongations-at-break around 8% (comparable to many commercial polymeric materials). Small quantities (5 – 10% w/w) of miscible low-Tg polymers or low-molecular-weight blend components can increase tensile strengths to 65 MPa or extend elongations-at-break to 15%. The constituent macromolecular species are associated complexes that are assembled from individual components as a result of strong noncovalent forces between lignin substructures. Interacting aromatic rings within the interiors are cofacially offset with respect to one another, while those in the peripheral domains of the complexes are often positioned in edge-on arrangements. X-ray powder diffraction reveals that continuity between complexes is established through their peripheral domains during casting of lignin-based plastics. Thus, a marked increase in the ratio of peripheral to interior aromatic rings in the complexes occurs as the MBML is cast to form a cohesive plastic (Figure C-CP-1.1).

In regard to the tensile behavior of the MBML-based polymeric materials, a roughly linear relationship between toughness and elongation-at-break holds (Figure C-CP-1.2) providing that the stress–strain curve does not embody undue plastic deformation.

The correlation between tensile strength and modulus is less exacting (Figure C-CP-1.3), but the relationship between toughness and tensile strength is very tenuous.

The first production trials for NARA ligninsulfonate-based plastics involved softwood ligninsulfonates (M_w and M_n estimated to be 23,000 and 12,900, respectively) derived from forest residues primarily composed of Douglas-fir (J.Y. Zhu et al., Bioresource Technology, 2015, 179, 390-397). After consecutive ultrafiltration through 200 kDa and 4 kDa nominal-molecular-weight-cutoff membranes, the phenolic hydroxyl groups of the retained ligninsulfonate were methylated with dimethyl sulfate in aqueous 50% dioxane at pH ~12. After acidification to pH 9, the dioxane was removed and the remaining aqueous solution was ultrafiltered with water through a 1 kDa membrane, whereupon the retentate was freeze-dried. The partially methylated ligninsulfonate was protonated using Amberlite IR120 in methanol before the sulfonic acid groups were methylated with diazomethane in chloroform.

Solution-casting of the methylated ligninsulfonate (MLS) in DMSO with small proportions of miscible blend components produces polymeric materials that are comparable in strength to those formed from methylated softwood ball-milled lignin. For example, MLS-based blends with 15% poly (trimethylene glutarate) exhibit the same tensile strengths and elongations-at-break as MBML-based blends with 30% poly(ethylene succinate). However, at a molecular level MLS-based plastics are fundamentally different from their MBML-based counterparts. X-ray powder diffraction studies demonstrate that the proportion of cofacially offset aromatic rings increases dramatically in materials composed entirely of MLS as they are cast (Figure C-CP-1.4). Such an effect is the reverse of what is observed when materials containing only MBML are cast (Figure C-CP-1.1). Estimates for the cost(s) of producing MLS-based materials are being evaluated at the time of writing.

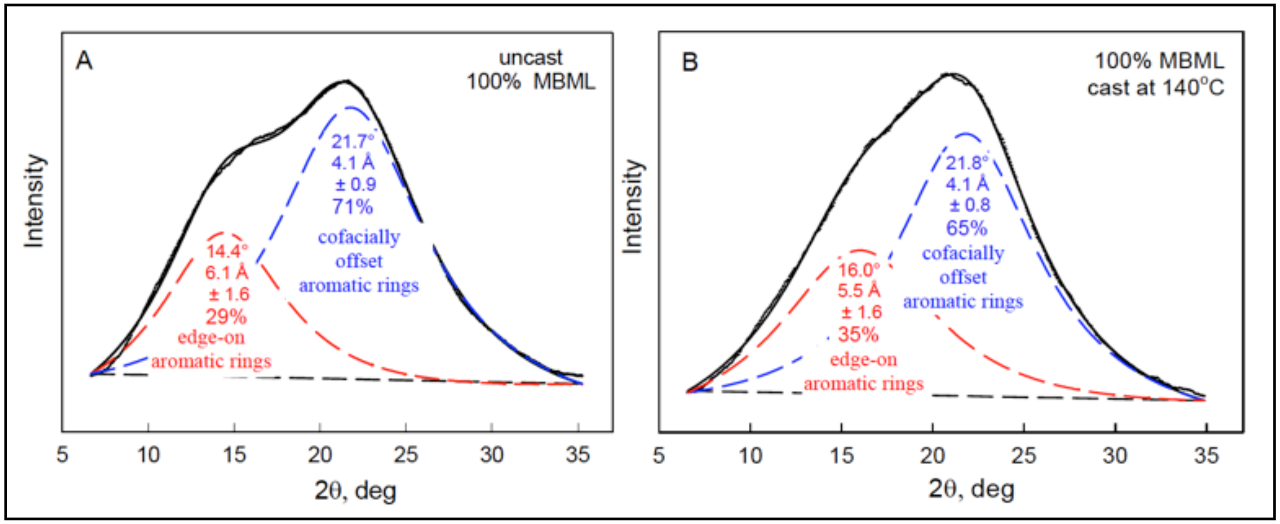


Figure C-CP-1.1. X-ray powder diffraction patterns of uncast and cast methylated ball-milled lignin-based materials can be described as sums of two Lorentzian functions I(x) = I(0)/(1 + x2/hwhm2), x = 2θ – 2θk, where I(x) is the scattered intensity at x from the Bragg angle 2θk for the peak, 2θ is the scattering angle, and hwhm is the half-width at the half-maximum of the peak. During casting, the proportion of aromatic rings in edge-on arrangements with respect to one another increases so as to establish continuity between neighboring methylated lignin complexes.

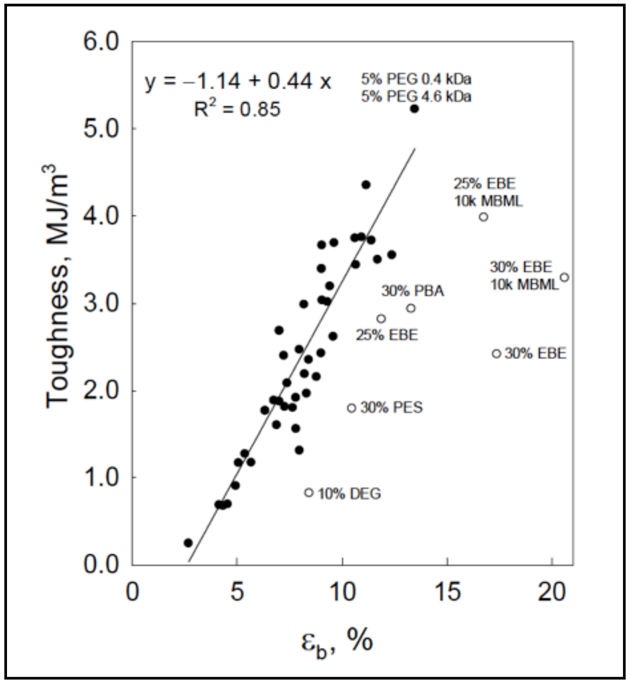


Figure C-CP-1.2. Correlation between toughness and elongation-at-break (εb) for polymeric materials with the highest attainable MBML contents. (Open circles denote data points that are not included in the linear regression analysis: they represent tensile behavior that embodies substantial plastic deformation.) Abbreviations: DEG, diethyl glutarate; EBE, poly(ethylene oxide-b-1,2-butadiene-b-ethylene oxide); PBA, poly(butylene adipate); PEG, poly(ethylene glycol); PES, poly(ethylene succinate).

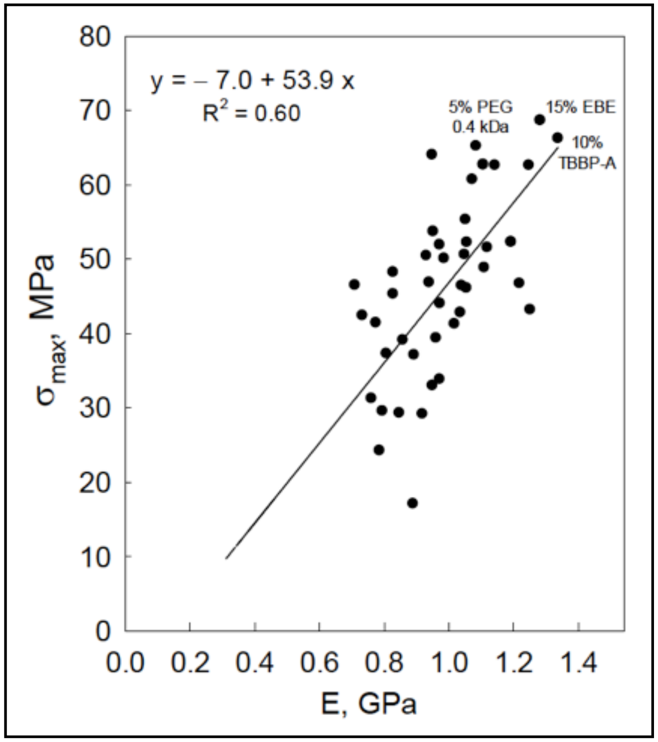


Figure C-CP-1.3. Correlation between tensile strength (σ_{max}) and modulus (E) for polymeric materials with the highest attainable MBML contents. Abbreviations: EBE, poly(ethylene oxide-b-1,2-butadiene-b-ethylene oxide); PEG, poly(ethylene glycol); TBBP-A, 3,3′,5,5′-tetrabromobisphenol A.

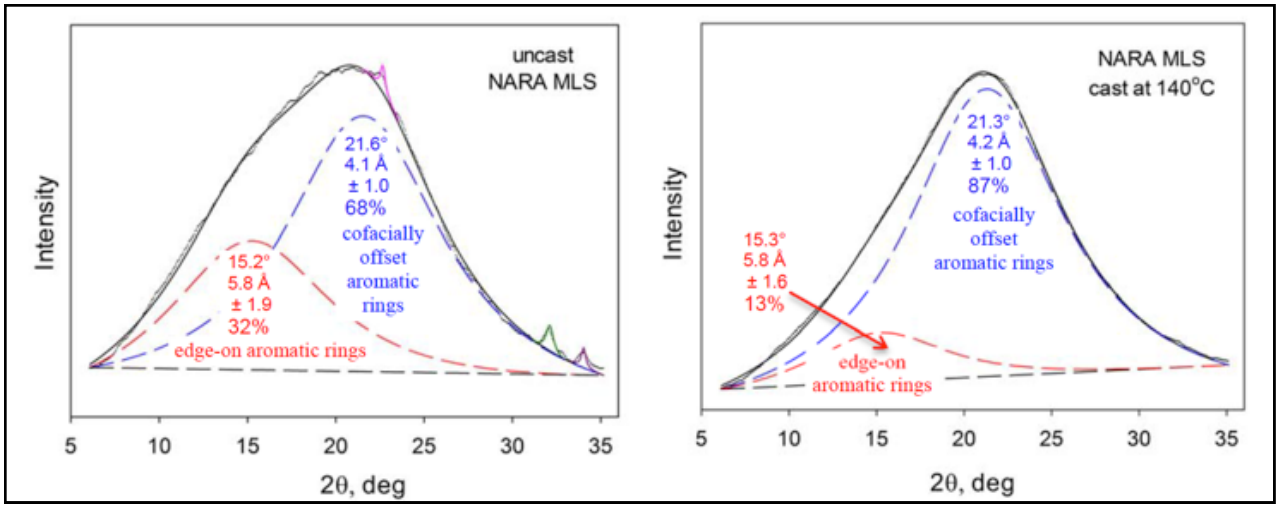


Figure C-CP-1.4. X-ray powder diffraction patterns of uncast and cast methylated ligninsulfonate-based materials can be described as sums of two Lorentzian functions I(x) = I(0)/(1 + x2/hwhm2), x = 2θ – 2θk, where I(x) is the scattered intensity at x from the Bragg angle 2θk for the peak, 2θ is the scattering angle, and hwhm is the half-width at the half-maximum of the peak. During casting, the proportion of aromatic rings in cofacially offset arrangements with respect to one another increases dramatically, as opposed to what is observed with 100% MBML-based materials.

Recommendations | Conclusions

For the first time, NARA ligninsulfonate-based plastics have been successfully produced as a result of methylating the phenolic hydroxyl groups and sulfonic acid residues in the starting material (supplied by Dr. J.Y. Zhu at the Forest Products Laboratory). Formulations with small proportions of miscible blend components have resulted in plastics that possess quite similar tensile properties to analogous blends based on methylated ball-milled softwood lignins.

Production costs are, of course, augmented by two consecutive methylation steps requiring different reagents. Therefore, at the time of writing, conditions are being developed through which derivatization is limited to a single methylation step that can be readily adapted to industrial practice. Preliminary results have confirmed that such a goal is well within reach. Accordingly, in future work, simple methylation conditions will be developed for producing methylated ligninsulfonate-based blend formulations that compare favorably in their mechanical properties with a range of commercial polymeric materials (Table C-CP-1.1). Accompanying techno-economic analyses will be used for guidance in recommending alternatives for this important segment of the overall NARA process.

Table C-CP-1.1. Tensile properties of selected engineering

Thermoplastic	Tensile strength (MPa)	Elongation at break (%)
Polystyrene	46	2.2
Styrene-acrylonitrile	72	3
Acrylonitrile-butadiene-styrene (ABS)	48	8
Flame-retardant ABS	40	5.1
Polypropylene	32	15
Polyethylene	30	9

*Davis, J.R., Tensile Testing 2nd ed., ASM International, Materials Park, OH, 2004

Physical and Intellectual Outputs

RESEARCH PRESENTATIONS

Oral Presentation entitled “Formulations for Coproduct Lignin-based Plastics” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at NARA Coproducts Team Meeting, Spokane, WA, July 10, 2014.

Oral Presentation entitled “Prospects for Lignin-based Plastics from Biorefineries” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at Lignin 2014 Conference, Umeå, Sweden, August 24–28, 2014.

Oral Presentation entitled “Lignin-based Plastics from Biorefineries” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at VTT Technical Research Centre of Finland, September 3, 2014.

Poster presentation entitled “Plastics Containing 85-100% Levels of Simple Lignin Derivatives” by Yun Yan Wang, Yi-ru Chen and Simo Sarkanen at 2014 NARA Annual Meeting, Seattle, WA, September 15–17, 2014.

Oral Presentation entitled “Highest Attainable Lignin Contents in Polymer Materials from Biorefineries” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at Lignobiotech III Symposium, Concepción, Chile, October 26–29, 2014.

Oral Presentation entitled “Formulations for Coproduct Lignin-based Plastics” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at NARA Coproducts Team Meeting, Pullman, WA, November 19, 2014.

Oral Presentation entitled “Formulations for Coproduct Lignin-based Plastics” by Simo Sarkanen, Yun-Yan Wang and Yi-ru Chen at NARA Coproducts Team Meeting, Pullman, WA, March 19, 2015.

Oral Presentation entitled “Macromolecular Characterization of Plastics with 85-100% Levels of Methylated Native Softwood Lignin” by Yun-Yan Wang, Yi-ru Chen, and Simo Sarkanen at the 249th American Chemical Society National Meeting, Denver, Colorado, March 22–26, 2015.

INTELLECTUAL PROPERTY

Compositions Including Lignin: Chen, Y.-r.; Sarkanen, S.; Wang, Y.-Y. 2015, International Patent Application No. PCT/US2015/020599, filed March 13.

TASK C-CP-2: CONVERSION OF LIGNIN TO HIGH VALUE, LARGE MARKET PRODUCTS

Key Personnel	Affiliation
Manuel Garcia-Perez	Washington State University

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. This process is being used to supply the carbohydrates for the fermentation to isobutanol for fuel production. A key component of the proposal 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.

We have focused our efforts on two target products to be produced from the lignin: moderate value activated carbon (AC) and high value AC for us in energy storage devices. It was found that with the new EPA requirements that coal-burning facilities must reduce their mercury emissions, the market for AC designed to clean up flue gas emission has grown rapidly. Our primary goal has become to develop an AC that will be effective in mercury capture from coal combustion flue gases. 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. The second is a new and emerging market, where there is a need for a sustainable, low-cost alternative to current materials. There are also numerous other known applications for AC materials. The key to designing AC materials for specific applications is to develop methodologies to prepare materials with precisely engineered pore structures and surface chemistry. We anticipate that thorough characterization of the properties of the AC materials prepared for the applications mentioned above will provide insight into other potential applications, such as the adsorption of metals, organic compounds, phosphates, and other environmental contaminants released into air and water. The research conducted on AC materials will therefore provide a platform for the development of a family of carbon products from lignin-rich biorefinery residues.

Another more traditional area that we are pursuing is the use of the lignin sulfonate produced by the mild bisulfite process as a viscosity modifier for wet cement.

Activities and Results

In previous work, two series of activated carbon (AC) materials were prepared from Ca^{2+} fermentation residual solids (FRS) derived from mild bisulfite (MBS) pretreated residuals (referred to herein as MBS FRS), and also from FRS from the wet oxidation (WOX) process. The AC materials were prepared at 700oC using physical activation with CO$_2$. The pore structures of these AC materials have been characterized in detail with gas physisorption and samples have been tested for elemental mercury (Hg0) capture from flue gas at the laboratory scale. The results of the last two rounds of testing conducted in April 2014 (Round 1) and November 2014 (Round 2) for Hg adsorption capacity are shown in Figures C-CP-2.1, C-CP-2.2 and C-CP-.3. The equilibrium vapor phase Hg0 adsorption capacities (herein referred to as the Hg0 adsorption capacity) are plotted vs. the activation time (which was previously shown to be correlated with the porous structure of the AC materials).

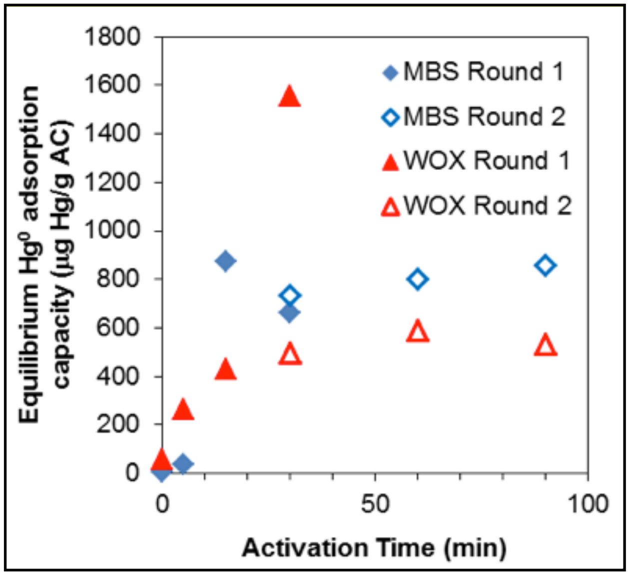


Figure C-CP-2.1. Equiibrium Hg^0 adsorption capacities measured in bench scale fixed bed test. Experiments were conducted at 300°F (149oC). Simulated coal flue gas composition was 1500 ppm SO$_2$, 400 ppm NO$_x$, 50 ppm HCl, 7% H2O, 12% CO$_2$, 6% O$_2$, and either 24 or 56 µg Hg^0/Nm^3 in Round 1 and 2, respectively. Gas flow rate was 1 L/min measured at 70°F.

The first round of testing showed that chars and AC with low degree of activation were ineffective for Hg0 capture under these flue gas conditions. The working hypothesis during preparation for Round 2 was that longer activation times would lead to better performance in Hg0 capture. The main results from analysis of the equilibrium capacity data from Round 2 were:
1) The MBS based AC had higher adsorption capacities compared to the WOX AC.
2) The rather high adsorption capacity of the WOX material activated for 30 minutes measured in Round 1 was not reproduced in Round 2.
3) Increasing activation time from 30 to 90 minutes only slightly increased the Hg0 capacity of the MBS AC.

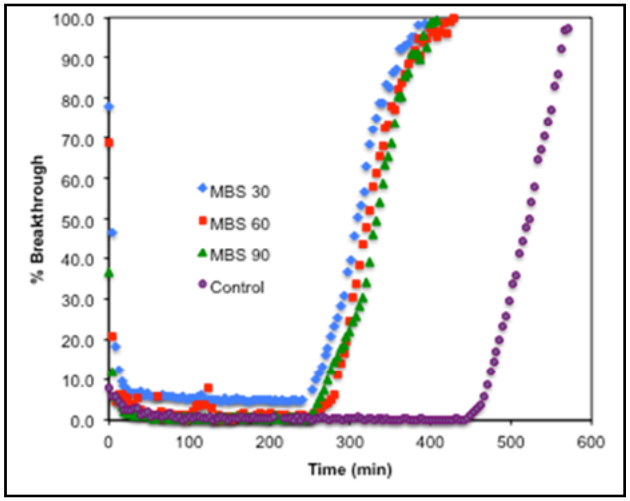


Figure C-CP-2.2. Breakthrough curves for MBS FRS AC prepared with activation times of 30, 60, and 90 minutes (denoted MBS 30, MBS 60, and MBS 90), respectively) showing the percentage of the inlet Hg concentration measured at the outlet.

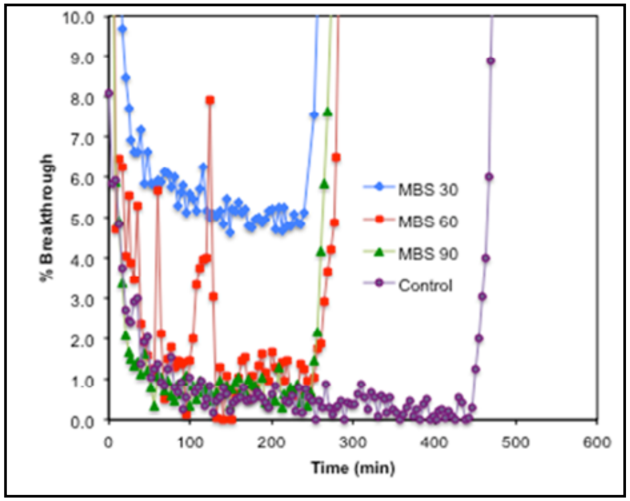


Figure C-CP-2.3. Zoomed in view of breakthrough curves in Fig. 1 for MBS FRS AC prepared with activation times of 30, 60, and 90 minutes showing the percentage of the inlet Hg concentration measured at the outlet.

The results also showed that all of the FRS-based AC had lower Hg0 capacities compared to the control materials, which had an average capacity of 1319 µg Hg/g AC (number of controls tested, n = 2).

Closer inspection of the raw adsorption data offered some additional information regarding the effectiveness of the AC materials in Hg0 capture. Breakthrough curves for the MBS AC materials prepared in Round 2, which show the concentration of Hg in the vapor phase at the outlet of the fixed bed as a percentage of the inlet Hg concentration, are shown in Figures C-CP-2.2 and C-CP-2.3, for MBS AC activated for 30, 60, and 90 minutes.

Recommendations | Conclusions

The transition of the AC work from Weyerhaeuser to Washington State University was a significant disruption to the progress of the AC project. The AC work has regained momentum, albeit with fewer personnel. The above results taken together with previous results suggest that it is possible to produce effective Hg0 adsorbents from FRS, but more work needs to be done to improve the performance in Hg0 capture. The data in Figure C-CP-2.1 shows that the equilibrium Hg0 adsorption capacities are consistently lower than the control material (an unidentified, commercially available, untreated powdered AC used for Hg capture). Figure C-CP-2.1 also suggests that increased activation time had relatively little effect on the equilibrium capacities. However, the breakthrough curves shown in Figure C-CP-2.2 and C-CP-2.3 show that the efficiency of Hg removal from the simulated flue gas was increased from around 95% to greater than 98% (here efficiency is defined as 1 - % breakthrough) when the activation time was increased from 30 to 90 minutes. The MBS 90 sample actually performed quite similarly to the control prior to saturation, but became saturated at an earlier time compared to the control, leading to its lower measured equilibrium capacity. These results suggest that the activation did create an appropriate pore size distribution (PSD) for efficient Hg removal from the simulated flue gas.

Comparing the results from MBS and WOX (data for WOX not shown), the mesopore volume and mesopore size appear to be critical for achieving high efficiency removal of Hg from the simulated coal combustion flue gas.

Comparison of the adsorption isotherms and corresponding PSD for a commercially available untreated AC used for mercury capture provides some additional insight to guide future work. N2 adsorption isotherms and corresponding PSDs for MBS FRS AC, wood powder AC, and Norit Darco Hg are shown in Figures C-CP-2.4 and C-CP-2.5.

Figures C-CP-2.4 and C-CP-2.5 show that MBS FRS AC is comparable to the commercial sorbent in terms of micropore volume and total nanopore volume, but the commercial AC used for Hg capture has a greater proportion of large mesopores and macropores, whereas the maximum pore size in the MBS FRS AC is around ~11-12 nm. The data gathered to date suggest that strictly microporous carbons, such as FRS carbons with low activation, chars, and the wood powder AC included in Figure C-CP-2.4 and C-CP-2.5 are not suitable for Hg capture from coal combustion flue gas. Assuming that the AC used in the bench scale Hg0 adsorption capacity test was similar to Darco-Hg, it appears that it would be beneficial to modify the AC production process to produce a greater amount of larger mesopores and possibly macroporosity. Based on the results shown, modifications to the AC production process will be investigated to increase the amount of larger pores for Hg capture. Furthermore, the relocation of the AC work started at Weyerhaeuser to WSU in September 2014 presents some opportunities to explore synergies between some ongoing research in the Biosystems Engineering (BSE) department, CMEC, and the ongoing AC research described above. A reproducible and simple physical activation method has been shown to generate interesting mesoporous carbon materials from FRS. Now that the porosity of the physically activated materials is well-characterized, there are opportunities to build on this technology platform and study the adsorption of other environmental pollutants such as heavy metals and organic compounds from the aqueous phase. Studies on adsorption of some known environmental pollutants will allow comparison with other types of materlals and will provide insight on the range of potential adsorption applications of the materials that have been made from the FRS.

Research aimed at understanding the effects of processing variables and different activation conditions on porous structure is also being extended to the application of AC in electrochemical capacitors. The goal of this research is to modify the processing steps to obtain AC with abundant narrow microporosity and some degree of mesoporosity, high electrical conductivity, and high purity. Washing of precursors and carbons is being investigated both to understand the effect of inorganic species on porosity development and to reduce the ash content to meet the higher purity specifications of electrode carbons. Exposing the carbons to different acids or bases during washing has the potential to also influence the surface chemistry of AC, and so the effect of washing on surface chemistry also needs to be investigated. This research is intertwined with the study of combining chemical activation with physical activation to generate a higher microporosity for electrosorption of ions coupled with sufficient meso- and macroporosity to facilitate rapid diffusion of ions at high charge/discharge rates. Chemical activation involves impregnation of the solid AC precursor material with acids, bases, or other salts prior to carbonization and requires a washing step to remove and potentially recover the activation agent after thermal treatment. In order to produce a material with lower cost, it is desirable to minimize the complexity of the activation and purification processes and energy consumption during thermal treatment.

Lastly, the applicability of the AC production process developed for the MBS FRS is being evaluated on newer batches of lignin recently delivered to WSU. The goal of this work is mainly to determine whether slight modifications to the pretreatment, hydrolysis, and fermentation processes affect the characteristics of the AC materials produced. More specifically, it has not yet been determined whether the choice of cation (Ca2+ vs. Mg2+) or the use of FRS vs. SRS (fermented vs. saccharified but not fermented solids) have significant effects on the yield, char reactivity, or porosity of the AC materials. These issues are the subject of current ongoing research.

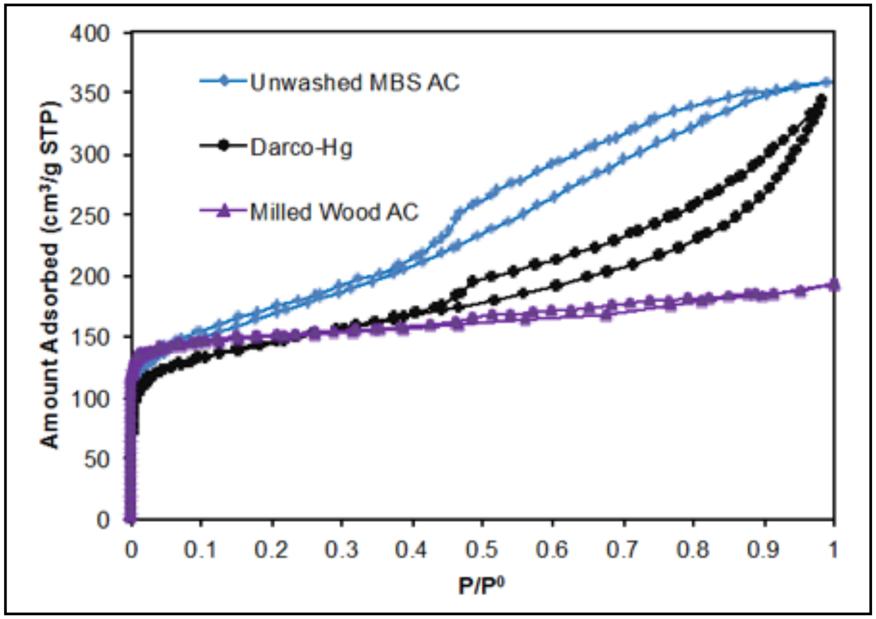


Figure C-CP-2.4. Nitrogen adsorption-desorption isotherms of AC materials measured at 77K.

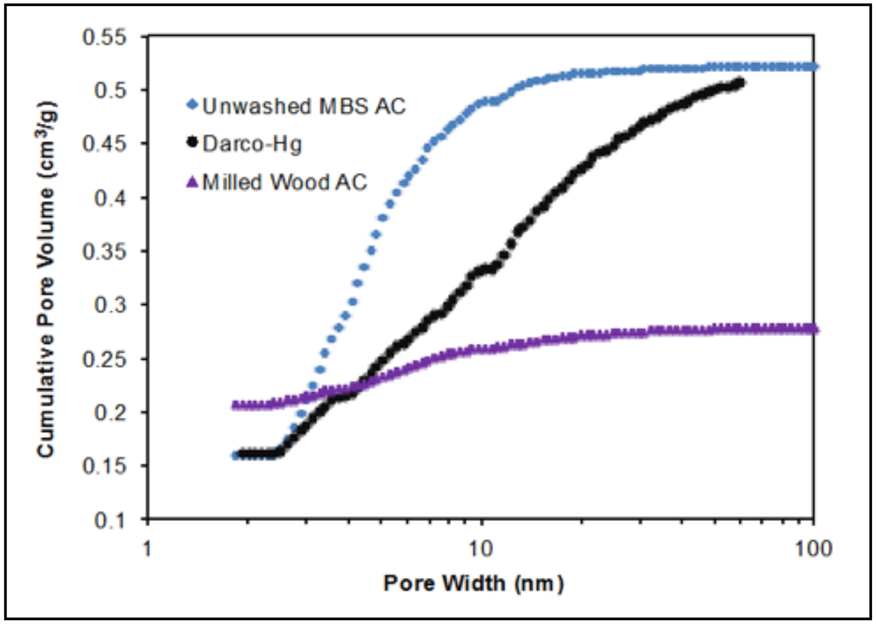


Figure C-CP-2.5. Cumulative pore size distributions of AC materials calculated from N2 adsorption isotherms by nonlocal density functional theory (NLDFT).

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, increasing 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 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 this 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 submitted recently for publication.

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

First, a though 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. 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) explore the application development using the lignin-derived polymers.

Activities and Results

Task C-CP-3.1, preparation of epoxies using lignomers, has been successfully accomplished as summarized in our last cumulative report. To date, approximately 80% of task 2 development of lignin-based epoxies using partially depolymerized lignin (PDL) has been completed in 4th year. At the same time we also explored depolymerization and modification of lignin in solid-state reaction for the past year. Task C-CP-3.3 was preliminarily investigated.

Task 2.1. Development of partially depolymerized lignin (PDL) epoxies

Partial hydrogenolysis of NARA lignin was studied under the catalysis of Raney Ni. Most of the experiments were conducted in a 100 mL pressure reactor. The NARA lignin samples were obtained from different pretreatment methods in different batches. In the 4th year, we focused on the CLE 62 (A) lignin and performed the partial hydrogenolysis in a 2 L pressure reactor. We investigated the hydrogenolysis of NARA lignin at two different reaction temperatures, 180 °C and 200 °C, respectively. As shown in Table C-CP-3.1, the catalyst Raney Ni could be reused for the second run and the yields of PDL obtained from the second runs only decreased a little. Compared to the yields obtained from the small pressure reactor (100 mL), the yield in the large rector at 180 °C or 200 °C decreased by ~9%, which is considered to be acceptable from the viewpoint of commercialization. On the other hand, the hydroxyl values of PDLs collected from the large reactor (2 L) at 180 °C or 200 °C were moderately higher than that of PDL collected from the 100 mL reactor. These results may suggest the process of partial hydrolysis of NARA lignin is scalable.

Use of PDL for preparation of PDL-epoxy resins was fully exploited. Because of its higher hydroxyl value, the PDL from hydrogenlolysis at 200 °C in the 2 L reactor was used for all the following reactions. The PDL-epoxy was prepared by traditional glycidylization by reacting PDL directly with epichlorohydrin (ECD) (Scheme C-CP-3.1). Initially, ECD was used as both reactant and solvent for the first step of reaction and the reaction temperature was conducted at 70 or 117 °C. However, PDL exhibited a poor solubility in ECD, and the resulting PDL-epoxies were hardly soluble in any solvents, not even in the mixture solvent (CDCl3/pyridine) for 31P NMR analysis. It was also difficult to determine its epoxy value by a titration procedure which involves hydrolysis with HCl in actone followed back titration using NaOH aqueous solution. The result may suggest the low reaction efficiency of glycidylation of PDL without a suitable solvent or partial self-polymerization of the lignin derivative. In order to improve the reaction efficiency of glycidylation, DMSO was used as the reaction solvent as shown in Scheme 1. As reported in the previous report, DMSO is a good solvent for PDL and its use may avoid the partial self-polymerization and improve the reaction efficiency. The yields of PDL-epoxy were 86.6% at 70 °C and 100% at 117 °C, suggesting high temperature is helpful for completing glycidylation reaction. The solubility of PDL-epoxies in organic solvents increased with the reaction temperature increasing from 70 to 117 °C. For the rest experiments, the PDL epoxy samples used are all prepared by this method with DMSO as a co-solvent.

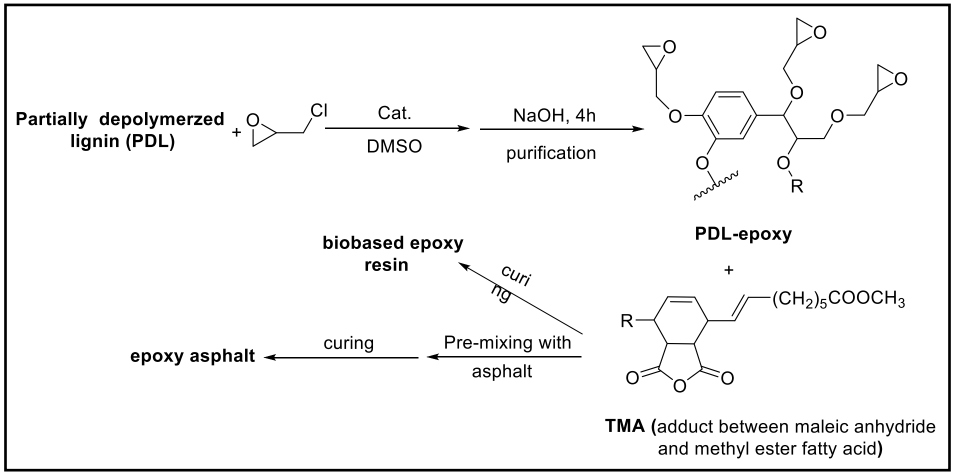
We also determined the hydroxyl value of PDL epoxies and PDL by 31P NMR as shown in Figure C-CP-3.1. The hydroxyl groups can be categorized in three groups, aliphatic, aromatic and carboxylic. The calculated hydroxyl values for three depolymerized lignin samples are summarized in Table C-CP-3.2. Compared to the original PDL (Figure C-CP-3.1), the signals for the aromatic hydroxyls of PDL-epoxies in the region of 136.6-144.7 ppm became very weak in PDL-epoxy-70 °C and almost disappeared in the spectrum of PDL-epoxy-117 °C. Further, the signal of the carboxylic acid hydroxyl in the range of 133.6-136.6 ppm completely disappeared in the spectra of both PDL-epoxy-70 °C and PDL-epoxy-117 °C. On the contrary, the intensity of aliphatic hydroxyl with chemical shift 145.5-150.0 ppm apparently became strong in the epoxy products. In Table C-CP-3.2, the hydroxyl value of aromatic OH decreased from 3.7 mmol/g in PDL to 1.7 mmol/g in PDL-epoxy-70 °C and to 0 mmol/g in PDL-epoxy-117 °C. That means the phenolic hydroxyl groups was fully reacted with reaction temperature increased from 70 to 117 °C. And the disappearance of carboxylic acid hydroxyls in both PDL-epoxies indicate that carboxylic acid OH was highly reactive even at the lower temperature of 70 °C. However, the aliphatic OH value increased greatly from 0.7 mmol/g of the original PDL to 2.4 mmol/g for the PDL-epoxy-70 °C and 2.7 mmol/g for PDL-117 °C. There were possible two reasons: one was when PDL reacted with ECH to produce PDL epoxy, some unreacted OH groups may react with the forming the epoxy ring grafted on PDL and the epoxy rings would be reopened to produce more aliphatic OH group. Another one was some of epoxy rings weren't formed in second closing step during preparation PDL-epoxy. Whatever, 31P NMR results proved that epoxy based on PDL was successfully synthesized by the conventional method using ECH.

Figure C-CP-3.2 shows the infrared spectra of the PDL and PDL-epoxies prepared at 70 and 117 °C, respectively. Figure C-CP-3.2 shows the FTIR of PDL and PDL-derived epoxies. All samples exhibited a broad band around 3460-3480 cm-1, which was attributed to the stretching of the phenolic and aliphatic hydroxyl groups. The bands around 2933 and 2832 cm-1, arising from the CH stretching in the aromatic methoxyl groups and the methyl and methylene groups of the side chains. The absorptions at 1700 cm–1, 1597 cm–1 and 1506 cm–1 were attributed to the carbonyl group and the aromatic skeletal vibration, respectively. The C-H deformations band of asymmetric methyl and methylene appeared at 1460~1470 cm–1. By comparing the spectra of PDL and PDL-epoxies, the apparent differences were seen at ~1700 cm–1 and the fingerprint region at ~908 cm–1. The absorption intensity of the carbonyl group at ~1700 cm–1 in the PDL-epoxies spectra shifted to a slightly higher wavenumber, which was due to the C=O groups in the newly formed glycidyl ester epoxy groups. Also, a new peak at 908 cm -1 in the spectra of PDL-epoxies appeared, which was attributed to the oxirane ring as noted. The FTIR results suggest that PDL was successfully converted to PDL-epoxies through direct glycidylation with ECH using DMSO as a co-solvent at 70 and 117 °C.

The resulting PDL-epoxies were cured by a tung oil fatty acid-derived anhydride, the adduct of methyl eleostearate and maleic anhydride (TMA) as shown in Scheme 1 C-CP-3.1. The curing procedure was as follows: epoxy and TMA were mixed in a weight ratio of 1:0.88. 2-ethyl-1-4-methylimidazole was used as the catalyst and added at 1.0 wt% on the basis of the total weight of curing agent and epoxy. The ingredients were mixed at 70 °C (preheated in an oven) and grounded to a homogeneous mixture. The mixture was transferred into an aluminum mold with dimensions of 30 mm×18 mm × 5 mm. The curing was performed at 150 °C for 2 h then at 200 °C for 1 h. The cured samples were carefully removed from the mold and used for the thermal analysis.
A commercial bisphenol A type epoxy DER332 was also selected to cure with TMA. The curing behavior and thermal properties of DER332/TMA and PDL-epoxy/TMA were compared. Figure C-CP-3.3 shows the DSC thermograms of the curing of the two epoxies at different heating rates and the plots of 1/(Tp) versus ln(ϕ). The DSC results are summarized in Table C-CP-3.2. The curing of each epoxy exhibited only one exothermic peak during the non-isothermal

Table C-CP-3.1. Results of hydrogenolysis of NARA lignin in a 2 L pressure reactor

Entry	Yield / %		Hydroxyl value / mmol/g		Note
1	66.7	75.3a	4.01	3.83a	180 oC
2	57.1	-	4.31	-	180 oC, Cat. reused
3	57.3	66.0a	5.07	4.38a	200 oC
4	53.3	-	5.52	-	200 oC, Cat. reused



Scheme C-CP-3.1. The synthesis route of PDL-epoxy

Table C-CP-3.2. Hydroxyl values of PDL and PDL-epoxies determined by 31P NMR

	Hydroxyl value mmol/g			Total / mmol/g
	Aliphatic	Aromatic	Carboxylic	
PDL-epoxy-117 °C	2.7	0	0	2.7
PDL-epoxy-70 °C	2.4	1.7	0	4.1
PDL	0.7	3.7	0.3	4.7

test. As the heating rate (ϕ) increased, the peak exothermic temperature (Tp) shifted to higher temperature, which was a typical methodological phenomenon for non-isothermal curing. By extrapolating the results to the point of a infinitely slow heating rate, the calculated curing temperature at zero heating rate was obtained and could be used as a reference in the selection of isothermal curing temperatures. Table C-CP-3.2 shows that the calculated Tp at the zero heating rate is 129.9 °C for PDL-epoxy-117°C/TMA and 134.4 °C for DER332/TMA. These results indicate that the curing temperatures of PDL-epoxy-117°C was lower than the conventional epoxy curing temperatures. On the other hand, the activation energy of curing (Ea) of PDL-epoxy-117°C/TMA was 87.7 KJ/mol which was notably higher than that of curing of DER332/TMA (68.3 KJ/mol). The higher Ea of the PDL-epoxy-117°C/TungMA was likely due to the solid form of PDL-epoxy-117°C which would result in low compatability to diffuse with TMA in the stage of curing.

Figure C-CP-3.4 shows the curves of storage modulus (E′) and damping (tan δ) as functions of temperature for PDL-epoxy and DER332 epoxy resins cured with TMA. The glass transition temperatures (Tgs) of the cured samples were determined from the peak temperatures of the tan δ. The Ve of the cured epoxy resin can be estimated using the following equation based the theory of rubber elasticity:

$$v_e = \frac{E}{3RT} \qquad (1)$$

where E is the elastic modulus of the thermoset in the rubbery state, R is the gas constant and T is the absolute temperature. Since measuring the elastic modulus of thermoset in rubbery state is a very tedious experiment, it is a convenient custom to use E′ in the rubbery state, e.g., at Tg + 50 °C, to substitute E in the calculation. The cured PDL-epoxy resins had higher E′ at room temperature than that of the cured DER332 resin. This was probably because PDL-epoxy had more bulky structures than DER332, therefore resulted in more rigid resins at room temperature. In Table C-CP-3.3, it is noted that the Tg and crosslinking density of PDL-epoxy resins were higher than that of the DER332 resin. It is understood that higher crosslink density and more rigid chain segment lead to a higher Tg.

Figure C-CP-3.5 shows the TGA results of the cured resins, and Table C-CP-3.2 summarizes the char yield at 585 °C and temperatures at which 5% weight loss (T5%) and 10% weight loss (T10%) were incurred. PDL-epoxy-117 °C/TMA had higher T5% and T10% values than that of DER332/TMA. On the other hand, the char yield of PDL-epoxy-117 °C/TMA at 585 °C was obviously higher than DER332/TMA because of the presence of more rigid molecular structure in lignin. These results indicated that the thermal stability of PDL-epoxy resin was almost as good as that of epoxy resins based on bisphenol A.

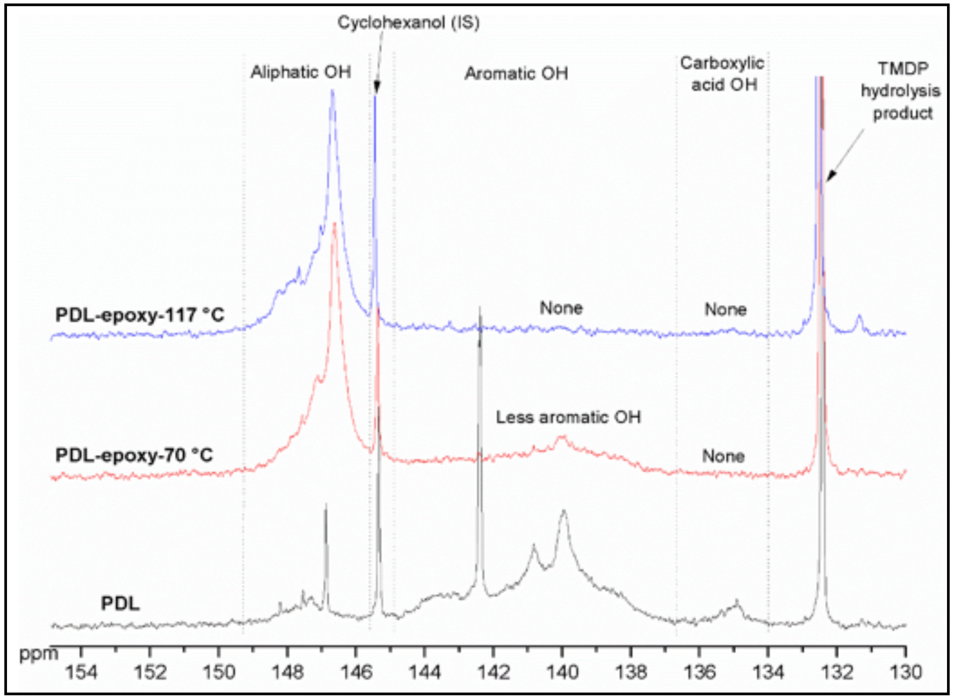


Figure C-CP-3.1. ^{31}P NMR spectra of before and after epoxidation of PDL-epoxy at different temperatures.

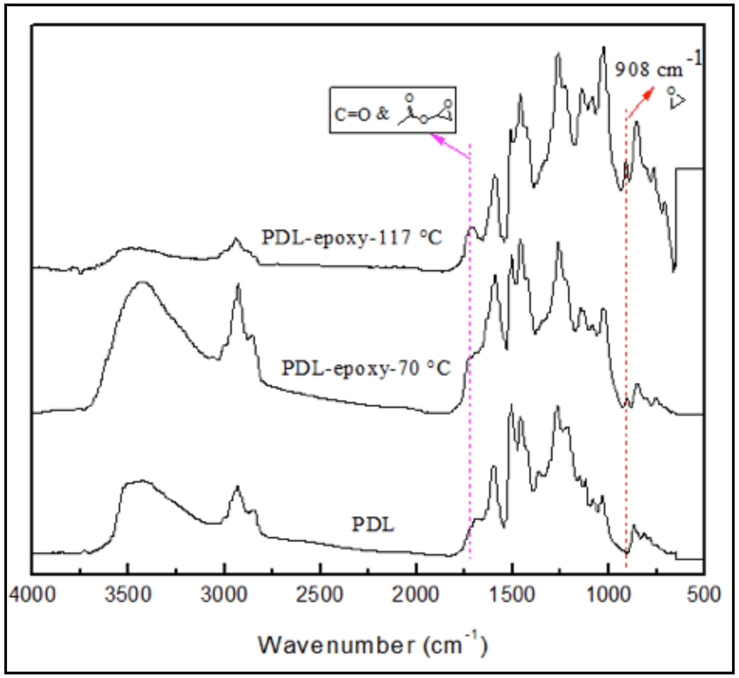


Figure C-CP-3.2. The FTIR spectra of PDL PDL-epoxy-70 °C and PDL-epoxy-117 °C.

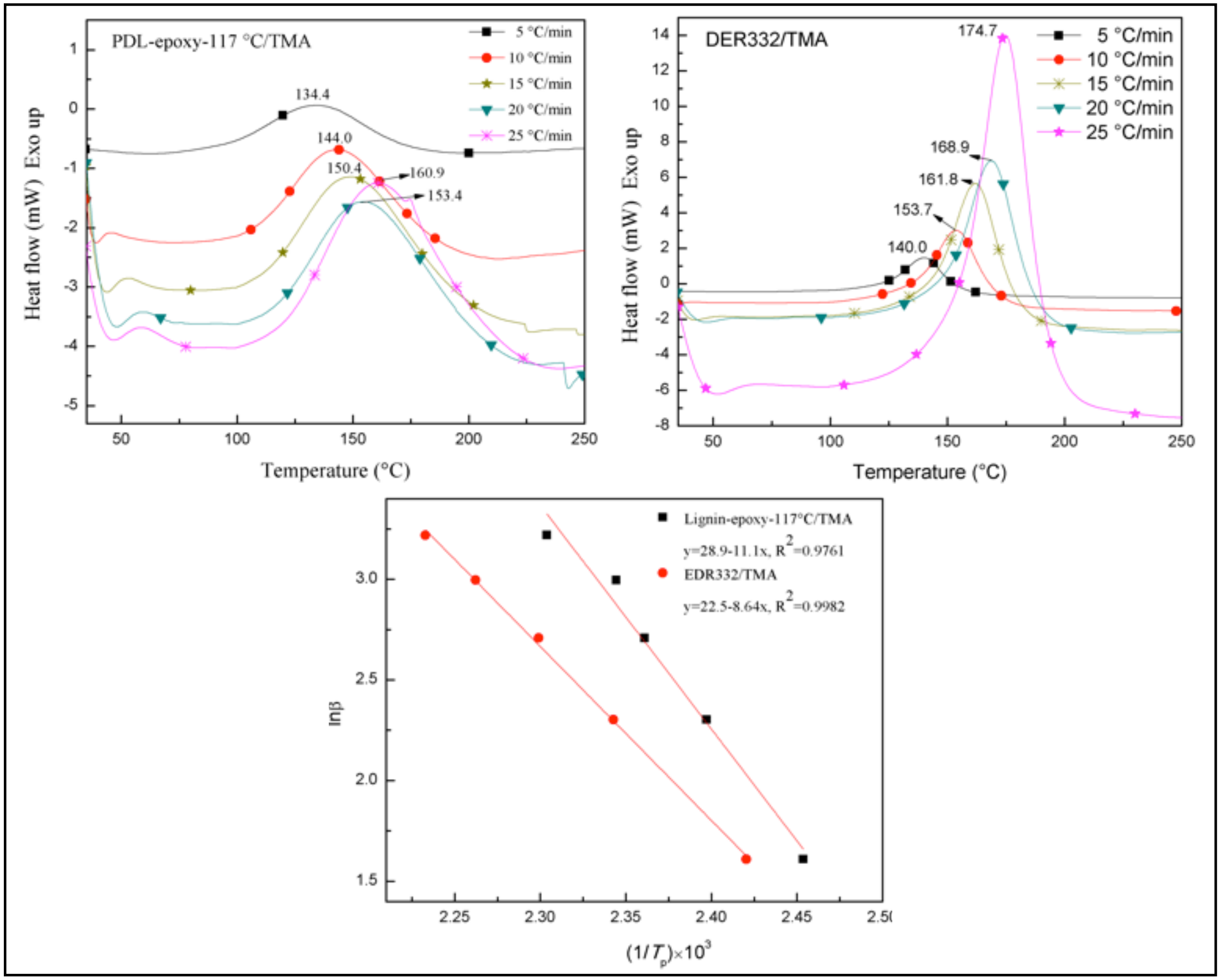


Figure C-CP-3.3. The representative DSC thermograms of non-isothermal curing of the epoxies at different heating rates and the plots of 1/(Tp) versus ln(ϕ)

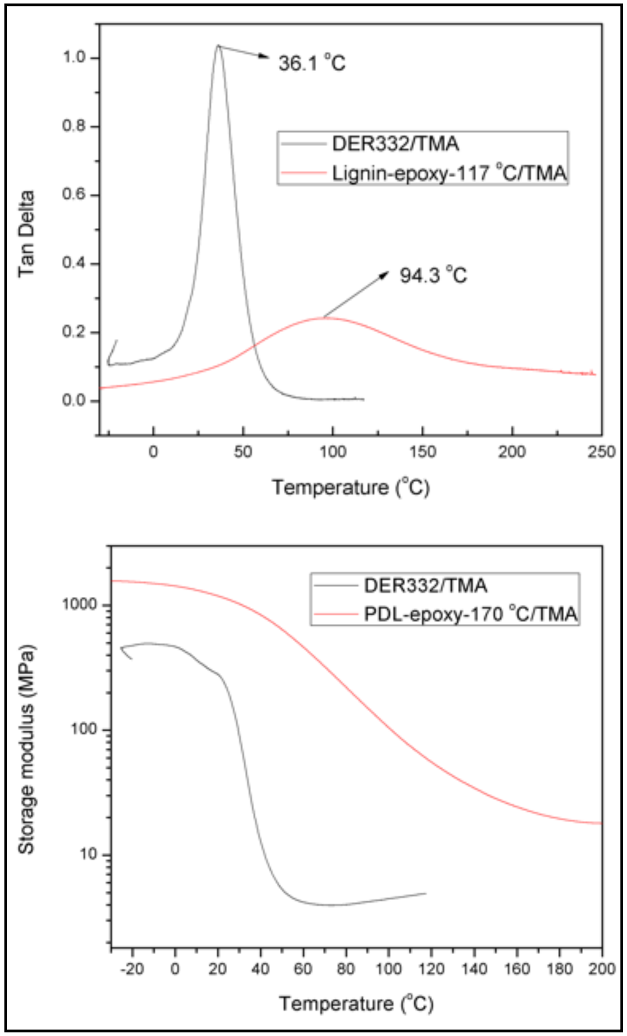


Figure C-CP-3.4. Storage modulus and tan δ versus temperature for DER332 and PDL-epoxy-170 ºC cured with TMA.

Table C-CP-3.3. DSC results of non-isothermal curing and thermal properties of cured epoxies

Epoxy	Tp(°C)a	Ea (KJ/mol)	Tg(°C)[a]	ve (x103 mol/mm3)	T5%(°C)[b]	T10%(°C)[b]	Char yield at 585 °C
PDL-epoxy-117 °C/TungMA	129.9	87.7	94.3	3.02	272.3	311.1	34.7 %
DER332[c]/TungMA	134.4	68.3	36.1	0.46	219.8	289.9	6.43 %

a) Linear extrapolation at =0, b) T5% and T10%: temperature of 5% degradation and 10% degradation, c) DER332 epoxy resin (epoxy equivalent weigh (EEW) = 175 g/mol, Dow Chemical Company)

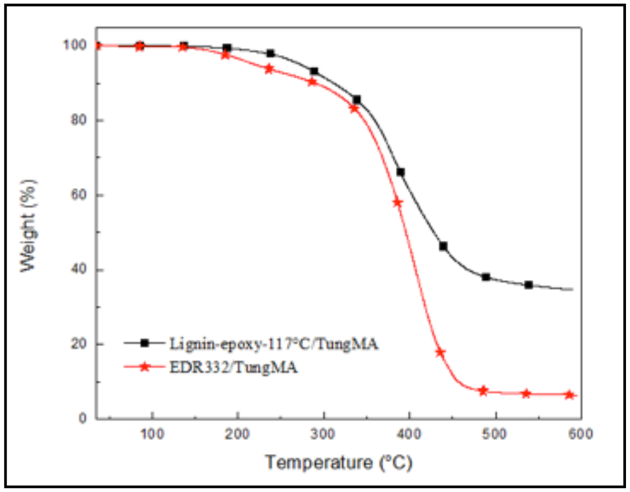
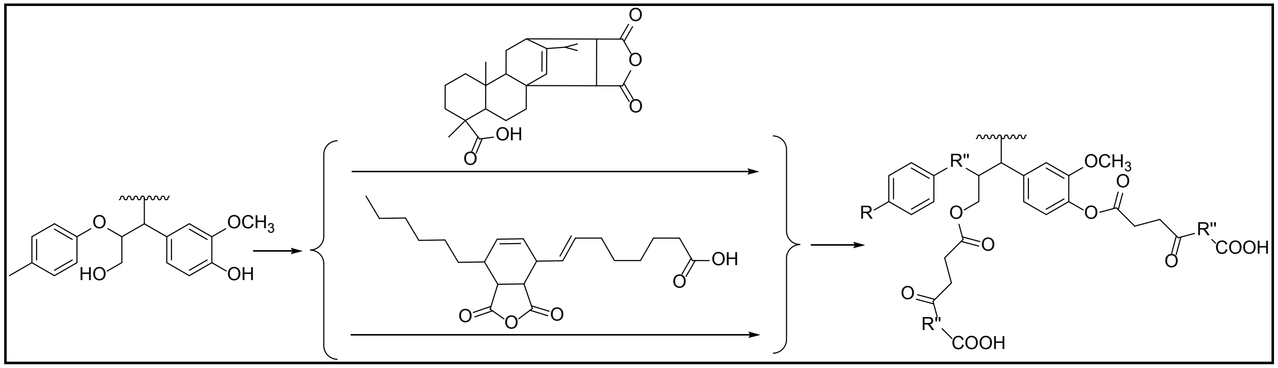


Figure C-CP-3.5. TGA plots of the cured epoxy resin under nitrogen atmosphere.

Task 2.2. Development of partially depolymerized lignin (PDL)-derived curing agents

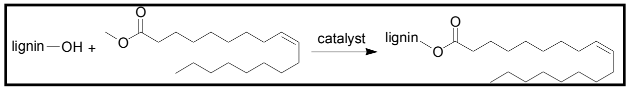
At the same time, two biobased anhydride, maleated rosin and maleated tung acid, were chosen to modify PDL for PDL-based curing agents. As shown in Scheme C-CP-3.2, the resulting PDL curing agents contains two carboxylic acid. The preparation procedure was as follows: PDL, maleated rosin or maleated tung acid, Cat. dimethyl benzylamine and acetone were added into the flask at room temperature. Then the temperature was raised to 70 oC and the reaction was continuously stirred for 18 h. After reaction, acetone was removed by rotatory evaporation. The residue was washed by ethyl ether, acetone and water. The product PDL-MLHSS was obtained from freeze-drying. Yield was calculated by 87.5% (PDL-MLHSS), 81.7% (PDL-MTA) based on PDL, repectively. The characterization and application of these curing agents was in progress.



Scheme C-CP-3.2. The synthesis route of PDL curing agent.

Task 2.3. Explore depolymerization and modification of lignin in solid state reaction

Partial depolymerizations of lignin via both hydrogenolysis and base catalyzed depolymerization (BCD) have proved to be effective in terms of molecular weight reduction, increased hydroxyl value and solubility in organic solvents. However, both processes still require elevated pressure and temperature, though the reaction conditions are moderate compared to conventional hydrogenolysis and BCD. Therefore, we are exploring methods for modification of lignin in a solvent-free and room temperature environment. To this end, reaction under the ball milling condition is a right choice. First, transesterification between lignin and fatty acid ester was studied to introduce fatty acid ester chains onto lignin. Methyl oleate was initially used as the alkylating agent because the characteristic carbon-carbon double bonds are ready identified in the modified products. The oleated lignin was prepared through transesterification using organosolv lignin (OL) reacted with methyl oleate as shown in scheme C-CP-3.3. In Figure C-CP-3.6, two olefinic protons at ~5.3 ppm and three methylic protons at ~3.7 ppm were observed for methyl oleate. After modification and purification, the three methylic protons at ~3.7 ppm disappeared for oleated OL since the unreacted methyl oleated residue were completely removed after purification process. Compared to the spectrum of OL, the new peak at ~5.3 ppm was observed in the spectrum of oleated OL and was attributed to two olefinic protons originated from methyl oleate. This result shows that the fatty acid chains were introduced into the structure of lignin through mechanically activated transesterification between organosolv lignin and methyl oleate in ball mill.



Scheme C-CP-3.3. Transesterification between OL and methyl oleate.

The hydroxyl values of organosolv lignin and oleated OLs were determined by 31P NMR as shown in Figure C-CP-3.7. The calculated hydroxyl values for OL and oleated OLs samples are summarized in Table C-CP-3.4. Compared to OL (Figure C-CP-3.7), the signal intensity of the aliphatic hydroxyls of oleated OLs in the region of 146-150 ppm significantly decreased and became very weak. On the contrary, the intensity of aromatic and carboxylic hydroxyls with chemical shifts at 133.6-136.6 ppm and 136.6-144.7 ppm remained almost unchanged. As shown in Table C-CP-3.1, the hydroxyl value of the aliphatic OH decreased from 2.57 mmol/g in OL to 0.64 mmol/g in oleated OL#2. Meanwhile, the hydroxyl value of aromatic OH was relatively the same for OL and OL#2 (2.60 and 2.22 ppm). This result means the transesterification mainly took place between the aliphatic hydroxyl groups of lignin and the ester bonds of methyl oleate during ball milling process rather than between the phenolic hydroxyl groups of lignin and the ester bonds of methyl oleate. Compared to that of OL, the total hydroxyl value of oleat-

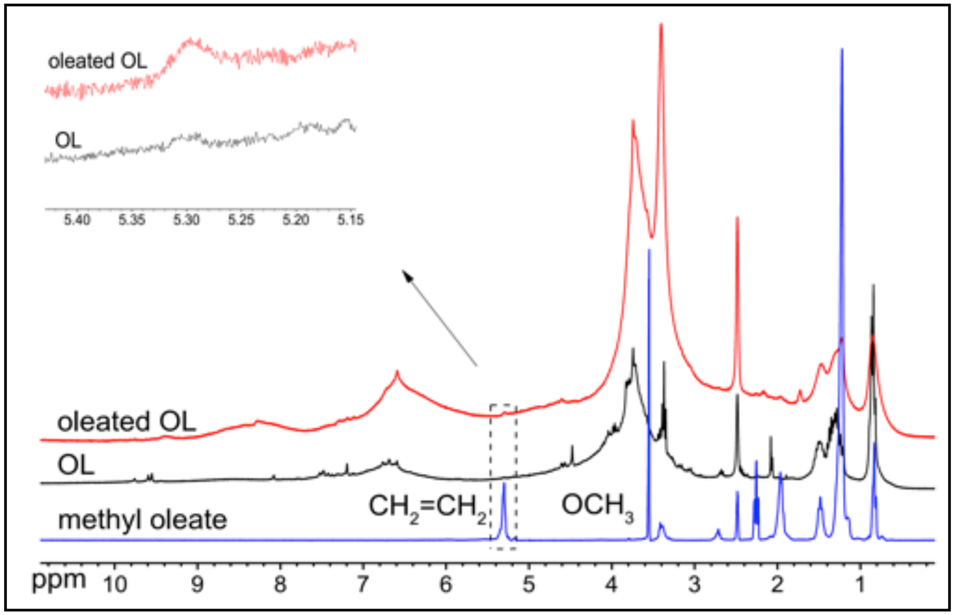


Figure C-CP-3.6. ^{1}H NMR spectra of methyl oleate, organosolv lignin and oleated OL.

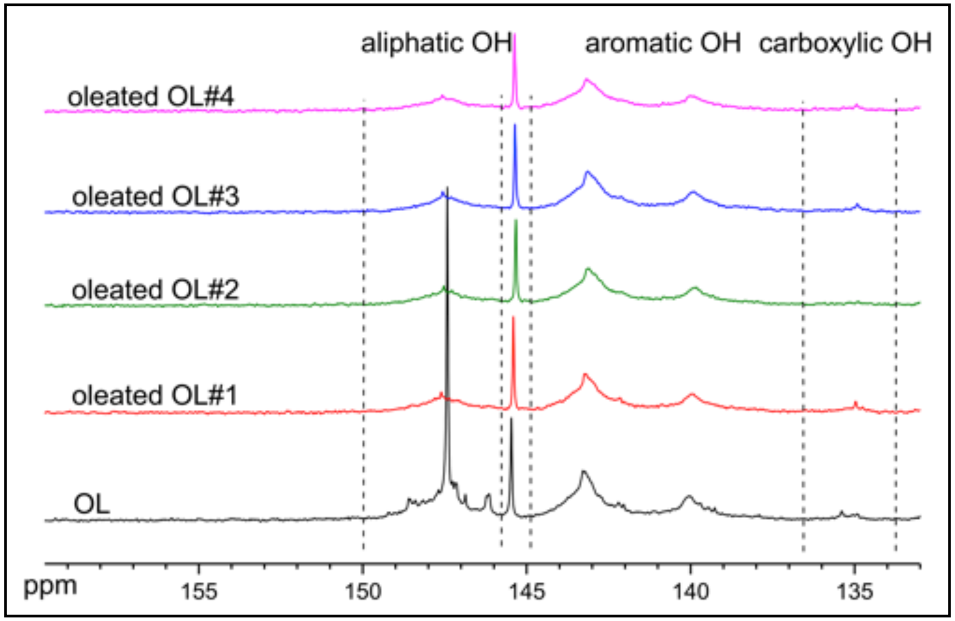


Figure C-CP-3.7. ^{31}P NMR spectra of organosolv lignin and oleated OLs at various compositions.

ed OLs significantly reduced from 5.17 mmol/g to ~2.9 mmol/g. Additionally, the oleated OL#2 (nOL-OH:nMO = 1:0.6) has the lowest hydroxyl value, indicated that this composition might have the optimal reaction conversion and efficiency. The reaction conversion of the transesterification between methyl oleate and organosolv lignin was around 25% at various compositions.

The conversion was calculated through the following equation:

$$x = \frac{(a-b)\times 10^5}{a\times b\times 264+1000\times a}$$

where, x: reaction conversion; a: hydroxyl value of starting lignin (OL), mmol/g; b: hydroxyl value of modified lignin (oleated OL).

Table C-CP-3.4. Hydroxyl value, conversion and particle size of OL and oleated OLs.

Sample	$n_{OL\text{-}OH}$:n_{MO}	Hydroxyl value (mmol/g)			Conversion %
		Aliphatic	Aromatic	Total	
OL	/	2.57	2.60	5.17	/
oleated OL#1	1:0.5	0.70	2.19	2.89	25.02
oleated OL#2	1:0.6	0.64	2.22	2.86	25.46
oleated OL#3	1:0.7	0.59	2.34	2.93	24.43
oleated OL#4	1:0.8	0.72	2.33	3.05	22.72

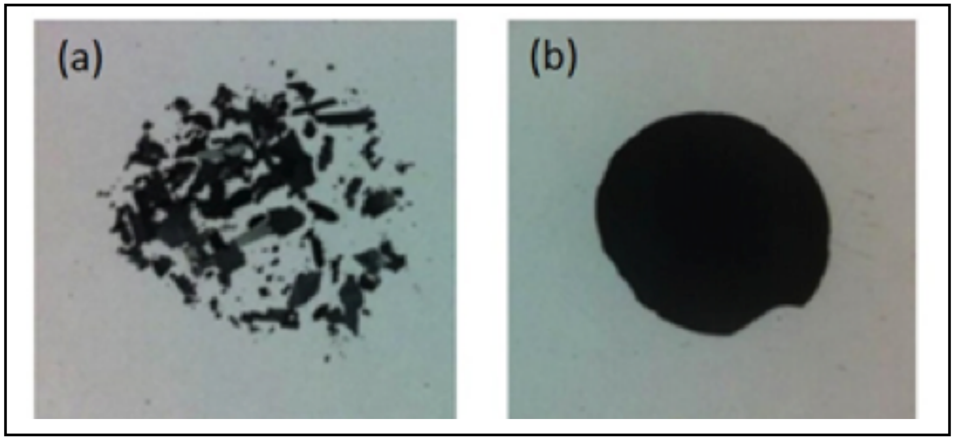


Figure C-CP-3.8. Photographs of (a) untreated OL and (b) oleated OL#2 after hot-pressing at 180 °C.

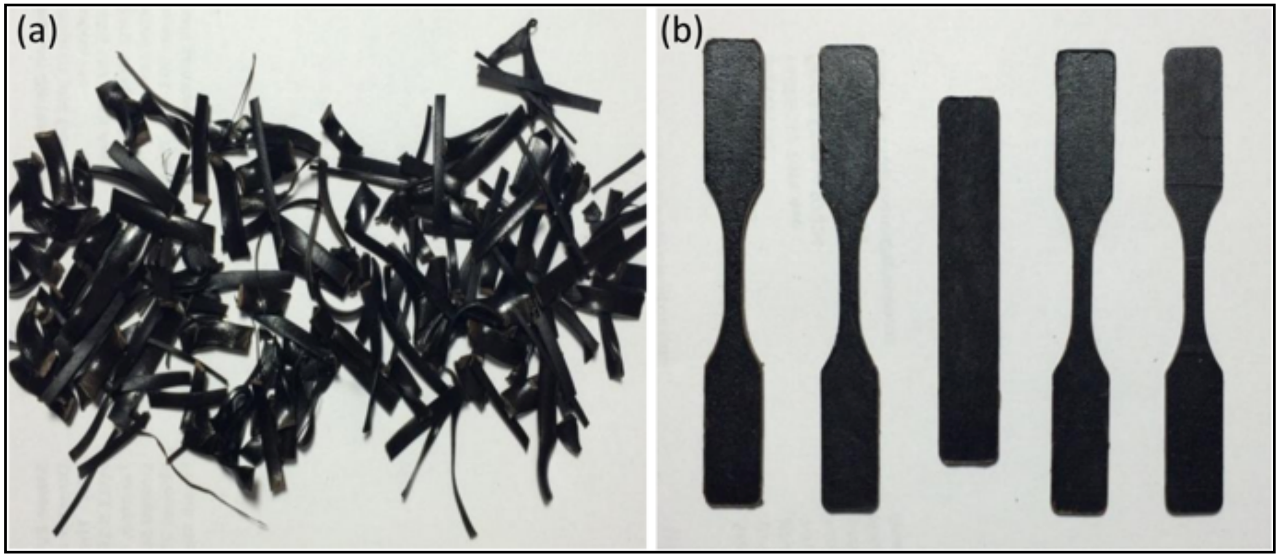


Figure C-CP-3.9. PLA/oleated OL blends: (a) samples through melt extrusion; (b) sample bars from melt molding.

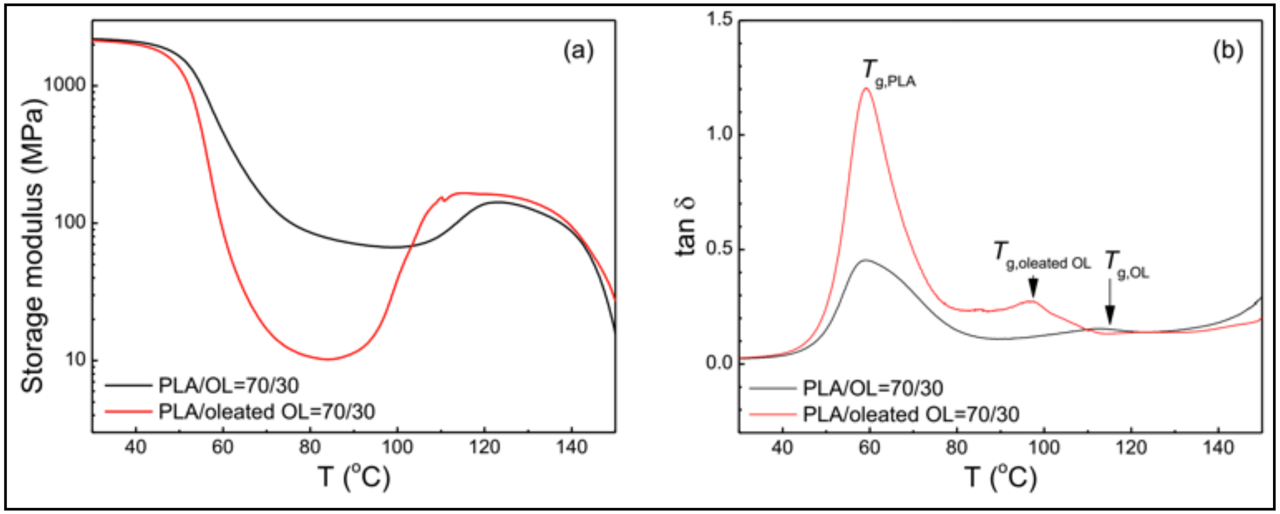


Figure C-CP-3.10. DMA curves of (a) storage modulus and (b) tan δ of the PLA/OL blends with and without mechanochemical modification.

As shown in Figure C-CP-3.8, the oleated OL#2 formed into thin and smooth film after hot pressing at 180 °C while the untreated OL shattered into pieces. The untreated OL showed lack of thermoplasticity when cooled from the melt, while the oleated OL became pliable at 180 °C and reformed into film upon as thermoplastics. Therefore, the thermoplasticity of OL was improved through the mechanically activated transesterification using methyl oleate reacted with OL.

In Figure C-CP-3.9, the PLA/oleated OL blends were successfully prepared through melt extrusion at 180 °C (Figure C-CP-3.9 (a)), the standard tensile and impact specimens were prepared through melt molding (Figure C-CP-3.9 (b)). During melt extrusion, PLA pellets and oleated OL were completely and homogenously mixed at 180 °C, and then the extrudate was cooled under room temperature. The extruding process is fluent and continuous. Moreover, the process of the melt molding is quite smooth as well. Therefore, the PLA/oleated OL blends exhibited pretty good melt processibility.

Figure C-CP-3.10 shows storage moduli (E') and tan δ of the PLA/OL blends. With increasing temperature, both blends experienced rapid drop in E' in the glass transition region (~60 °C) of PLA phase. The PLA/oleated OL blends exhibits lower E' than the PLA/OL blend in rubbery state, one possible reason is the introduction of long fatty chains of methyl oleate onto OL which improved the molecular mobility of the blends. As temperature further increased, E' started to increase at ~100 °C for the blends, this recovery of E' is believed to result from the cold crystallization of PLA. Due to the enhanced molecular mobility of plasticized PLA, an early cold crystallization was noted for PLA/oleated OL blend. In Figure C-CP-3.10b, two distinct peaks at 60 and 105 °C corresponded to Tgs of PLA and lignin phases. Compared with PLA/OL blends, Tg of PLA phase in oleated blends exhibited a slight increase, while Tg of OL phase greatly decreased. The shift of Tgs suggests the compatibility of PLA and OL was improved for the PLA/oleated OL blends. Therefore, the mechanically activated transesterification between OL and methyl oleate OL resulted in the increased compatibility between PLA and OL. The height of tan δ, also known as damping, represents the ability of accomplishing energy absorption and diepersal. The PLA/oleated OL blends exhibited higher damping value when compared with the PLA/OL blends in the temperature region from 40 to 110 °C. One reason for the increased damping value of the PLA/oleated OL blends is that the introduction of long fatty acid chains onto OL increased the mobility among molecular chains, which resulted in the improved flexibility and led to the higher damping value. Another possible reason is the introduction of fatty acid chain acted as a soft portion, which decreased the rigidity and increased the elasticity of the PLA/oleated OL blends. Therefore, the PLA/oleated OL blends had better damping properties than the PLA/OL blends.

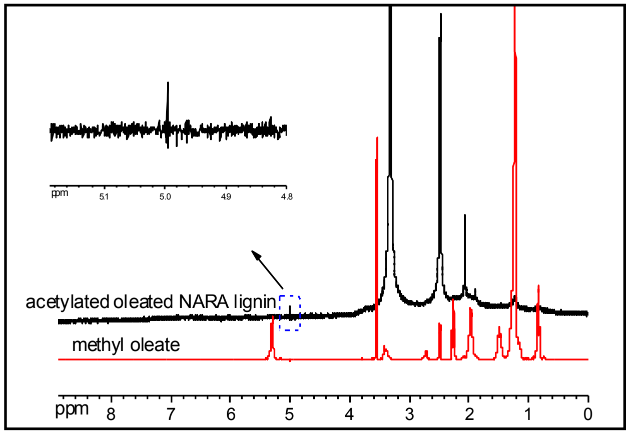


Figure C-CP-3.11. ^{1}H-NMR spectra of oleated NARA lignin and methyl oleate.

After the preliminary exploration of using organosolv lignin (which has a better solubility), NARA lignin was used to react with methyl oleate through ball milling. In order to increase the solubility of oleated NARA lignin in DMS-d6, the samples was first acetylated then purified to remove unreacted methyl oleate. The acetylated oleated NARA lignin was used for 1H-NMR analysis as shown in Figure C-CP-3.11. The three methylic protons from methyl oleate at ~3.7 ppm disappeared for the oleated NARA lignin since the residue methyl oleated were completely removed after purification, while the two olefinic protons (C=C) at ~5.3 ppm appeared and a little shifted to ~5 ppm for the oleated NARA lignin. Therefore, the transesterification between NARA lignin and methyl oleate was initially proved to occur during ball milling process.

Task C-CP-3.3. Application Development for PDL-Based Epoxy Asphalt

The asphalt was successfully modified by adding different amount of PDL-based epoxy/TMA mixture. As summarized from above discussion, the epoxy resin derived from PDL-epoxy/TMA show comparable properties comparing to commercial one. Because of the bulk structure in lignin, that will result in high Tg and good mechanical and thermal performance of the final epoxy resin. So the addition of PDL based epoxy resin into the asphalt was supposed to improve the temperature resistance and whole performance grade of the asphalt.

The preparation process of epoxy asphalt was as follows: Asphalt was heated to 90 ±5 °C in an oven for 30 min. The liquid mixture of PDL-epoxy/TMA (no curing) was added into the asphalt in a mortar and blend the mixture till the mixture became completely homogenous. Epoxy-asphalts modified with 7.5, 15.0, 22.5 and 30.0 wt % epoxy resin were prepared, respectively. The mixture of epoxy asphalt was transferred into teflon mold. The curing process was performed at 150 °C for 2 h and then at 200 °C for 1 h. Then the samples were cut into dimensions of 30 mm×18 mm and used for dynamic mechanical analysis. The characterization results of epoxy asphalt will be reported in next report.

Recommendations | Conclusions

Partial hydrogenolysis of NARA lignin was conducted in a 2-L reactor with a decent conversion and showed good reproducibility. An efficient and simple preparation method of PDL-epoxy was developed through direct-glycidylation reaction with epichlorohydrin using DMSO as co-solvent. The epoxy resins based on PDL epoxy showed competitive properties, suggesting the PDL-epoxy is a potential alternative to petroleum based epoxy for certain applications. The preparation of PDL based curing agents was also successfully conducted via two biobased maleated anhydrides. The resulting PDL curing agents have multifunctional groups and displays competitive advantage in application of epoxy resin. The further characterization of epoxy asphalt will be carried out by DMA, Reometer, DSC, etc. Structure characterization of PDL curing agents and cuing behavior of PDL curing agent with commercial DER332 will be further investigated.

Esterification of lignin through transesterification between organosolv lignin and methyl oleate was successfully achieved by mechanochemical reaction ball milling. The hydroxyl value decreased from 5.17 mmol/g of untreated OL to ~2.9 mmol/g of oleated OLs, the transesterification was mainly occurred between the aliphatic hydroxyls of OL and the ester bonds of methyl oleate. After mechanochemical modification, the oleated lignin exhibited improved thermoplasticity. Furthermore, the oleated OL was melt blended with PLA through twin-screw extrusion, the PLA/oleated OL blends exhibited good processibilty. Compared to the PLA/OL blends, the PLA/oleated OL blends exhibited better compatibility between PLA and lignin, which supported by the obvious shift of glass transition temperature of oleated lignin.

Next, the effects of milling conditions (such as milling time, types and content of catalyst, types of ball mills, etc.) on the transesterification between lignin and methyl oleate will be investigated. Characterization of oleated NARA lignin will be carried out by 31P-NMR, FT-IR, etc., and the oleated NARA lignin will be melt blened with PLA. Other alkylating agent such as soybean oil will be used to modify lignin through mechanochemical grinding, and other reaction types concerning lignin through ball milling will be continuously explored.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Xin, J., Zhang, P., Wolcott, M.P., Zhang, J., Hiscox, W.C., & Zhang, X. (2014). A novel and formaldehyde-free preparation method for lignin amine and its enhancement for soy protein adhesive, Industrial Crops and Products, under review.

Li, M., Xina, J., Zhanga, J. and Xia, J. (2015). Application development of partially depolymerized lignin epoxy resin in epoxy asphalt, completed.

Guo, X., Xin, J. & Zhang, J. (2015). Mechanochemical synthesis of oleated lignin and properties of its blends with PLA, completed.

CONVERSION

PRETREATMENT TEAM

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: Assist in optimizing large scale pretreatment and lignin product development

The termination of the diluted acid pretreatment activity allowed us to focus on developing new pathway/technology for biorefinery lignin conversion and product development. This activity was initially scheduled to start in the second half of the third year. Significant progress has been made this year as shown in the task progress. This conversion technology will be investigated on NARA lignin samples.

Task C-P-2.2: Diluted acid pretreatment of Douglas-fir wood and forest residues

This activity has been terminated. However, the Ph.D student Carlos Alvarez, a Fulbright scholar, has started to work on an alternative pretreatment method with a focus to maximize hemicellulose recovery. This activity is mainly funded by Carlos Alvarez's Fulbright scholarship. Carlos presented his results at The American Institute of Chemical Engineers annual meeting (AICHE).

Task C-P-2.3: Identify new approach to selective conversion of softwood hemicellulose to fuel precursors and/or value chemical in high yield

It has been a great challenge to develop an economically viable pretreatment method to deconstruct softwood to produce fermentable sugars for biofuel production. One of the factors contributing to this challenge is the low recovery of carbohydrates, especially hemicellulose, to monosaccharides. The objective of this task is to identify new approach to incorporate catalysts to softwood pretreatments to improve hemicellulose conversion to platform chemicals. This is an unfunded research activity which will be conducted by a PhD student funded by a Fulbright scholarship.

Activities and Results

This project is not currently funded by NARA. The research activity is leveraged by a Fulbright Scholarship to a PhD student Carlos Alvarez's and Sungrant project which support another PhD student Ruoshui Ma.

We have made significant progress toward lignin depolymerization and application as well as identifying new approach for biomass hemicellulose utilization. Four papers have been published in ChemSusChem (2), Bioresearch Technology and Bioenergy Research. The paper entitled "*Catalytic Oxidation of Biorefinery Lignin to Value-added Chemicals to Support Sustainable Biofuel Production*" ChemSusChem 2015, vol. 8, p. 24 has been listed as one of the most accessed paper in ChemSusChem (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1864-564X/homepage/2476_mostaccessed.html).

WE have demonstrated new pathways to selectively depolymerization of biorefinery lignin to monomeric phenolic compounds and dicarboxylic acids (Figure C-P-2.1).

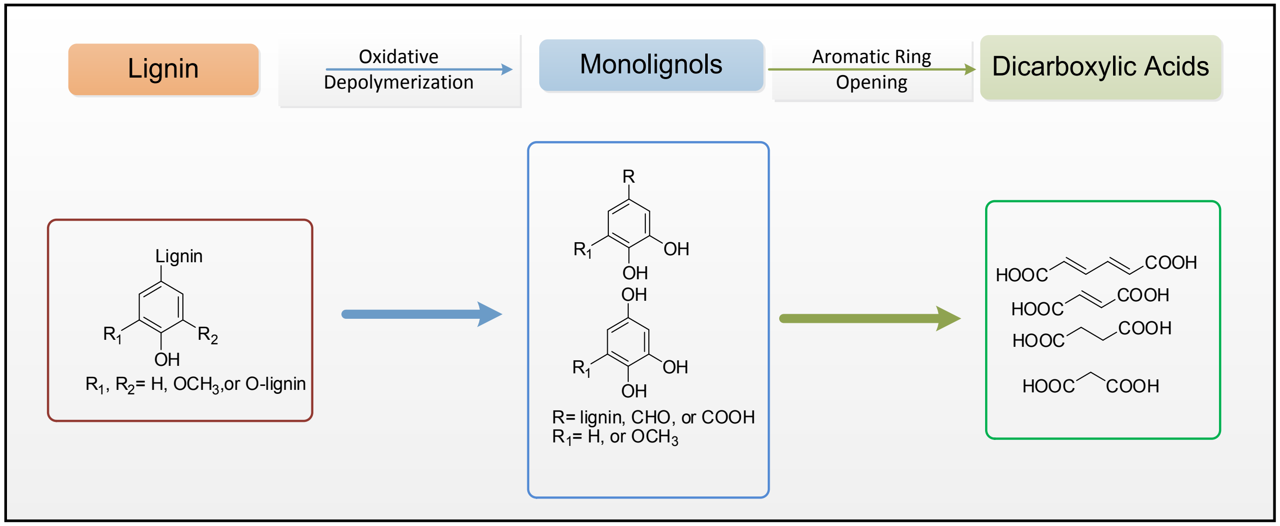


Figure C-P-2.1. Selective conversion of biorefinery lignin to monomeric phenolic compounds and dicarboxylic acids

Recommendations | Conclusions

Our recent work on lignin depolymerization and conversion to monomeric phenolic compounds and dicarboxylic has opened new avenues toward lignin conversion and utilization will attract considerable amounts of interest. Dr. Xiao Zhang visited Solvay Chemical Headquarter in Houston in October 2014 and learned that chemical companies are looking into similar chemistries we applied on lignin for phenolic chemicals production. Therefore further investigation to gain detail understanding of these pathways will be of great commercial and scientific interest. We have not systematic investigated these conversions on NARA lignin (sulfite lignin and milled wood lignin) yet. We hope to have finical support from NARA in the next year to allow us to focus on evaluating these conversion technologies on both sulfite lignin and milled wood lignin from sugar depot.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS (ACCEPTED OR COMPLETED)

1. Ma, R.S., Xu, Y. & Zhang, X. (2015). Catalytic Oxidation of Biorefinery Lignin to Value-added Chemicals to Support Sustainable Biofuel Production. ChemSusChem, 8(1), 24-51.

2. Alvarez-Vasco, C. & Zhang, X. (2014). Alkaline hydrogen peroxide (AHP) pretreatment of softwood: The effect of pretreatment conditions and hemicellulolytic enzymes addition on sugar yields, Bioresource Technology. In preparation.

3. Ma, R.S., Yan, X. & Zhang X. (2014). Catalytic oxidation of biorefinery lignin to value-added chemicals to support sustainable biofuel production. ChemSusChem. Accepted.

4. Alvarez-Vasco, C., Guo, M. & Zhang, X. (2015). Dilute acid pretreatment of Douglas fir forest residues: pretreatment yield, hemicellulose degradation, and enzymatic hydrolysability. BioEnergy Research, 8(1), 42-52. doi:10.1007/s12155-014-9496-7.

RESEARCH PRESENTATIONS

1. Oral presentation: “Catalytic Oxidation of Biorefinery Lignin to Value---Added Chemicals to Support Sustainable Biofuel Production From Lignocellulosic Biomass” Frontier in Biorefinery, Oct.21-24, 2014 ST Simons Island GA.

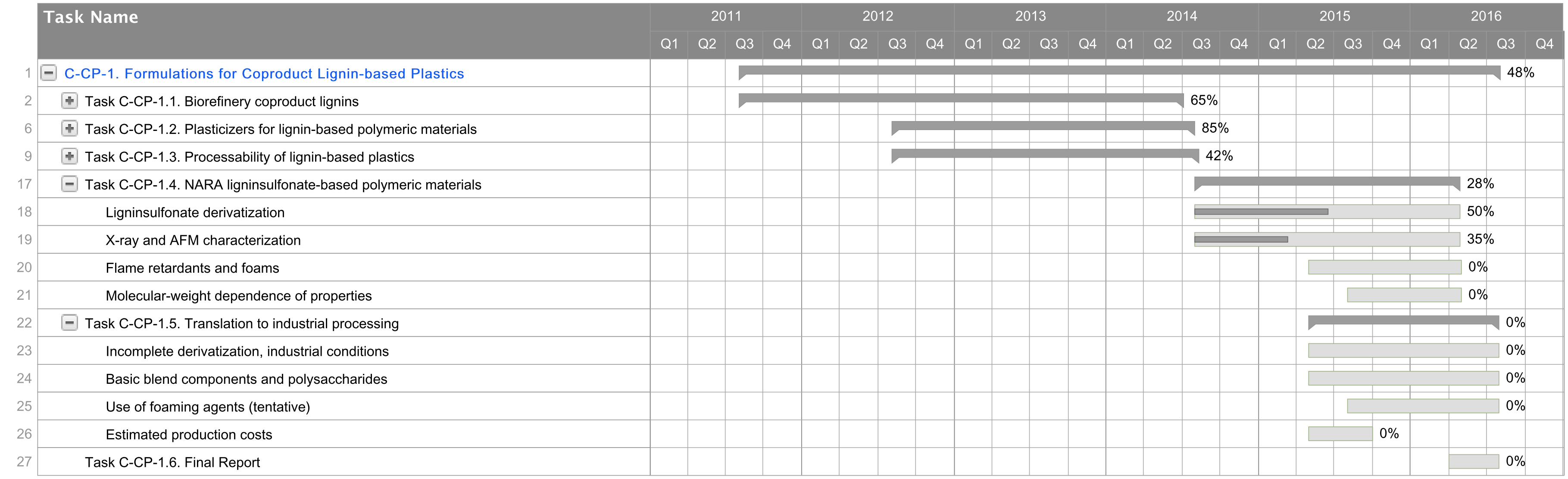
2. Oral presentation: Chemical Conversion of Biorefinery Lignin to Value Added Platform Chemicals, American Institute of Chemical Engineers (AICHE) Meeting, Altlanta GA, Nov. 17-20, 2014, presented by PhD student Ruoshui Ma

3. Oral presentation: Selective Conversion of Biorefinery Lignin to Dicarboxylic Acids, American Institute of Chemical Engineers (AICHE) Meeting, Altlanta GA, Nov. 17-20, 2014, presented by PhD student Ruoshui Ma

4. Oral presentation: “Potential of Alkaline Hydrogen Peroxide (AHP) As Softwood Forest Residue Pretreatment Method: Hemicellulose and Cellulose Conversion to Sugars and Chemicals”, American Institute of Chemical Engineers (AICHE) Meeting, Atlanta, GA. November 18, 2014. presented by PhD student C. Alvarez-Vasco.

5. Oral presentation: “ Metal Catalyzed Conversion of Biomass to Maximize Hemicellulose Sugar Conversion to Valuable Organic Acids”, American Institute of Chemical Engineers (AICHE) Meeting Atlanta, GA. November 17, 2014. presented by PhD student C. Alvarez-Vasco.

Conversion-CP_Sarkanen



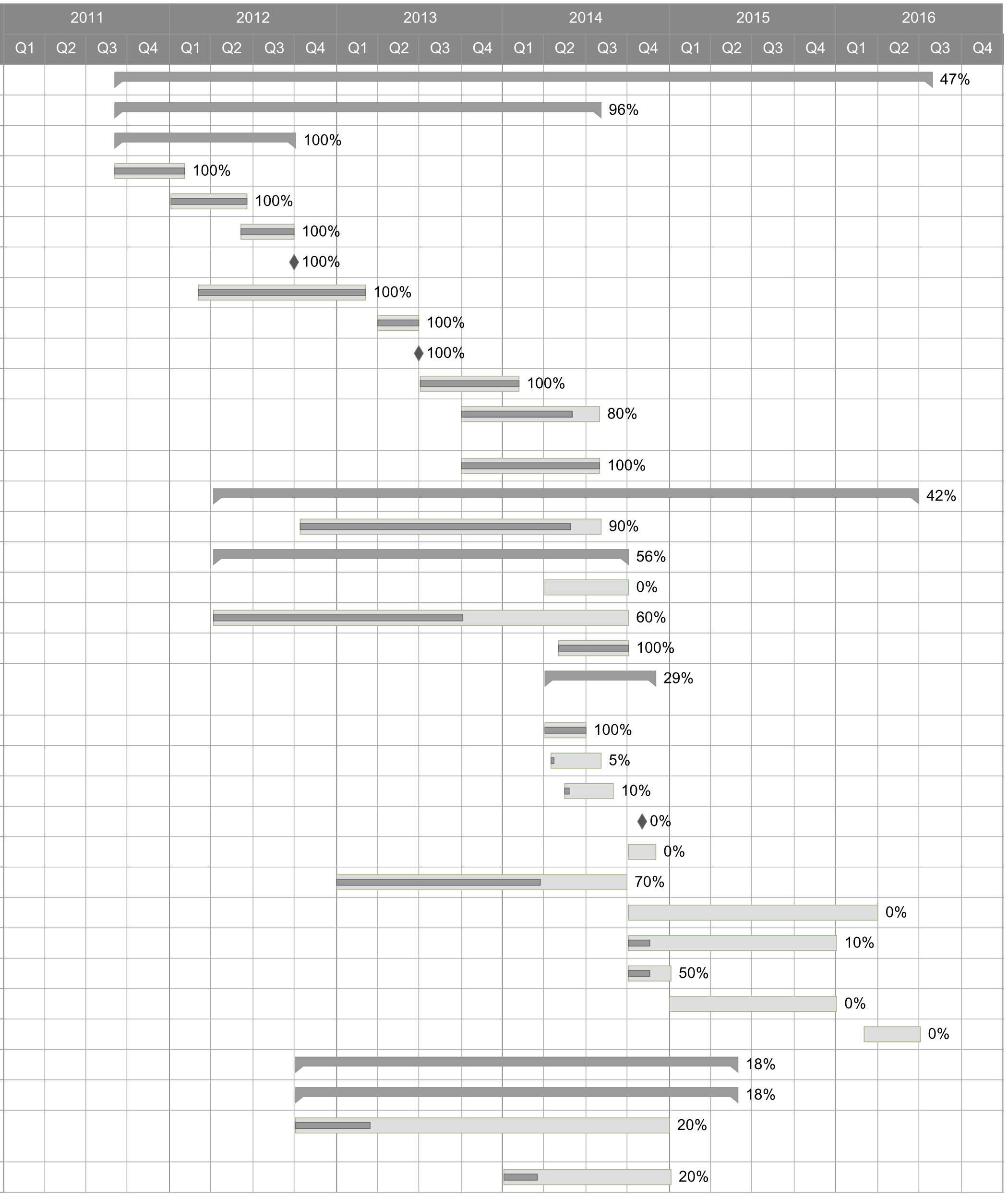
1	C-CP-1. Formulations for Coproduct Lignin-based Plastics	48%
2	Task C-CP-1.1. Biorefinery coproduct lignins	65%
6	Task C-CP-1.2. Plasticizers for lignin-based polymeric materials	85%
9	Task C-CP-1.3. Processability of lignin-based plastics	42%
17	Task C-CP-1.4. NARA ligninsulfonate-based polymeric materials	28%
18	Ligninsulfonate derivatization	50%
19	X-ray and AFM characterization	35%
20	Flame retardants and foams	0%
21	Molecular-weight dependence of properties	0%
22	Task C-CP-1.5. Translation to industrial processing	0%
23	Incomplete derivatization, industrial conditions	0%
24	Basic blend components and polysaccharides	0%
25	Use of foaming agents (tentative)	0%
26	Estimated production costs	0%
27	Task C-CP-1.6. Final Report	0%

Exported on April 24, 2015 11:12:50 AM PDT

Page 1 of 1

Conversion-CP_Garcia-Perez

	Task Name	
1	C-CP-2. Conversion of Lignin to High Value, Large Market Products	47%
2	Task C-CP-2.1. Characterization of NARA Lignin	96%
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	100%
10	Report on isolation procedure and structural analysis of lignin	100%
11	Evaluate methods to isolate lignin from hydrolysis residuals	100%
12	Write and submit paper(s) for publication on the properties of the NARA lignin and the activated carbons made from NARA lignins	80%
13	Analyze the lignin produced on a larger scale by the 3 current processes	100%
14	Task C-CP-2.2. Convert lignin to high surface area activated carbon	42%
15	Develop lab carbonization/activation process	90%
16	Task C-CP-2.2.1. Refine lab carbonization/activation process	56%
17	Develop yield-performance-economics curve	0%
18	Determine whether one- or two- activation process on product performance	60%
19	Develop initial commercial scale production model	100%
20	Task C-CP-2.2.2. Search and obtain an industrial partner to help with commercial development	29%
21	Develop an intellectual property plan for protection of activated carbon IP	100%
22	Make initial contact with potential partners	5%
23	Develop criteria for partner selection	10%
24	Selection of partner	0%
25	Develop and have signed appropriate agreements with partner	0%
26	Evaluate product economics	70%
27	Conduct Customer Trials	0%
28	Develop plan and process for scale to pilot	10%
29	Locate facility for pilot scale production	50%
30	Product pilot scale quantities of AC	0%
31	Summary report on customer trials (activated carbon)	0%
32	Task C-CP-2.5. Study other potential uses of NARA lignin	18%
33	Task C-CP-2.5.1. Evaluate lignin or derivatives for use in super capacitors	18%
34	Evaluate physically activated carbons developed for mercury adsorption for use in supercapacitors	20%
35	Develop criteria for improved supercapacitor performance.	20%



Exported on April 24, 2015 11:29:47 AM PDT

Page 1 of 2

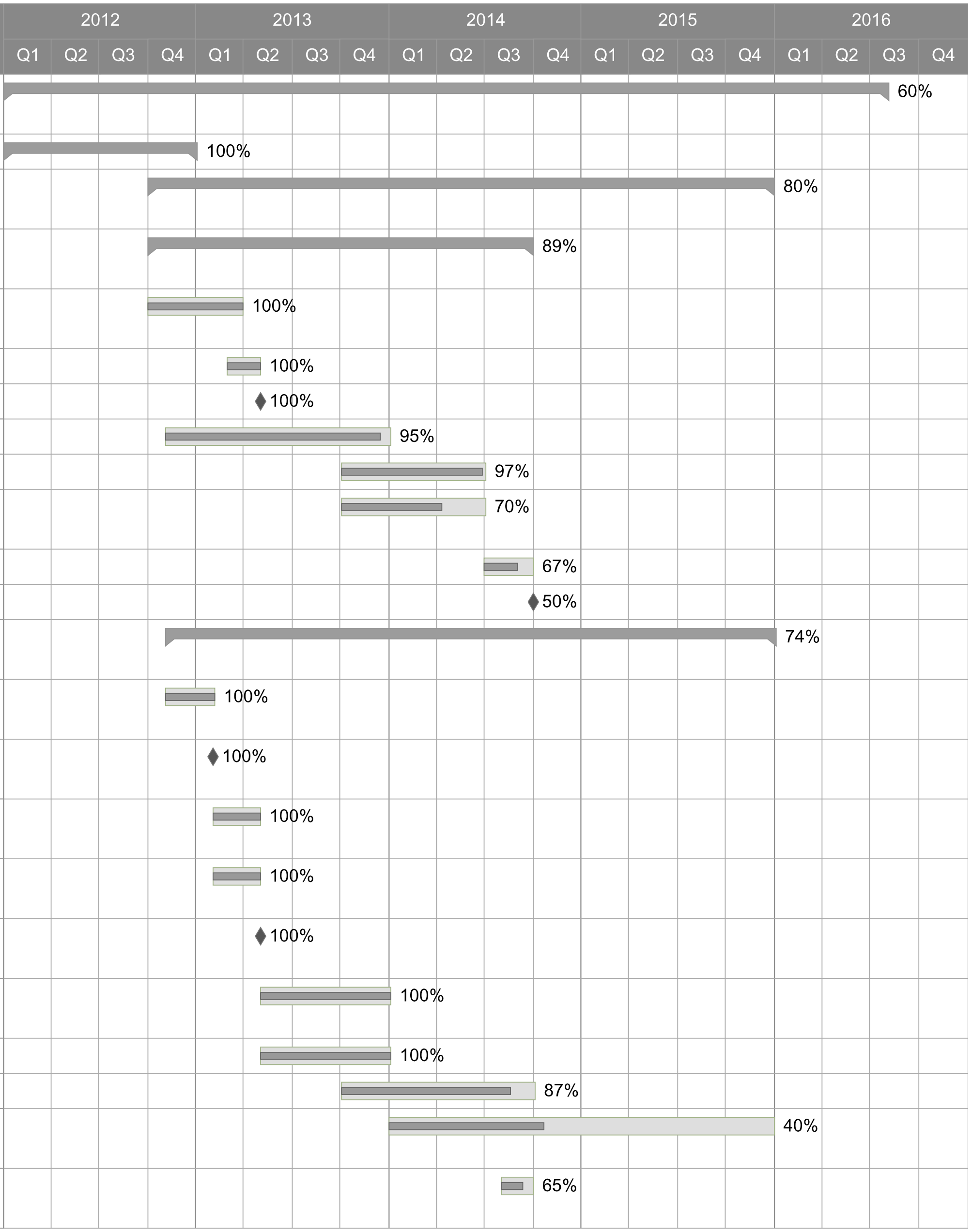
	Task Name	
36	Modify carbonization/activation and post-treatments to include chemical activation and surface chemistry conrtol for electrochemnical applications	15%
37	Evaluate effect of washing on supercapitor performance	10%
38	Task C-CP-2.6. Evaluate effects of NARA spent sulfite liquor on fresh cement properties	30%
39	Task C-CP-2.7. Write Final Report	0%

Exported on April 24, 2015 11:29:47 AM PDT

Page 2 of 2

Conversion-CP_Zhang_Wolcott

	Task Name	
1	C-CP-3. Novel Engineering Polymers from Lignin-Derived Building Blocks	60%
2	Task C-CP-3.1. Preparation of epoxies using lignomers	100%
11	Task C-CP-3.2. Development of partially depolymerized lignin (PDL) epoxies and lignin modification	80%
12	Task C-CP-3.2.1. Preparation of epoxies and curing agents from lignin fragments	89%
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	100%
15	**Viability of preparation methods assesssed**	100%
16	Assess various PDL products for MW, hydroxy number, solubility	95%
17	Develop synthesis methods for PDL derived epoxy and curing agent	97%
18	Characterize curing behavior and physical performance of DPL derived materials	70%
19	Report PDL epoxy development and performance	67%
20	**Viability of PDL epoxy determined**	50%
21	Task C-CP-3.2.2. Explore deploymerization of lignin and preparation epoxies and curing agents using partially depolymerized lignin (PDL)	74%
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	100%
25	Preliminary assessment for hydrogenolysis of NARA lignin using Reney Ni	100%
26	Assess performance producing PDL using both method: Target >70% yield	100%
27	Refine assessment for liquefaction of NARA lignin in supercritical solvents	100%
28	Refine assessment for hydrogenolysis of NARA lignin using Reney Ni	100%
29	Explore methods for enhancing the efficiency of lignin depolymerization	87%
30	Explore depolymerization and modification of lignin in solid state reaction	40%
31	Prepare articles and presentation for the efficacy of liquefaction and hydrogenolysis depolymerization of NARA lignin	65%



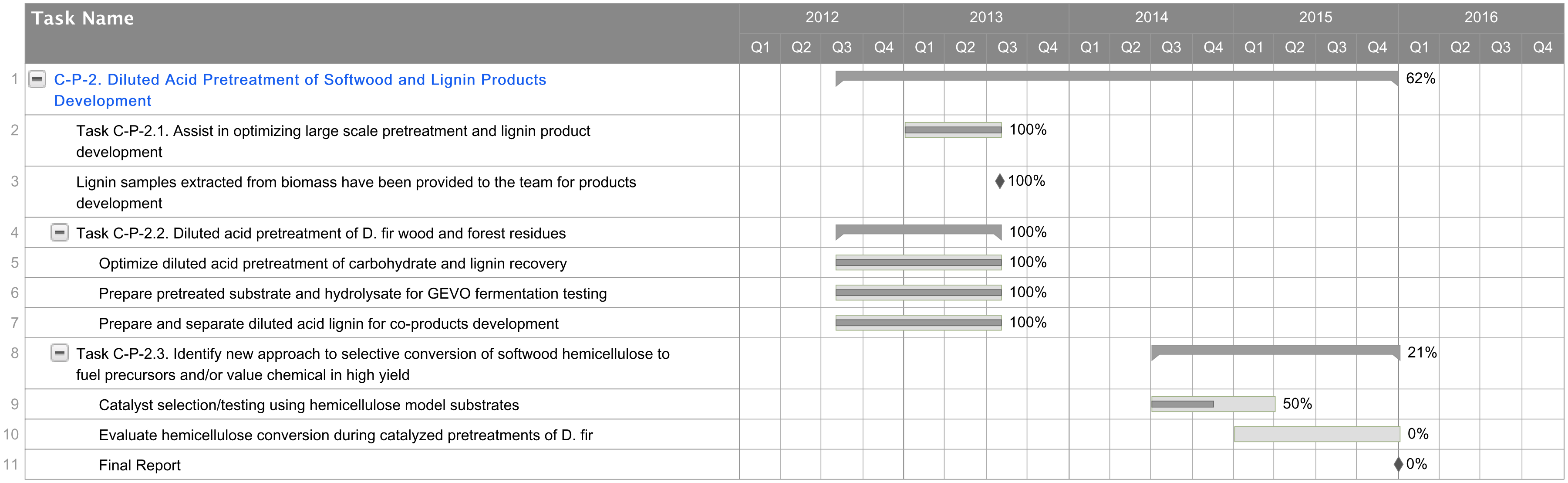
Exported on April 24, 2015 11:48:57 AM PDT

	Task Name	
32	**Performance of liquifaction and hydrogenolysis methods have been assessed on NARA lignin**	75%
33	Task C-CP-3.3. Application Development for PDL-Based Epoxy Asphalt	23%
34	Preliminary development of epoxy asphalts formulations using commercial components	45%
35	Preliminary development of epoxy asphalts formulations using Kraft epoxy	100%
36	Develop PDL-derived epoxy asphalt	20%
37	Evaluate performance and application for PDL-derived epoxy asphalt	20%
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%

Exported on April 24, 2015 11:48:57 AM PDT

Page 2 of 2

Pretreatment_XZhang



	Task Name	
1	C-P-2. Diluted Acid Pretreatment of Softwood and Lignin Products Development	62%
2	Task C-P-2.1. Assist in optimizing large scale pretreatment and lignin product development	100%
3	Lignin samples extracted from biomass have been provided to the team for products development	100%
4	Task C-P-2.2. Diluted acid pretreatment of D. fir wood and forest residues	100%
5	Optimize diluted acid pretreatment of carbohydrate and lignin recovery	100%
6	Prepare pretreated substrate and hydrolysate for GEVO fermentation testing	100%
7	Prepare and separate diluted acid lignin for co-products development	100%
8	Task C-P-2.3. Identify new approach to selective conversion of softwood hemicellulose to fuel precursors and/or value chemical in high yield	21%
9	Catalyst selection/testing using hemicellulose model substrates	50%
10	Evaluate hemicellulose conversion during catalyzed pretreatments of D. fir	0%
11	Final Report	0%

Exported on April 24, 2015 12:43:49 PM PDT

Page 1 of 1

NARA Goal Three

3RD Cumulative Report

April 2014 - March 2015

Rural Economic Development

Enhance and sustain rural economic development.

SUMMARY

ENVIRONMENTALLY PREFERRED PRODUCTS (EPP), LIFE-CYCLE ASSESSMENT (LCA), COMMUNITY IMPACT ASSESSMENT (CIA)

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

ENVIRONMENTALLY PREFERRED PRODUCTS TEAM

The Environmentally Preferred Products (EPP) Team evaluates the social viability of the industry. This analysis of social sustainability investigates community social assets, stakeholder needs and perceptions, market opportunities for biojet and co-products, and governmental regulations and incentives for renewable products. To evaluate community social assets, the EPP team refined the biogeophysical and social asset assessment described in NARA Year-3 reporting to incorporate NARA's new goals of retrofitting existing facilities. The EPP team reassessed the site selections in the Western Montana Corridor (WMC) region and applied the refined assessment to the Mid-Cascade-to Pacific region (MC2P). The results for the revised WMC assessment were submitted for publication to the Journal of Politics. Regional and national benchmark metrics to assist in identifying receptive communities for biofuel facilities have been created (Task SM-EPP-1.5)


NARA Image

To evaluate stakeholder needs and perceptions, a qualitative analysis was completed on the stakeholder survey described in the NARA Year-3 reporting period. Findings show that a majority of stakeholders support using woody biomass to produce bioenergy or a refined liquid biofuel, and they recognize the benefits, such as improved regional economies and reduced fire hazards. Findings also show that stakeholders are concerned about the potential negative impacts on soil and wildlife by forest residual use. Published survey results are anticipated in late spring 2015. (Task SM-EPP-1.4).

To better define market opportunities for biojet and co-products, the EPP team mapped and generated datasets regarding U.S. biofuel biorefineries (n=412). The team is currently examining cellulosic and algae biofuel biorefinery (BR) product portfolios and evaluating the strategic relationships across value chains through surveys and interviews. To assess and improve our understanding of biojet opportunities, in-person interview protocols, that include scripts, interviewee lists and methodology, and an online e-survey questionnaire have been developed and will be presented in summer 2015 to key aviation supply chain stakeholder groups in the four-state NARA region (Task SM-EPP-1.6). The team completed a preliminary examination of lignin value-added markets and identified activated carbon (AC) as a potential high-growth market for mercury sequestration from power plant flue gas due. Potential AC buyer populations have been identified, and primary data collection is scheduled for summer-fall 2015 to: (1) better understand the value proposition for NARA AC vis-à-vis existing AC products; and (2) delineate the product and service characteristics buyers desire for an AC to sequester mercury from coal-fired power plant flue gas (Task SM-EPP-1.8).

To better understand governmental regulations, incentives for renewable products, and life-cycle assessment approaches for biofuels and co-products, a literature review was completed (Task SM-EPP-1.2). Based on this information, a comparative life cycle assessment (LCA) for different fossil/biomass derived PET bottle production scenarios was finalized (Task SM-EPP-1.7) plus life-cycle iterations were completed for activated carbon and paraxylene production (Task SM-EPP-1.9). The PET bottle LCA indicates that PET bottles derived from forest residuals generate significantly less greenhouse gas effects compared to PET bottles derived from corn stover or crude oil if avoided impacts are taken in consideration. It is clear from these assessments that the type and quantity of co-products can significantly affect the level of greenhouse gas emissions. A mixed integer linear programming (MILP) optimization model is being constructed to help evaluate the economically optimal co-product type and quantity produced while minimizing negative environmental impacts.

LIFE CYCLE ASSESSMENT TEAM

The Life Cycle Assessment (LCA) Team assesses the environmental and economic impacts of producing aviation biofuels, using NARA's chosen production pathway, and compares those impacts to the production of petroleum-based fuel. For this reporting period, the LCA team replaced a majority of the surrogate processes used to structure the LCA with modules and data developed by NARA team members. The LCA team also established a final model integration plan to be implemented once the relevant NARA research teams define all bio-refinery and co-product processes. The final LCA documents should be ready for submission to the International Organization for Standardization (ISO) by the end of summer, 2015 (SM-LCA-1).

COMMUNITY IMPACT ASSESSMENT TEAM

The community impact assessment (CIA) spreadsheet model developed for the western Montana corridor (WMC) region, as reported in NARA year-3 results, was adapted for the western Washington and Oregon region (WWO). To determine the most accurate source of forest biomass potential in the region, biomass supply data from the Western Biomass Assessment and from the NARA Supply Model (Task SM-SP-3) were entered into separate spreadsheets and compared. Distinctions regarding biomass supply and distribution were apparent; however, total sector economic impact differences are relatively small: $244 million (WA Biomass Assessment) versus $258 million (NARA Supply Model), and it was determined that the NARA Supply Model data would be used in the CIA. In addition, it was determined that the calculated county multipliers for the WMC and WWO regions differed. A further breakout of the sectors will allow more precise multiplier estimates associated with the forestry sector (Task SM-LCA-1.3).

SIGNIFICANT OUTPUTS REPORTED FOR THE EPP, LCA, AND CIA TEAMS

- A dataset was developed to identify, classify and locate all US biorefineries (Task SM-EPP-1)
- A environmental and economic optimization model was established in GAMS optimization software (Task SM-EPP-1)
- Co-product use and allocation scenarios were modeled – including emission credit calculations for co-product scenarios (Task SM-EPP-1)
- A peer-reviewed manuscript (Pelton et al) was published titled "Hotspot Scenario Analysis: Comparative Streamlined LCA Approaches for Green Supply Chain and Procurement Decision Making" doi: 10.1111/jiec.12191 (Task SM-EPP-1).
- A comparative life cycle assessment for varied fossil and biomass derived PET bottle production scenarios was finalized (Task SM-EPP-1).
- A peer-reviewed manuscript (Pierobon et al) was published titled "Evaluation of Environmental Impacts of Harvest Residue-based Bioenergy Using Radiative Forcing Framework" doi:10.1016/j.foreco.2014.10.010 (Task SM-LCA-1).
- A peer-reviewed manuscript (James et al) was published titled "Deep soil: quantification, modeling, and significance of subsurface nitrogen" doi:10.5558/tfc2014-120 (Task SM-LCA-1).
- A peer-reviewed manuscript (Littke et al) was published titled "Effects of geoclimatic factors on soil water, nitrogen, and foliar properties of Douglas-Fir plantations in the Pacific Northwest" doi:10.5849/forsci.13-141 (Task SM-LCA-1).
- A peer-reviewed manuscript (Littke et al) was published titled "Assessing Nitrogen Fertilizer Response of Coastal Douglas-fir in the Pacific Northwest using a Paired-tree Experimental Design" doi:10.1016/j.foreco.2014.07.008 (Task SM-LCA-1).

SIGNIFICANT OUTCOMES

- None reported

NARA Image

SUSTAINABLE PRODUCTION TEAM

To provide specific information regarding the impact of removing forest residuals on tree growth productivity, soil, and water, the Sustainable Production Team evaluates the influence of biomass harvesting scenarios, develops potential forest management prescriptions, assesses forest residual availability from harvest of highly managed stands, and considers the impact of industry feedstock requirements on overall supply chain dynamics. In whole, this team provides a host of primary data to improve and verify a variety of predicted impacts from an industry that would use forest residuals to produce biojet fuel and co-products.

Soil Nutrients

To develop improved tools and models used to predict soil nutrient levels, 160 decaying stump samples from stumps cut in years spanning 1992 through 2013 were taken from five sites. These samples were analyzed for density and nutrient (carbon and nitrogen) content. The data will be incorporated into a model used to estimate decomposition rates and contribute to developing a carbon life cycle assessment. Additional deep soil excavations were performed this year to measure soil nutrients, moisture levels and temperature. The data will be used to determine the importance of hydraulic redistribution during the dry summer season (Task SM-LCA-1.1). New versions of biomass equations were completed In NARA Year-4 to estimate nutrient and carbon removal under various levels of biomass harvesting. These equations provided estimates of soil nutrient replenishment rates, atmospheric deposition rates, and nutrient release rates for a number of western U.S. Douglas-fir sites and help determine sustainable nutrient levels for bioenergy feedstock production (Task SM-SP-4).

Soil and Tree Productivity

The NARA LTSP site located near Springfield Oregon is structured to provide long-term analysis on the impacts of forest residual removal and soil compaction on soil and plant productivity. The site is also used to study forest residual removal impact on soil water retention and wildlife. In NARA Year-3, timber harvest was completed on the 83-acre site, and 28 1-acre plots were treated with varied biomass removal and soil-compaction treatments. Seedlings were planted and fencing plus monitoring equipment were installed. For this reporting period, post-treatment soil and biomass effects plus seedling growth after one year growing season were measured (Tasks SM-SP-1; SM-SP-8). Preliminary results show that organic material removal results in warmer soil temperatures to a depth of 100 cm; however, no changes in soil respiration have yet been detected due to the temperature increase (Task SM-SP-8). Traps were established to quantify the emergence of ground nesting bees and other invertebrate pollinators. Captured bees are being identified to species in an effort to determine whether organic material removal impacts pollinator diversity (Task SM-SP-6). Microbial population data was collected from individual treatment plots, and the results indicate that the varied organic material treatments had no effect on microbial ecology (Task SM-SP-5-water).

Water and Wildlife

Additional research on the effects of forest residual removal on wildlife, air quality and stream erosion was conducted outside of the NARA LTSP site. A hillslope model approach was used to model stream flow and sediment transport in north central Idaho as impacted by forest residual removal. Preliminary results indicate that biomass removal decreased average bed material diameter by up to 3 mm and increased bedload transport by up to 5% (Task SM-SP-5-Water). Based on 14,000 bird community observations, preliminary occupancy models have been run for stand-level and landscape-level impacts of intensive forest management on species richness, cavity-dwellers, and individual bird species from eight study regions, including two in the Pacific Northwest (Task SM-SP-6). A series of regional air quality simulations were completed to investigate the impact of prescribed fires on local and regional air quality. These simulations show that harvesting woody biomass for biojet fuel production will decrease the amount of slash burning that occurs in the region by 70% and produce a positive air quality benefit (Task SM-SP-5-Air).

Biomass Availability

Multiple efforts are being conducted to provide analysis and tools used to determine the amount of sustainable forest residual feedstock in the NARA four-state region. The NARA biomass supply model was used to estimate impacts to standing biomass supply if RIN credits were applied to federal lands or if public harvests were changed dramatically. Results will be provided in the next reporting period. A variant of the supply model was also used to determine optimal depot facility locations (Task SM-SP-3; Task E-3). To determine the amount of forest residuals left after logging operations, Montana's Bureau of Business and Economic Research (BBER) Forest Industry Research Group extended the logging utilization fieldwork to account for over 2,000 felled trees at 100 sites throughout Idaho, Montana, Oregon and Washington. This effort provides logging residue estimates for each NARA state at the state and county levels. Years 2002 through 2012 timber harvest data (in MBF Scribner) by county and ownership for ID, MT, OR and WA; 2013 data for all ownerships in Washington; and 2013 data for several but not all owners in Oregon, Idaho and Montana are available (Task SM-SP-7). To quantify the effect of regional land management policy and market trends on the supply of available biomass, the first NARA based Integrated Fireshed-Level Adaptive Management Evaluation Site (IFLAMES) was established at Warm Springs, Oregon, and pre-treatment measurements were completed and summarized (Task SM-SP-2)

TECHNO ECONOMIC ANALYSIS

To understand the economic considerations and sustainability of a biojet fuel and co-products industry based on wood residuals, a techno-economic analysis (TEA) is underway. A rough draft of the ASPEN Model and Integrated Biorefinery Report is near completion. This document is intended to demonstrate the mass and energy flows in the NARA biorefinery as well as the capital and operating costs for each department (Task SM-AM-1). A sensitivity analysis was completed for some of the uncertain factors that would impact the internal rate of return (IRR) of a wood-to-biofuels and co-product biorefinery. This data, coupled with a projection of the mass and economic values applied to anticipated revenue streams, demonstrates the challenges of estimating product prices, yields and the value of Renewable Identification Numbers (RINs). A significant development in this reporting period is that the yield estimated for activated carbon was reduced from 40% to 22.5%, which reduces annual revenue by $84 MM. Taken together, the latest "base case" expected rate of return for a biorefinery is 12% (Task SM-TEA-1).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR THE SUSTAINABLE PRODUCTION AND TEA TEAMS

- NARA graduate student Kevin Vogler submitted his master's thesis at Oregon State University titled "Sustainable Biomass Supply from Fuel Reduction Treatments: A Biomass Assessment of Federally Owned Land in Eastern Oregon " Link (Task SM-SP-2).

- The first NARA-based Integrated Fireshed-Level Adaptive Management Evaluation Site (IFLAMES) was established at Warm Springs, Oregon (Task SM-SP-2).

- NARA graduate student Mindy Crandall submitted her doctoral dissertation at Oregon State University titled "The effects of increased supply and emerging technologies in the forest products industry on rural communities in the northwest U.S." Link (Task SM-SP-3).

- NARA graduate student Kristin Coons submitted her master's thesis at Oregon State University titled " Douglas–fir (Psuedotsuga menziesii) biomass and nutrient removal under varying harvest scenarios involving co-production of timber and feedstock for liquid biofuels." Link (Task SM-SP-4).

- Soil samples for all treatments at the NARA LTSP site were obtained, and DNA samples were analyzed to detect 56 genera of soil microbes (Task SM-SP-5-Water).

- A general technical report titled " Logging Utilization in Idaho: Current and Past Trends" was authored by BBER staff and published by the USDA Rocky Mountain research Station http://www.fs.fed.us/rm/pubs/rmrs_gtr318.pdf (Task SM-SP-7).

- Draft tables covering the Oregon timber harvest and forest products industry for 2013 were made available online http://www.bber.umt.edu/pubs/forest/util/ID_logging_util_2014.pdf (Task SM-SP-7).

SIGNIFICANT OUTCOMES

- Due to the BBER NARA-funded logging utilization research, BBER and the US Forest Service Forest Vegetation Management staff (Ft. Collins Service Center) are jointly modifying the Forest Vegetation Simulator to more accurately predict post-harvest logging residue volumes and biomass (Task SM-SP-7).

TRAINING

Name	Affiliation	Role	Contribution
Allan Gao	WSU	Graduate Res Asst	Allan is the primary Aspen modeler on the team and is creating the model as well as producing various reports, which document the mass and energy balances in the refinery.
Tait Bowers	UW	PhD student	Research on LCA; presentations and publications
Jason James	UW	MS student	Field and lab, presentations, publications
Matt Norton	UW	MS student	Field and lab, presentations, MS thesis
Chrisitiana Dietzen	UW	PhD student	Field and lab, presentations
Marcella Menegale	UW	PhD student	Field and lab, presentations
Kim Littke	UW	Post-doctoral researcher	Field and lab, presentations, publications
Ike Nwaneshiudu	UW	Post-doctoral researcher	Research on pre-treatment and ASPEN modeling; presentations and publications
Cody Sifford	UW	MS student	Research on air quality modeling; presentations and publications
Cindy X. Chen	UW	PhD student	Research on logistics LCA; presentations and publications
BJ Birdinground	UW	MS student	Research on timber inventory modeling
Francesca Pierobon	UW	Exchange PhD student	Research on carbon cycle modeling; presentations and publications
Luis Souza	Univ. Sao Paulo	Intern	Field and lab
Rodolfo Bernardi	Univ. Sao Paulo	Intern	Field and lab
Thiago Bonassi	Univ. Sao Paulo	Intern	Field and lab
Eduardo Marques	Univ. Sao Paulo	Intern	Field and lab
Dr. Ling Jiang	Chang'An Univ	(Visiting faculty)	Field and lab
Stephen Cline, MS	PSU	MS - SU/ FA '14	Lignin market opportunity - activated carbon
Wenping Shi	PSU Postdoc	PSU - NARA & FAA ASCENT	R-t-W SH Assessment and BGP/Social Asset Analysis
Wenping Shi, Ph.D.	PSU	Research; grad. Ph.D - Dec.'14	Social Asset dataset developer, analyst, and manager
Min Chen, Ph.D.	PSU	Research	Biorefinery structure and value stream outputs
Kristina Dahmann	PSU Post-J.D.	Res. Assoc.	Biofuel policy and law
Jennifer Schmitt	U MN Postdoc	Research Postdoc	Spatial variation aspects of supply chain structure and environmental assessment
Rylie Pelton	U MN	Research RA	Environmental assessment of intermediate products and co-products re: activated carbon; development of optimization model
Luyi Chen	U MN	Research RA	Environmental assessment of intermediate products: isobutanol to paraxylene
Jillian Moroney, Ph.D.	U of Idaho	Research; PhD	SH assessment; aviation fuel SH assessment
Ibon Ibarrola, MS & CLH Aviation, Madrid, Spain.	Polytechnic Univ. of Madrid	Research and industrial cooperator	Aviation fuel logistics; aviation fuel SH assessment; cooperator on the FAA COE Techno-Market Analysis proposal
Sanne Rijkhoff	WSU	Research; PhD	Social asset analysis

Natalie Martinkus	WSU	Research: PhD	Biogeophysical and social asset assessment
Preenaa Venugopal	PSU	NARA SURE (SU ’14 – PSU)	Potential Technological Pathways for the Production of Alternative Jet Fuel
Dr. Heather Root	Oregon State University	Post-Doc	JoF Review paper, Bird meta-analysis
Dr. Jim Rivers	Oregon State University	Post-Doc	Manipulative study on biofuel impacts on pollinators, White-crowned sparrow survival as a function of slash removal
Codey Mathis	Oregon State University	Undergraduate Student	Manipulative study on biofuel impacts on pollinators
Ian Lively	Oregon State University	Undergraduate Student	Manipulative study on biofuel impacts on pollinators
Kaedra Emmons	Oregon State University	Undergraduate Student	Manipulative study on biofuel impacts on pollinators
Theodore Squires	Oregon State University	Undergraduate Student	Manipulative study on biofuel impacts on pollinators
James Johnston	OSU	Graduate Student	Understanding of fire histories and treatment opportunities in the Blue Mountains
Katherine Morici	OSU	Graduate Student	Understanding longevity of fuels treatments (thinning and prescribed fire)
Kevin Vogler	OSU	Graduate Student	Regional biomass supply and economic accessibility
Kristin Coons	OSU	Graduate Student	Master’s thesis
Mohammad Hasan	Univ. of Utah	Graduate Student	Collection and analysis of microbial data, modeling of sediment transport, analysis of soil moisture.
Ross Wickham	WSU	Graduate Student	Numerical modeling of flow and sediment transport, field data collection
Eric Sorensen	Humboldt State Univ.	Undergraduate Student	Assistance with field data collection, literature review of sediment sampling techniques
Adrian Gallo	Oregon State Univ	Graduate Student	Installed and maintained field monitoring equipment, monitoring of soil respiration and collection of lysimeter solutions, performed density fractionations, developing data analysis method for soil temperature, moisture, and respiration data.
Mindy Crandall	OSU	Graduate (PhD)	Doctoral Candidate
Vikram Ravi	WSU, Civil Engr.	Grad Student	Responsible for all air model simulations and analysis

RESOURCE LEVERAGING

Resource Type	Resource Citation	Amount	Relationship or Importance to NARA
PSU GIA (Grant-In-Aid) (tuition)	Min Chen ($16,000/semester)	$80,000; FA '13, SP/FA '14, SP/FA '15;	Research on the US biorefinery structure; biopolymer market opportunity
Industrial Match from CLH Aviation	Ibon Ibarrola, CLH, NARA Affiliate Member	$15,000	Toward a better understanding of aviation fuel supply chains in the US and Spain
PSU Dickinson School of Law	Kristina Dahmann	$5,000 Match	Contributions toward understanding biofuel policy and law
AJF Supply Chain Analysis	FAA ASCENT1 Project	$1,400,000	Contributions toward understanding biofuel policy and law
PSU=$400K	US Regional (incl. NARA) AJF supply chain issues.	$40,000,000 for total 10-year program	Includes Alternative Jet Fuel research and development activities to better benchmark NARA efforts.
CLH Industrial Match for FAA	Ibon Ibarrola, CLH, industry cooperator	$200,000	AJF Supply Chain research in the NARA, MASBI, and ITAKA regions.
PSU RA + GIA support	Stephen Cline	$72,000; 2 yr. Dept funding	NARA SURE - Weyco (SU '13); PSU wages; MS – PSU.
UMN Buckman endowment	R. Pelton; UMN RA BBE/CFANS	$89,000 (2013-15)	Parameterized LCA of co-product (Activated Carbon) credit/debits to biojet fuel system.
UMN scholar recruitment	L. Chen; UMN RA BBE/CFANS	$43,000	Conducting parameterized LCA of co-product (bioPET) credit/debits to biojet fuel system.
NARA SURE program	Preenaa Venugopal	$6,000	Potential Technological Pathways for the Production of Alternative Jet Fuel
Funding	AFRI-USDA	$50,000	Allowed collection of data on white-crowned sparrow demography (in relation to fine woody debris amount)
Funding	NCASI	$34,890	Performing additional analyses on NARA samples

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

Task Description

A socio-market perspective of biorefinery value chain outputs requires an integrated, multi-faceted approach. Environmentally Preferred Products (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/ co-products including supply chain perceptions and issues; and (9) examine select intermediate/ coproducts and allocation of methods influencing the environmental assessment and reporting of aviation fuels.

Task 1 - 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 2 – 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 3 - 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 4 – This task operationalizes informed stakeholder mixed-method surveys in the NARA region.

Task 5 – This task's overall goal is to produce a refined community asset assessment model (CAAM) to apply to biofuel development issues throughout the NARA region. This model may then be refined and re-calibrated to apply to other US regions and to additional community asset situations, such as preparedness and response to wildfire.

Task 6 – One particular area of the aviation fuels space is biojet. This research will specifically target the supply chain aspect of biojet, from Refinery-to-Wing. Opportunities for utilizing the petro-jet supply chain, and the challenges that must be overcome to bring bio-jet to commercial scale, will be examined.

Task 7 – 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 8 - This task inventories, categorizes and locates all US biorefineries. In addition, the biopolymer and lignin market opportunities will be explored and key biorefinery product portfolio issues addressed.

Task 9 – 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

Task SM-EPP-1.1. "Public" stakeholders (SHs): demographic, psychographic, and market-specific assets through dataset analysis (Leigh Stowell, Rupasingha, and Roper-Putnam). (N. Martinkus, W. Shi, N. Lovrich, J. Pierce, M. Gaffney, S. Hoard, P. Smith, M. Wolcott)

The team completed this task in year 2 of the project. Various national data sets were combined that provide important information on different community and social assets utilized in Task 1.5. The team focused on combining Rupasingha, Roper-Putnam, Cultural Vitality Index, various public health data and education data into a single dataset that could be utilized for site selection determination. In 2014, the dataset was updated to include recent updates to Rupasingha, public health and education data. The national-level dataset provides social capital data (Rupashingha/Roper-Putnam), cultural data (Cultural Vitality Index), public health data (obesity rates, mortality rates, number of people insured, etc), and educational data at the county-level. The national dataset and a codebook have been developed by the Team and is currently being used for research described in Task SM-EPP-1.5.

Task SM-EPP-1.2. Review Sustainability Approaches: ecolabels, stds., product claims, LCA/EIO data sources & models. (R. Pelton, Luyi Chen, and T. Smith) Research for task 1.2 has been completed. A literature review was conducted, which identified 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. This review suggests overwhelming evidence toward 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 (see Figure SM-EPP-1.1). Efforts to assess co-product criteria influential to quantitative life cycle performance has also been completed, which will inform the continued development of Tasks 1.7 and 1.9. With regard to activated carbon co-products, the key criteria identified centers around the substitute fuel choice in combined heat and power (CHP). Specifically, additional energy inputs required for subsequent processing/drying of lignin, as part of the NARA process (e.g. natural gas, biomass, coal, etc.), should be specified as an important sustainability criteria as these inputs significantly alter the environmental performance (e.g. greenhouse gas (GHG) emissions) of both the primary jet fuel product and the activated carbon co-product. Similarly, energy in manufacturing and feedstock substituted (petroleum, corn, sugarcane, etc.) are key criteria in the assessment of paraxylene (and subsequent plastics and chemical) co-products. Finally, pretreatment pathways and their associated processes might be important criteria in the identification of low-carbon cement dispersant products produced as a co-product in isobutanol iso-paraffinic kerosene (IPK) production (see Table SM-EPP-1.1).

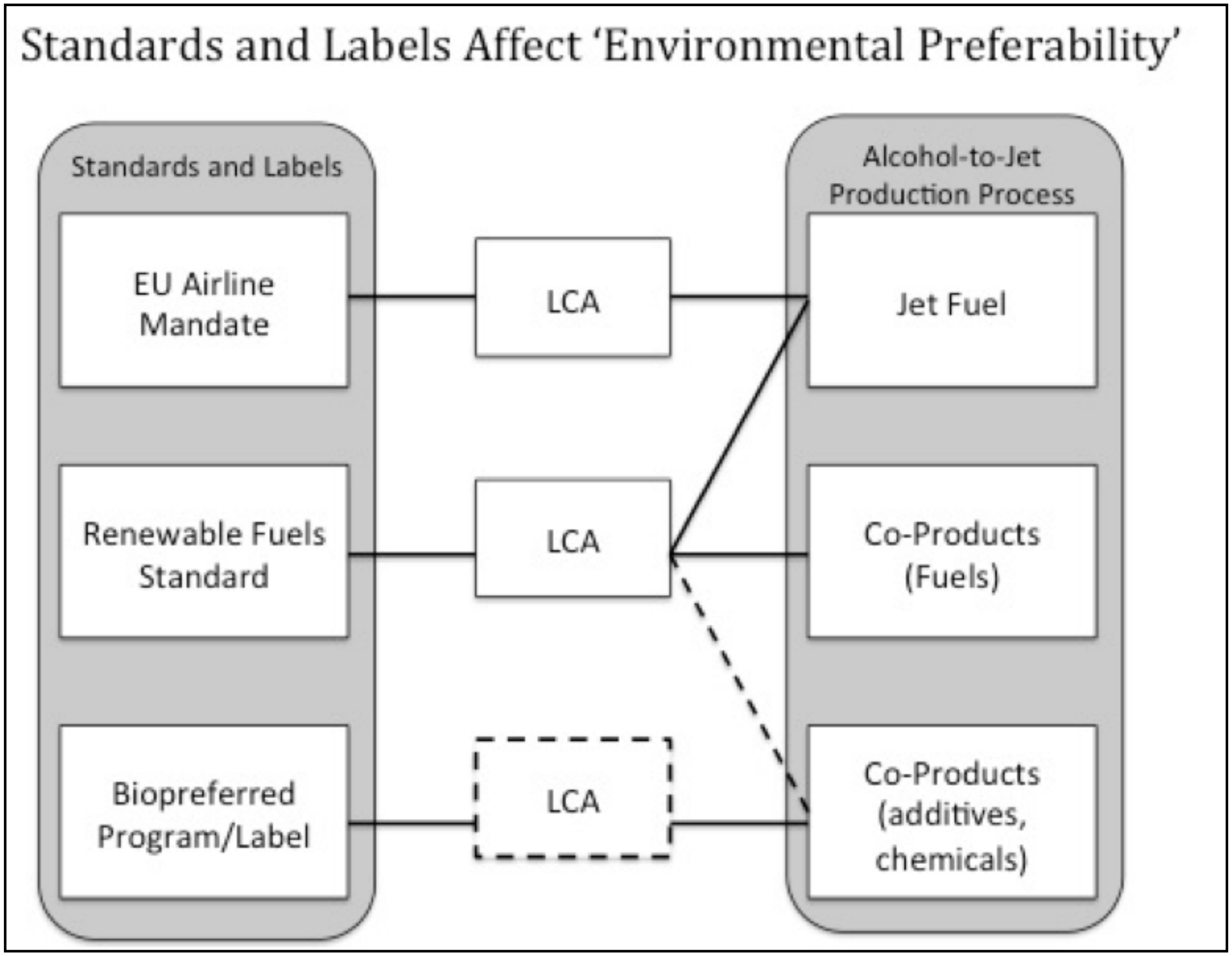


Figure SM-EPP-1.1. Fuel and product standards influence varying aspects of the alcohol-to-jet fuel production process.

Table SM-EPP-1.1. Co-product Criteria Assessment

	Recommended Impact Allocation Method	GHG Impact Levers	Directional Effects on Jet Fuel GHG Emissions[2]	Profit Levers	Directional Effects on Biofinery Profit[3,4]
Activated Carbon	Displacement	Preprocessing (drying) Substitute fuel choice in CHP[1]	+ or -	Dried lignin price relative to cost of drying and substitute fuel prices for CHP[1]	+ or -
Paraxylene	Displacement	Energy in Manufacturing PX	-	PX price relative to cost to process and price for jet fuel	+ or -
	or Mass Allocation	Fermentation (relative volume of IBA diverted to PX versus to jet fuel)	No effect		
Cement Dispersant	Mass Allocation	Pretreatment (relative volume of lignosulfonate versus sugars)	-	Lignosulfonate price relative to substitute fuel prices[5]	+ or -
Sold Electricity	Displacement	Facility energy use	-	Price for sold electricity	+

[1] CHP stands for combined heat and power.

[2] The + sign indicates jet fuel CO2e emissions could increase with the production of each co-product, the – sign indicates jet fuel CO2e emissions could decrease with the production of each co-product, + or – indicates jet fuel CO2e emissions could either increase or decrease depending on the production choices indicated in the GHG impact levers.

[3] Directional effects on the biorefinery profit assumes a baseline where jet fuel is the only saleable product.

[4] The + sign indicates biorefinery profit could increase with the sale of each co-product, the – sign indicates biorefinery profit could decrease with the sale of each co-product, and + or – indicates biorefinery profit could either increase or decrease depending on the dynamics of the profit levers.

[5] Assumes that the baseline red liquor use is for combined heat and power.

Task SM-EPP-1.4. "Informed" stakeholder interaction/operationalization (pop's., sampling, constructs, protocols). (J. Moroney, T. Laninga, M. Gaffney, and S. Hoard, K. Gagnon, P. Smith)

Informed SH Assessment Research Development

Prior research studies addressing salient biomass to bioenergy topics and issues were used to guide development of the research instrument (Adams et al, 2011; Becker et al 2011; Clement & Cheng, 2011; Davenport, 2007; Halder, 2011; Halder et al 2010; Mayfield et al 2007; Nelson, 2005; Plate, Monroe & Oxarart, 2010; Stidham & Simon-Brown, 2011; Tagashira & Senda (2011); Upham & Shackley, 2007). Prior research indicates that perception and acceptance are intertwined and multifaceted. Perceptions are impacted by education, experience, knowledge, values, beliefs, social background and identification with the community. Perceptions impact whether or not there is acceptance. Acceptance is also affected by communication, trust, environmental concerns, local community impact and knowledge, experience and education.

Previous studies utilized a variety of research methods, which included both quantitative and qualitative measures. Some of the salient issues in prior research include regional combined heat and power plants, utilization of forest materials, facility siting, social acceptance, forest management perceptions, bioenergy perceptions, trust, communication, local community impact and environmental concerns. We employed a mixed methods approach to administer the survey, which consists of open ended, multiple choice and Likert scale questions. The instrument was pilot tested using in-person interviews with 10 Western Montana Corridor (WMC) informed stakeholders. Using pilot test feedback and in collaboration with other USDA-NIFA Agricultural and Food Research Initiative Grant researchers the instrument was refined.

This study focused on potential NARA supply chain stakeholders (SH) deemed to be relatively informed regarding one or more critical elements within the biomass to biojet industry supply chain concept. The supply chain has three main nodes: feedstock, pre-conversion and conversion, and marketing and distribution. This project focuses on feedstock through pre-conversion and conversion. Marketing and distribution research is being completed by other NARA EPP researchers.

Development of the SH group list began with SH groups utilized in prior research. For reference, the groups used by Mayfield et al 2007 were renewable energy, economic development, forest management, and the forest products industry. Becker et al 2011 defined the SH groups as federal, state, tribal, and local government staff; loggers; manufacturers; community leaders; and environmentalists. Lastly, the SH groups used by Stidham and Simon-Brown 2011 were community organizations, conservation organizations, elected officials (staff of), energy utilities, federal agencies, forest industry sector, informed energy participants, state agencies, and tribal organizations.

Starting from a broad perspective, 21 stakeholder groups were identified, then categorized into three overarching categories for our sample frame:

1. Government/leadership
2. Environmental/conservation
3. Industry (feedstock, pre-conversion and conversion)

The survey was distributed to stakeholders in the Western Montana Corridor (WMC), Mid-Cascade to Pacific (MC2P), and the Columbia Plateau (CP) as part of an ongoing partnership with University of Idaho's Wood-Based Biofuels Project. As of survey completion in mid-November 2013, the overall response rate for all regions was 37%. During Phase 1 of surveying, 53 out of 151 surveys were completed by stakeholders in the WMC, and 19 out of 109 surveys were completed by C2P stakeholders. During Phase 2 of surveying, 13 out of 59 surveys were completed by WMC stakeholders, 68 out of 158 surveys were completed by C2P stakeholders, and 91 out of 391 surveys were completed by C2P stakeholders. During Phase 3 of the surveying process, 610 surveys were sent out to all non-respondents from all regions (see Figure SM-EPP-1.2). Eighty surveys were completed as a result of these mailings.

Additional efforts were made to boost response rates of environmental and tribal groups. Both of these stakeholder groups had lower response rates than other stakeholder groups. Working with Laurel James and Bob Dingethal, key contacts from the 2013 annual NARA meeting in Corvallis, allowed us to compile contact information for an additional 26 ENGOS and 14 tribal contacts. An email with the survey link was sent to each new contact, followed by a reminder email approximately one week later. Approximately four surveys were completed as a result of these additional efforts.

Non-response bias testing has been completed and analysis of these surveys in in progress. Comparisons were made between participants who completed the survey the first time they were contacted and participants who completed the survey after several contact attempts were made. Stakeholders who did not complete the survey were contacted via phone and asked to complete a short (5-10 min) version of the survey. The results generated by the phone surveys are being compared to the overall survey results to determine if there are any statistically significant differences between early and late respondents.

Findings presented at the Fall 2014 NARA conference in Seattle indicated that stakeholders who perceive themselves as more knowledgeable in various topics related to biofuels, production, and forest health are more supportive of using woody biomass to produce liquid jet fuel. Analysis is currently underway to determine the demographics of participants who are less knowledgeable about various topics in order to better understand how the education and outreach team can mitigate these knowledge gaps. Specifically, analysis is being done to determine if there are differences among demographic groups in terms of their knowledge, what demographic factors participants with similar concerns and levels of agreement have in common, and what are the main concerns and questions raised by participants by state.

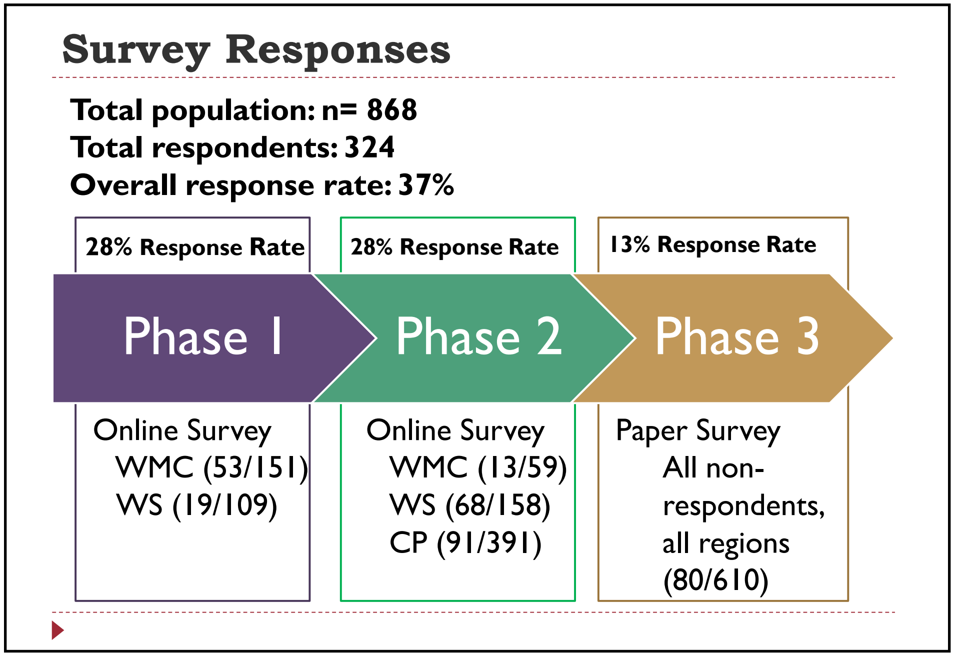


Figure SM-EPP-1.2. NARA Stakeholder Survey response information.

Qualitative survey research presented at the Association of Colligate Schools of Planning conference in Philadelphia at the beginning of November discussed analysis of qualitative survey results including how participants see current forest conditions in their regions, and the possible benefits or negative effects of using woody biomass in their region. Participants' answers were compared by stakeholder group, region, and state. Findings show that stakeholders support utilizing woody biomass to produce bioenergy or a refined liquid biofuel. We also know that stakeholders are concerned about the conditions of private and public forests and see that there are benefits to removing woody biomass to support a liquid biofuels industry that would positively impact forest conditions, regional economies, and reduce fire hazards. However, respondents do have concerns related to the negative impacts on soil and wildlife by the removal of forest residuals. Qualitative analysis is complete and a paper discussing these findings is in the process of completion.

Additional analysis of survey data is ongoing and is being written about in detail in J. Moroney's dissertation Barking up the Right Tree: A Social Assessment of Wood to Liquid Biofuels Stakeholders in the Pacific Northwest. The dissertation is formatted into three chapters which are written as journal articles to be submitted to peer review journals. The articles cover an overview of the quantitative survey findings, a write up of the qualitative survey findings, and an application article that identifies stakeholder concerns and questions and recommends outreach methods. J. Moroney will defend her dissertation in April, 2015, and the three articles will be revised and submitted to journals after.

Task SM-EPP-1.5. Refine Operationalization – Social Hotspot Analysis. (M. Gaffney, S. Hoard, S. Rijkhoff, *N. Martinkus, W. Shi, N. Lovrich, J. Pierce, P. Smith, and M. Wolcott)*

Biogeophysical and Social Assets for Biorefinery (BR) Site Selection

The refined operationalization of the social asset modeling has been completed. DGSS researchers have created regional and national benchmark metrics to assist in identifying receptive communities for biofuel facilities. The team argues that benchmark measures should be met or exceeded to be considered for site-selection. The benchmark measures were developed utilizing regional and national averages to determine appropriate cut-off points for each county. These benchmark metrics are available for the entire United States and can be incorporated into decision-making metrics. They allow for flexibility in the decision-making process as they can be adjusted based on the cut-off points that decision-makers view most appropriate. The national dataset and codebook developed for social asset measures is available to be incorporated in decision-making metrics.

The new Community Asset Assessment Model (CAAM) was combined with biogeophysical (BGP) asset modeling utilized in the Martinkus et al. (2014) publication to identify potential communities in the Western Montana Corridor region. The refined analysis of the Western Montana Corridor, which combines biogeophysical assets with more complete measures of each social asset component, has been submitted for review to the Journal of Politics.

The refined Community Assessment Model (CAAM) is being utilized in the MC2P, the entire NARA region and will applied to another US region (TBD) starting in Fall 2015. Currently, the refined CAAM model is being combined with an updated biogeophysical analysis to analyze the MC2P and the entire NARA region. The biogeophysical analysis is being updated to incorporate NARA's new goals of retrofitting existing facilities. Biogeophysical asset modeling is updating site selection models developed by Integrated Design Experience (IDX) students in cooperation with DGSS researchers and determining appropriate weights for each component. This refined BGP analysis is being combined with the CAAM modeling to identify potential communities in the MC2P and entire NARA region. A manuscript updating this analysis is being prepared for the Journal of Biomass & Bioenergy, expected submission is Summer 2015.

The team is also working on applying the refined CAAM modeling to another US region (TBD). In order to ensure that the social assets are appropriately weighted for each region and can predict successful community-level implementation, new US case studies for retrospective analysis are being identified. The benchmark measures developed for each social asset will be examined to determine their predictive capacity and appropriate weighting for analysis in the new region. In combination with biogeophysical assets, the model will be utilized to determine appropriate US communities. Ground truthing will then be utilized to validate selected communities and ensure support.

Task SM-EPP-1.6. Techno-Market Assessment: Jet Fuels. (I. Iborrola, M. Gaffney, S. Hoard, W. Shi and P. Smith)

Refinery-to-Wing (R-t-W) Stakeholder Assessment

The major objectives of the R-t-W SH assessment:

1. Identify key aviation fuel supply chain stakeholder groups in the Pacific Northwest region;
2. Assess perceptions of key regional stakeholders regarding the opportunities and barriers of blended Alcohol-to Jet Fuel (AJFs) into the aviation fuel supply chain; and
3. Examine AJF molecule tracking options for ASTM D7566 approved Alternative Jet Fuels (AJFs) blends into the ASTM D1655 Jet A1 aviation fuel supply chain.

The team has identified key aviation supply chain stakeholder groups in the four-state NARA region of Washington, Oregon, Idaho, and Montana for primary data collection via personal communications and secondary data search. Both in-person interview protocols including scripts, interviewee lists and methodology, and an online e-survey questionnaire have been developed to assess stakeholders' awareness and perceptions. These vehicles are ready to field, and will be implemented Summer 2015.

e-Survey

The e-survey questionnaire is designed to assess regional airport managers' awareness, opinions and perception regarding the opportunities and barriers to adding blended alternative jet fuel (AJF) into the aviation supply chain. Additionally, factors affecting an economically viable AJF production industry in the NARA region such as policy certainty, biorefinery technology breakthroughs, financial incentives, and the sustainability of AJFs are also addressed. Pre-testing has been completed and adjustments are being made based on the feedback. We are also seeking the cooperation of relevant and credible airport leadership groups.

In-person interviews

Stakeholder interviews are designed for in-depth exploration on select topics such as AJF molecule tracking from airport managers, airlines, Fixed Base Operators (FBOs), terminal/pipeline operators, and fuel resellers. As AJFs enter the jet fuel supply chain, questions arise regarding AJF molecule tracking. Demonstration-oriented AJFs are produced in batches and delivered in dedicated consignments. However, as "drop-in" AJF production is scaled-up, tracking blended AJF molecules becomes an issue.

Biofuels Policy

This work was designed to better understand biofuels policies and the impacts of such regulations on the development of the biofuels industry. Output from this work includes a literature review, peer-reviewed book chapter (Dahmann et al. 2015; accepted and in-press), several posters, and two presentations. The book chapter reviewed the history of U.S. federal renewable energy (bio)fuel policies and state developments, including of several state-level case studies, as well as, advancements in the forestry and U.S. military arenas.

Task SM-EPP-1.7. Economic, Environmental, & Social Assessment: Jet Fuels (R. Pelton, Luyi Chen, T. Smith)

A comparative life cycle analysis of different fossil/biomass derived PET bottle production scenarios has been finalized. Figure SM-EPP-1.3 displays the system boundary of the system considered in that analysis. Although the primary focus is to develop cradle to factory gate LCA for PET bottles produced from forest residues (woody biomass) derived terephthalic acid, the analysis also includes other partially/fully bio-based PET bottle scenarios to deliver more robust comparative results. Table SM-EPP-1.2 illustrates the 12 scenarios, where they are a complete permutation of three terephthalic acid (TA) production schema (from fossil, wood and corn stover) and four ethylene glycol (EG) production methods (from fossil, corn, switchgrass and wheat straw). Figure SM-EPP-1.4 shows the breakdown of impacts generated form unit processes for different TA/EG production methods combinations. As TA contributes to approximately 70% of the mass in final PET bottle product and EG takes about 30%, impacts generated from TA production should not exceeds the 70% threshold to be considered as a viable production scenario. However, for most of impact categories both corn stover and wood derived TA lead to more than 70% impacts. However, as Figure SM-EPP-1.5 shows the cumulative results, where displacement credits (avoided impacts) are taken into consideration, forest residue PET bottles have significantly lower environmental profile than fossil and corn stover bottles. It is obvious that the advantage of NARA PET bottles (from forest residue isobutanol) outshine traditional fossil bottles as well as corn stover bottles, however the results are highly dependent on allocation methods applied, value of excess electricity produced from the systems, and the value of impacts generated by slash pile burning of forest residues are two key factors contributing to credits of the bottle production system.

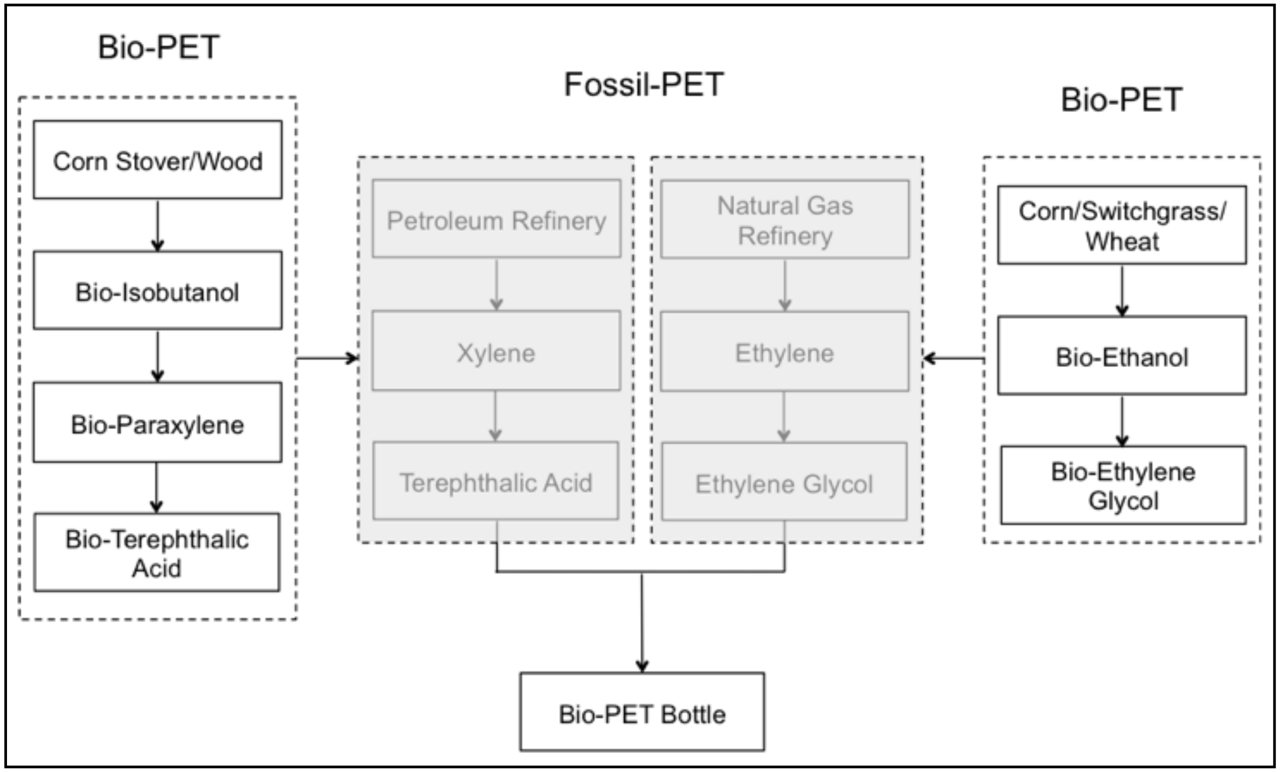


Figure SM-EPP-1.3. System Boundary of Comparative Life Cycle Analysis

Table SM-EPP-1.2. PET Bottle Production Scenarios of Comparative Life Cycle Analysis

TA/EG	Fossil	Corn	Switchgrass	Wheat Straw
Fossil	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Wood	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Corn Stover	Scenario 9	Scenario 10	Scenario 11	Scenario 12

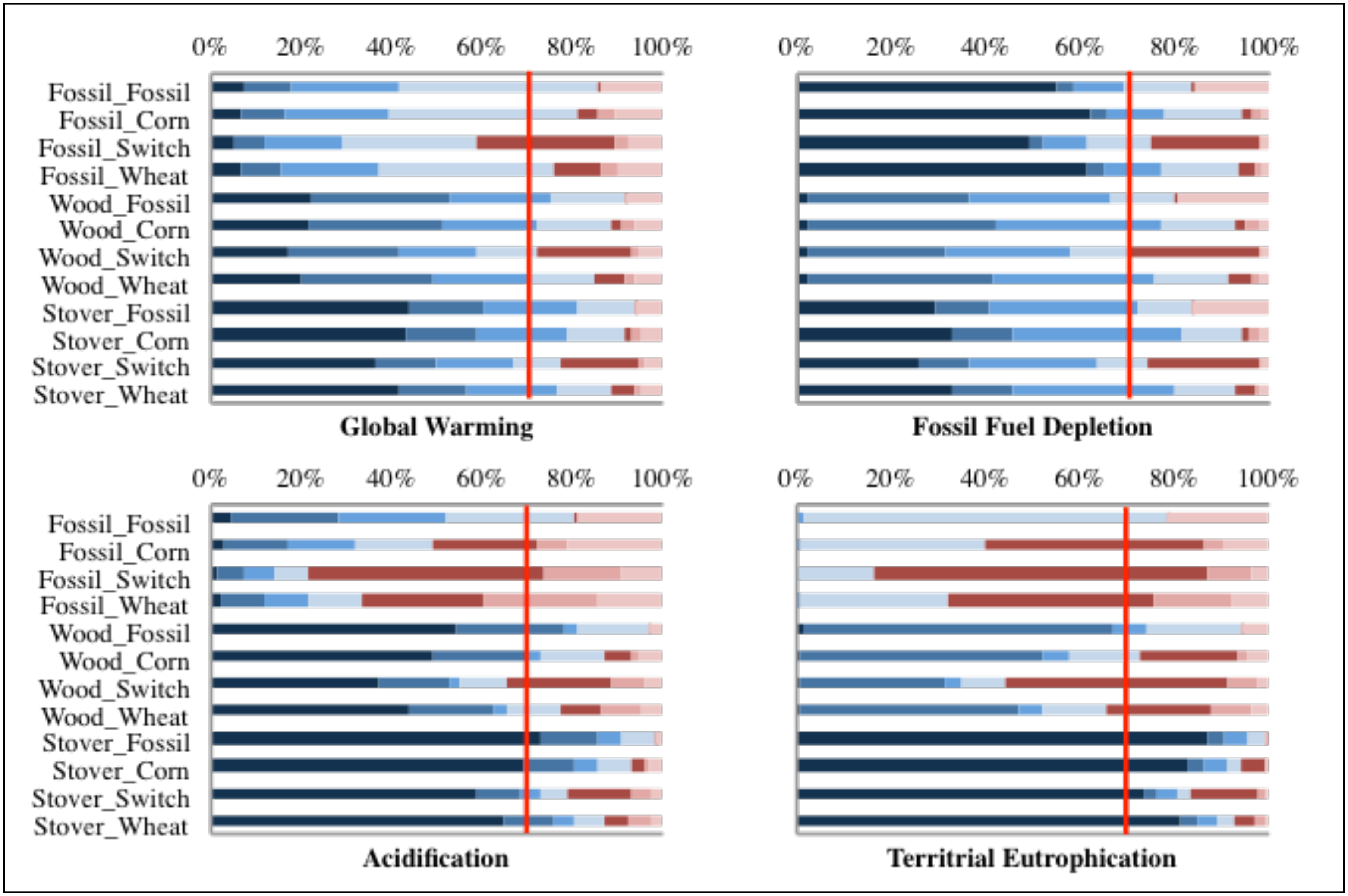
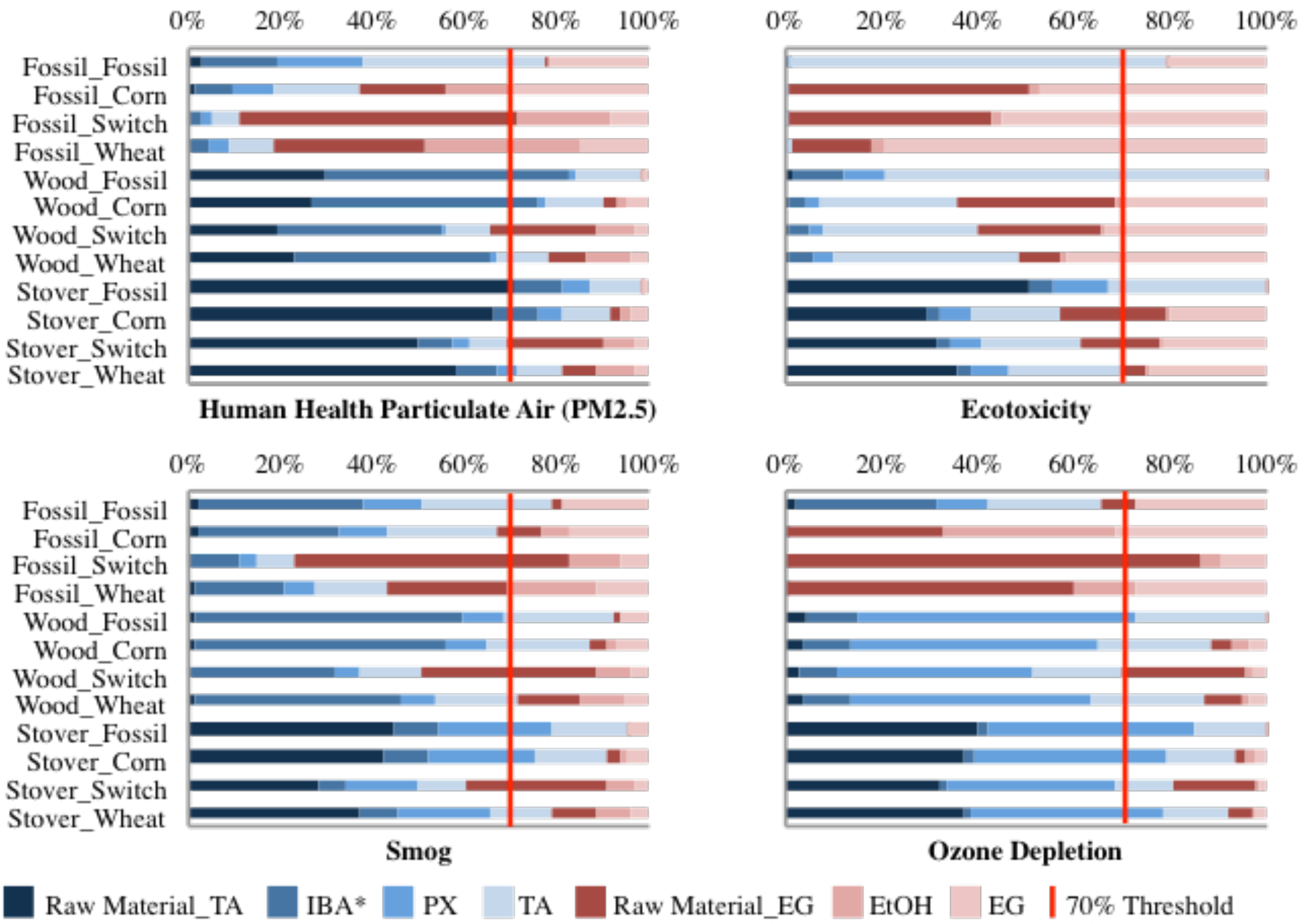


Figure SM-EPP-1.4a. Comparison of impacts generated from unit process for manufacturing terephthalic acid and ethylene glycol of 12 PET bottle production scenarios (scaled to 100%). Scenarios are marked as '(Raw material for TA)_(Raw material for EG)' at the vertical axis. Functional unit is 1 kg PET bottle final product. Each color block implied the impacts caused by conversion processes to acquire a particular intermediate product.



*For fossil based TA, no IBA is produced. PX are directly processed from a series of petroleum refinery co-products, so the IBA blocks for Fossil TA actually indicated impacts from petroleum refinery co-products.

Figure SM-EPP-1.4b. Comparison of impacts generated from unit process for manufacturing terephthalic acid and ethylene glycol of 12 PET bottle production scenarios (scaled to 100%). Scenarios are marked as '(Raw material for TA)_(Raw material for EG)' at the vertical axis. Functional unit is 1 kg PET bottle final product. Each color block implied the impacts caused by conversion processes to acquire a particular intermediate product.

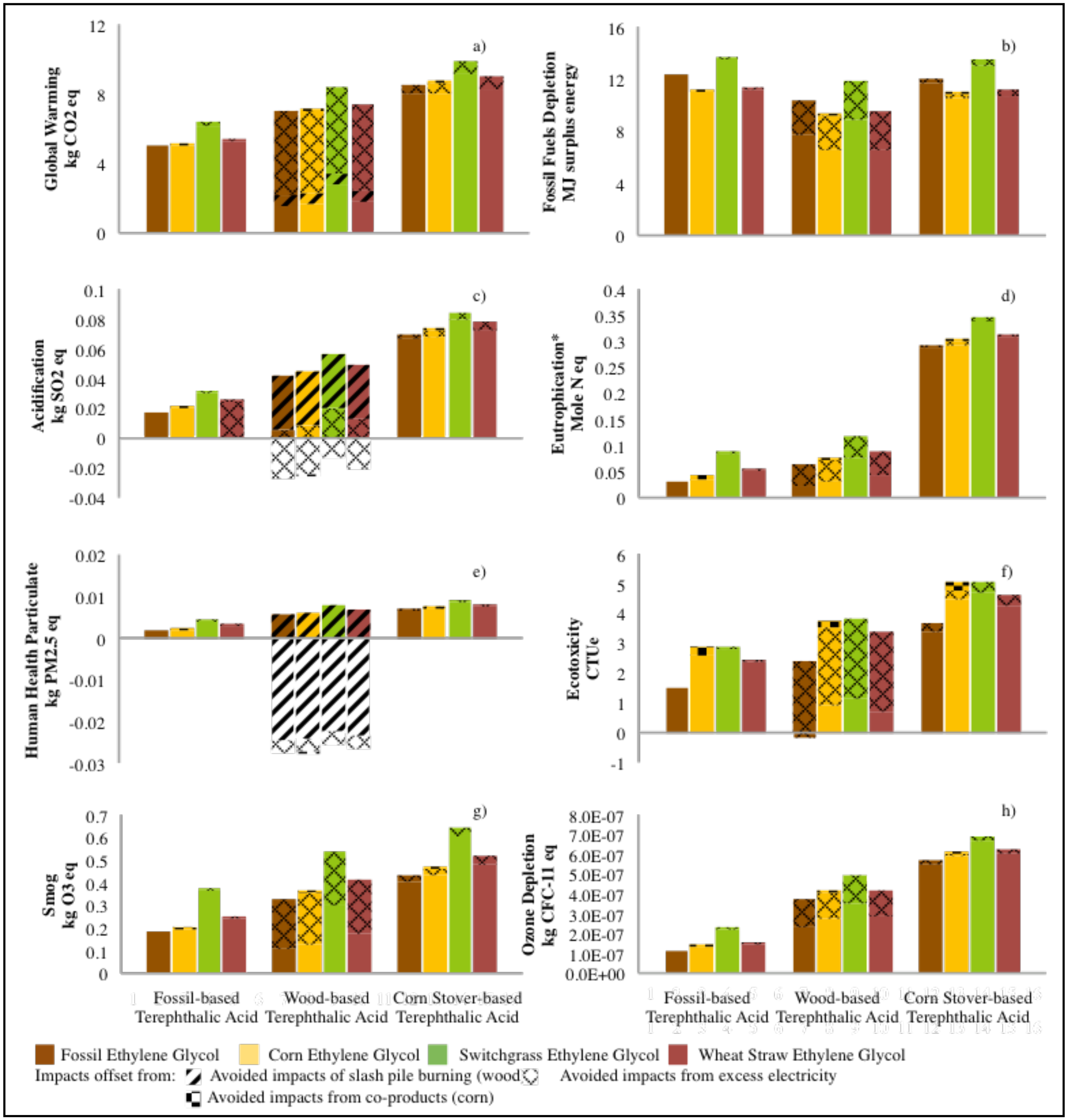


Figure SM-EPP-1.5. Comparative LCA results of 12 PET bottle production scenarios with terephthalic acid and ethylene glycol derived from different raw materials. a) IPCC Global Warming, exclude biogenic carbon (kg CO_2-Equiv.); b) TRACI Resource Depletion, fossil fuels (MJ surplus energy); c) TRACI Acidification (kg SO_2-Equiv.); d) Accumulated Exceedance (AE) Terrestrial Eutrophication Mole of N eq.); e) TRACI Human Health Particulate Air (kg PM2,5-Equiv.); f) TRACI Ecotoxicity (CTUe); g) TRACI Smog Air (kg O3-Equiv.); h) ReCiPe 1.08 Midpoint (H) – Ozone Depletion (kg CFC-11 eq).

Task SM-EPP-1.8. Techno-Market Assessment: Bio-Product Polymers (M. Chen, S. Cline, P. Smith)

Bio-Based Polymers

A techno-market assessment of selected bio-based polymers, which was initiated in January 2013, was completed by Year-3. Major research efforts have been focused on the bioplastics industry, including the global market and growth trend for the overall bio-plastics industry and comparisons between bioplastics and traditional plastics. Bio-PET30, projected to account for over 80% of total market share in 2016, is analyzed regarding value chain and market-driven factors [summarized in April 2014 Cumulative Report].

The Structure of U.S. Biorefineries

A review of secondary sources regarding U.S. biofuel biorefineries has been completed. Four biofuel biorefinery groups have been identified: corn grain ethanol biorefineries (N=207), biomass-based diesel biorefineries (N=140), "bolt-on" and "stand-alone" cellulosic biofuel biorefineries (N=58), and algae biofuel biorefineries (N=7). The competitive forces within the U.S. road transportation fuels industry, including established rivals, threat of substitutes and new entrants, and power of suppliers and buyers has been examined (Porter 1985) to help academic researchers, practitioners and policy makers better understand the relative position of biofuels in terms of opportunities and barriers. Compared to petro-based gasoline and diesel, renewable biofuels enjoy the benefits of lower GHG emissions, sustainability and energy security. However, substitutes and new entrants face entry barriers to the U.S. transportation fuel market, including feedstock costs and logistics, technical obstacles, and uncertainty in government policies. This work addresses potential barriers of biofuels scale-up; that is, production of value-added co-products (e.g. bio-based chemicals) and the formation of strategic relationships. A manuscript is in progress with submission plans for Summer 2015.

We have systematically identified renewable sugar (especially cellulosic sugar) and bio-chemical produc-

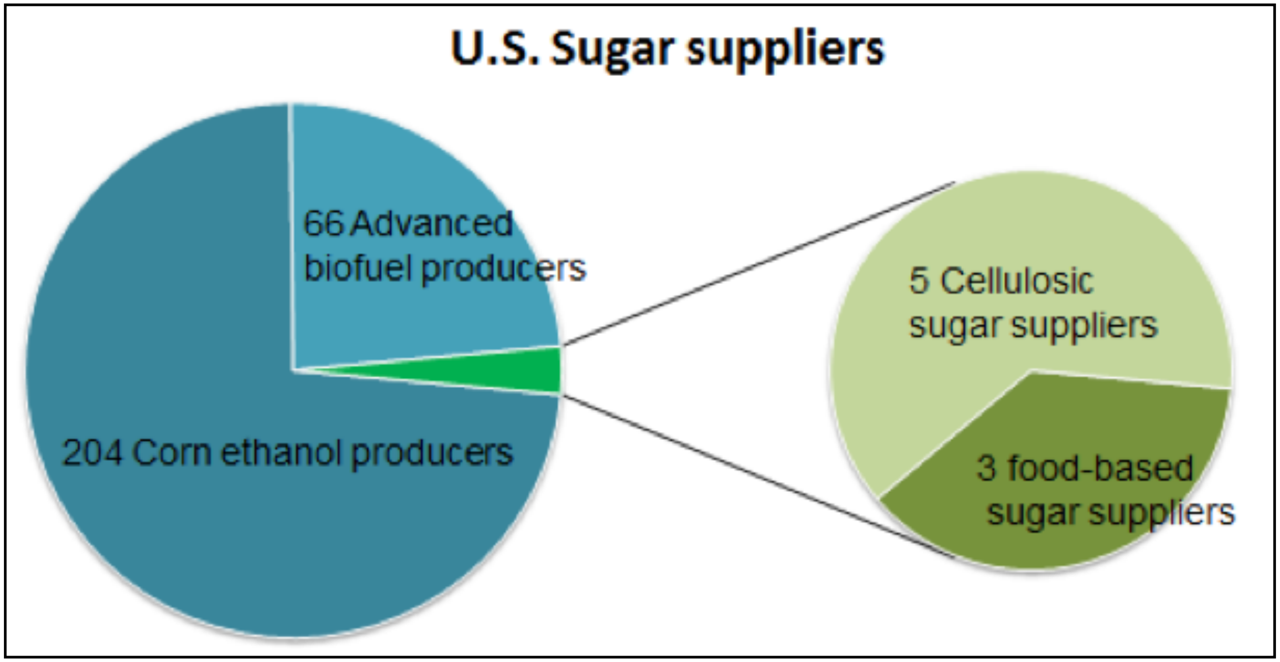


Figure SM-EPP-1.6. U.S. sugar suppliers

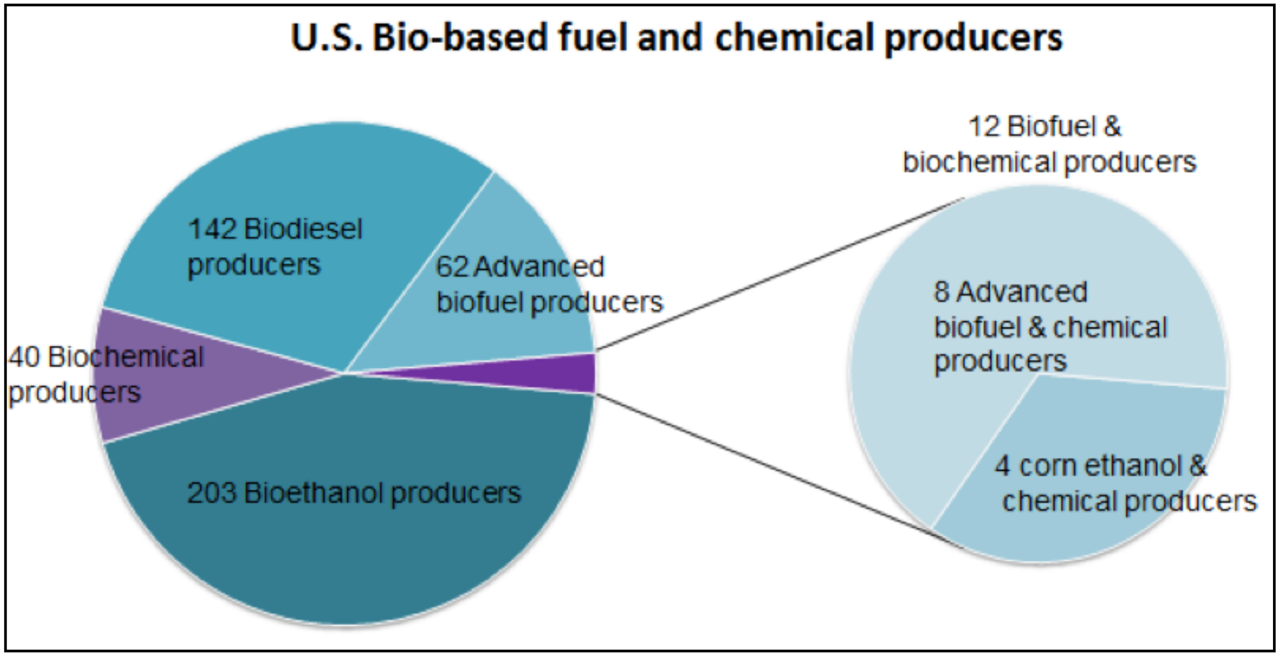


Figure SM-EPP-1.7. U.S. biofuel and biochemical producers

ers. To date, eight sugar suppliers have been identified through non-probability (judgmental or purposive) sampling (Figure SM-EPP-1.6), including:
(1) Food-based sugar suppliers: such as ADM, Cargill, Abengoa; and
(2) Cellulosic sugar suppliers: such as Virdia, BlueFire Renewables, Renmatix, Beta Renewables and Sweetwater Energy (Soare and Kersh, 2014).

In addition, we have identified forty biochemical producers, 207 bioethanol producers (of which 4 also produce biochemicals), and 70 advanced biofuel producers (of which 8 also produce biochemicals) (Figure SM-EPP-1.7).

The four corn ethanol and biochemical producers:
(1) ADM: propylene glycerol, ethylene glycerol;
(2) POET: specialty chemicals (edible protein product);
(3) Cargill: acrylic acid;
(4) GEVO: isobutanol;

The eight advanced biofuel and biochemical producers:
(5) Dupont T&L: 1,3-propanediol (PDO), 1,4-BDO;
(6) Virent: BTX (group of aromatic hydrocarbons benzene, toluene and xylene);
(7) Aemetis: isoprene;
(8) OPXBio: fatty acids, acrylic acid;
(9) Amyris: farnesene;
(10) Solazyme: algal oil
(11) LanzaTech: biobutanediene;
(12) Cobalt Technologies: biobutanediene

Future Research

The overall goal of the primary data collection effort is to better understand cellulosic and algae biofuel biorefinery product portfolio and new product development decisions and to explore strategic relationships in this industry sector. Previous literature indicates that alliances provide access to resources, markets, and technical information, and help companies to achieve economies of scales (Gomes et al., 2014; Ulaga and Chacour, 2001).

Co-Product Market Opportunity (in-progress)

1. Examine cellulosic and algae biofuel biorefinery (BR) value-stream outputs (product portfolios) via mixed method multi-stage design (May 2015 – July 2016).

   a. e-Surveys of cellulosic and algae biofuel BRs:
   • Examine cellulosic/ algae BRs potential to produce bio-based chemicals and/or sugars;
   • Investigate the drivers and barriers for developing new bio-based chemicals.

   b. Phone interviews of select BRs (based on 1-a findings):
   • Examine potential sources of new ideas about bio-based chemicals;
   • Develop a theoretical and conceptual research framework to examine the perceived factors affecting new idea/product selection; and
   • Explore current and future specific classes of bio-based chemicals of greatest interest to cellulosic and algae biofuel BRs.

2. Evaluate strategic relationships across value chains of cellulosic/algae-based products via qualitative design (May 2015 – July 2016).

   c. In-depth interviews:
   • Define and categorize buyer-seller relationships across the value chain of cellulosic/ algae-based biofuels, biochemicals and sugars; and
   • Investigate the benefits and impediments of forming long-term strategic relationships.

Lignin in Activated Carbon Markets:

Lignin typically represents 15% to 40% of a biorefinery's lignocellulosic feedstock and identifying value-added market opportunities is critical to a firm's bottom line (Ragauskas n.d.; Smolariski 2012; McCarthy 1999). Lignin, as a feedstock, however, is limited due to restricting factors outlined by Vistal and Kraslawski (2011) including:

- The recovery of lignin from the product streams
- The purification of lignin
- The heterogeneous structure of lignin, and
- The unique reactivity of lignin.

Research suggests lignin may be a viable and economic feedstock for the manufacturing of activated carbon for mercury sequestration from power plant flue gas due to its high carbon content and abundant supply (Ragan et al. 2011; Carrott et al. 2007). Experts agree the activated carbon market has great potential to drastically grow over the upcoming years. Greiner et al. (2010) projected the volumes of activated carbon (AC) to sequester mercury from flue gas streams to grow from 35,000 metric tons in 2009 to 420,000 metric tons by 2014. Additionally, Transparency Market Research (PRWeb 2013) projected the powdered activated carbon market to grow at nearly 14% per year from 2013 to 2019.

The growth in the activated carbon market is due largely to the Mercury and Air Toxic Standards (MATS) mandate implemented on 16 December 2011. MATS affects both new and existing U.S. coal and oil-fired electric utility generating units greater than 25 megawatts (MW) and supplying electricity to the National Power Grid (EPA 2011). Approximately two-thirds of the U.S. coal fired capacity has already complied with MATS to allow operation through 2016 (EIA 2014). MATS will require coal-fired power plants to capture as much as 90% of mercury released into the atmosphere.

In 2012 the U.S. activated carbon market was valued at $1.9 billion, at the current CAGR growth rate in 2019 the activated carbon market is expected to be valued at $4.2 billion (PRWEB 2013) due largely to the new EPA emissions standards. Further, according to Transparency Market Research (2013), the powdered activated carbon compound annual growth rate is estimated at 13% (PRWeb, 2013).
Exploratory work indicates that activated carbon is purchased either directly from the supplier or via a chemical brokerage company (Carter 2015). Upon delivery by rail, truck, or barge, the AC is then blown

via flexible tubing into a silo where it is stored until needed (The Babcox and Wilcox Company 2015; Fesseden 2012). Each power plant uses activated carbon differently (Carter 2015) to address mercury emissions which are regulated on a quarterly basis (Carter 2015). Some power plants run their AC injection system continuously due to the type of coal being burned, while others run the system sparingly to meet quarterly regulations.

The population of coal-fired power plants who may potentially buy lignin-based AC has been identified (EIA 2015) exploratory content analysis of current AC suppliers' websites conducted and a database and map developed in preparation of primary data collection. Content analysis identified 33 AC (for this application) product and service attributes to be refined and tested in interviews and surveys of AC buyers. The next step is to query these potential buyers to better understand the value proposition for NARA AC vis-à-vis existing AC products and to better delineate the product and service characteristics buyers desire in an AC for mercury sequestration from coal-fired power plant flue gas.

The EPA has recently (Feb 2015) released comments regarding an updated MATS proposed rule. The edited rule addresses issues regarding how plant malfunction reporting is accomplished. Moreover, the open comment period remains open through April 3rd, 2015. Comments will be addressed and a new proposed rule will be published. As of the recent publication, the MATS implementation, scheduled for April 2016, remains on schedule.

Task SM-EPP-1.9 Economic, Environmental and Social Assessment; Bio-Product Polymers (R. Pelton, L. Chen, J. Schmitt, T. Smith)

Several life cycle assessment iterations for activated carbon and paraxylene have been completed to begin to assess the environmental implications of different co-product output configurations. Each iteration reflects the changes in assumptions and data that have resulted from ongoing communication with the NARA TEA team. It is clear from these assessments that the type and quantity of co-products can have significant effects on the greenhouse gas emissions of the primary jet-fuel products due to the recommended methods for allocating environmental impacts, and the substitute product choices (such as substituting lignin fuels for fossil fuels to produce internal energy). This in turn can have significant implications for the ability of the jet fuel to adequately meet the Renewable Fuels Standard GHG emission reduction targets, which can affect the ability of the refinery to secure the sale of RIN credits, thereby potentially bringing the economic viability of the refinery into question.

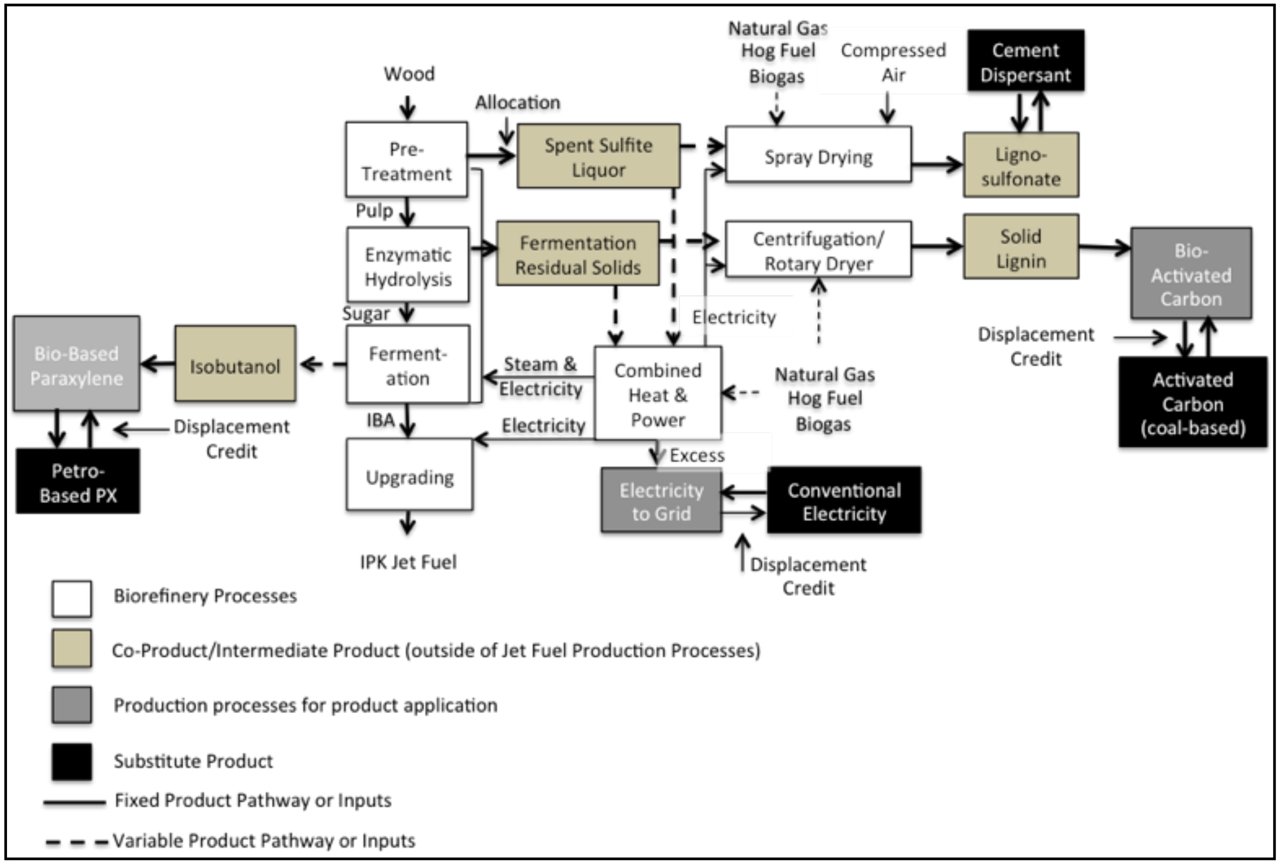


Figure SM-EPP-1.8. Biorefinery co-product options and corresponding methods to allocate impacts.

To produce the economically optimal quantity and type of co-products under a variety of market conditions while considering the environmental impacts, a mixed integer linear programming (MILP) optimization model is being constructed. The MILP considers the marginal environmental impacts of product outputs, the marginal operating costs, and the marginal sales prices. The marginal environmental impacts have been determined using information from the NARA LCA and TEA team, as well as various assumptions taken from the literature (Davis et al 2013; Humbird et al 2011). Recent adjustments to assumptions and data will be incorporated in the beginning of June, once coordination with the technical economic assessment team occurs in May. The marginal operating costs have been determined using the NREL techno-economic assessment of the isobutanol (from corn stover) to renewable diesel pathway (Davis et al 2013; Humbird et al 2011), and the marginal prices have been determined from a variety of literature and market sources. The co-products under consideration for potential product output options, and the corresponding recommended allocation methods that will be used are depicted in Figure SM-EPP-1.8. The optimization model is currently specified to reflect the annually optimal product outputs for validation purposes, however this will be later altered to a multi-period specification to reflect more frequent changes in market prices and the possibility to store product outputs for sale in alternative periods under more favorable market price conditions.

In addition to bioenergy research directly addressing the NARA Isobutanol pathway, additional research exploring economic assessment of biomass gasification technologies and their integration with concentrated solar technologies for process heat was also conducted. Implications of this work identify competing energy technologies for large scale biomass utilization in the western united states which could be economically viable, even at reasonably low product gas prices (approximately $4.50/MBtu and higher) and significant facility capital costs ($60-$100 million). The work – while largely funded by outside sources, but leveraging knowledge gained from this project – resulted in a publication in Biomass and Bioenergy.

Recommendations | Conclusions

We continue to struggle a bit with coordination with other groups creating information critical to LCA modeling for the EPP Team, however, we are planning a meeting for the end of May to rectify these issues. In general, timing has been a challenge, but we have made progress in developing our methods and approaches based on literature-driven assumptions and plan to update the models with NARA specific data this summer.

Task SM-EPP-1.1. "Public" stakeholders (SHs): demographic, psychographic, and market-specific assets through dataset analysis (Leigh Stowell, Rupasingha, and Roper-Putnam). (N. Martinkus, W. Shi, N. Lovrich, J. Pierce, M. Gaffney, S. Hoard, P. Smith, M. Wolcott)

Completed with published journal output – Biomass & Bioenergy

Task SM-EPP-1.2. Review Sustainability Approaches: ecolabels, stds., product claims, LCA/EIO data sources & models. (R. Pelton, Luyi Chen, and T. Smith)

Completed with published journal output – J. of Industrial Ecology

Task SM-EPP-1.4. "Informed" stakeholder interaction/operationalization (pop's., sampling, constructs, protocols). (J. Moroney, T. Laninga, M. Gaffney, and S. Hoard, K. Gagnon, P. Smith)

Findings show that stakeholders support utilizing woody biomass to produce bioenergy or a refined liquid biofuel. They are also concerned about the conditions of private and public forests and see that there are benefits to removing woody biomass to support a liquid biofuels industry that would positively impact forest conditions, regional economies, and reduce fire hazards. However, respondents do have concerns related to the negative impacts on soil and wildlife by the removal of forest residuals.

Qualitative analysis is complete and a peer-reviewed journal article is in progress. Additional quantitative and qualitative analysis of survey data is in progress and J. Moroney's dissertation "Barking up the Right Tree: A Social Assessment of Wood to Liquid Biofuels Stakeholders in the Pacific Northwest" will be completed May 2015 with additional journal articles to be submitted in 2015.

Task SM-EPP-1.5. Refine Operationalization – Social Hotspot Analysis. (M. Gaffney, S. Hoard, S. Rijkhoff, N. Martinkus, W. Shi, N. Lovrich, J. Pierce, P. Smith, and M. Wolcott)

Completed a refined operationalization of the social asset modeling has been completed and combined with biogeophysical (BGP) asset modeling (Martinkus et al. 2014 – Biomass & Bioenergy). A refined analysis of the Western Montana Corridor, which combines biogeophysical assets with more complete measures of each social asset component, has been submitted for review to the Journal of Politics.

The refined Community Assessment Model (CAAM) is currently being deployed in the MC2P and the entire NARA region. A manuscript updating reflecting these refinements is being prepared for the Journal of Biomass & Bioenergy for Summer 2015. Future efforts will apply the CAAM to other geographic regions within the US (TBD).

Task SM-EPP-1.6. Techno-Market Assessment: Jet Fuels. (I. Iborrola, M. Gaffney, S. Hoard, W. Shi and P. Smith)

Refinery-to-Wing Stakeholder Assessment: R-t-W SH's have been identified in the NARA region. Primary data collection via in-person interviews and an online e-Survey will be implemented Summer 2015. The e-survey assesses regional airport managers' awareness, opinions and perception regarding the opportunities and barriers to adding blended alternative jet fuel (AJF) into the aviation supply chain. Additional SH interviews will examine AJF molecule tracking from airport managers, airlines, Fixed Base Operators (FBOs), terminal/pipeline operators, and fuel resellers.

Biofuels Policy: Completed with in-press peer-reviewed book chapter output - Dahmann et al. 2015.

Task SM-EPP-1.7. Economic, Environmental, & Social Assessment: Jet Fuels (R. Pelton, Luyi Chen, T. Smith)

Completed a comparative life cycle analysis of different fossil/biomass derived PET bottle production scenarios.

Task SM-EPP-1.8. Techno-Market Assessment: Bio-Product Polymers (M. Chen, S. Cline, P. Smith)

Bio-Based Polymers

Completed an overview of the bioplastics industry, including the global market and growth trend for the overall bioplastics industry and comparisons between bioplastics and traditional plastics. Bio-PET30, projected to account for over 80% of total market share in 2016, was examined regarding value chain and market-driven factors [summarized in April 2014 Cumulative Report].

The Structure of US Biorefineries

Completed a review of secondary sources with mapping and datasets regarding U.S. biofuel biorefineries (n=412). Currently examining cellulosic and algae biofuel biorefinery (BR) value-stream outputs (product portfolios) via mixed method multi-stage design and evaluating strategic relationships across value chains of cellulosic/algae-based products via qualitative design (May 2015 – July 2016).

Lignin in Activated Carbon Markets:

Completed a preliminary examination of lignin value-added markets and identified activated carbon as a potential high-growth market for mercury sequestration from power plant flue gas due. AC growth is due largely to the US EPA Mercury and Air Toxic Standards (MATS) mandate implemented on 16 December 2011. Potential AC buyer populations have been identified and primary data collection is scheduled for Summer-Fall 2015 to: (1) better understand the value proposition for NARA AC vis-à-vis existing AC products; and (2) delineate the product and service characteristics buyers desire in an AC for mercury sequestration from coal-fired power plant flue gas.

Task SM-EPP-1.9 Economic, Environmental and Social Assessment; Bio-Product Polymers (R. Pelton, L. Chen, J. Schmitt, T. Smith)

Completed several life cycle assessment iterations for activated carbon and paraxylene – leveraging other work – resulted in a Biomass & Bioenergy publication. Plan to assess the environmental implications of different co-product output configurations using a mixed integer linear programming (MILP) optimization model. We are also exploring economic assessment of biomass gasification technologies and their integration with concentrated solar technologies for process heat.

Physical and Intellectual Outputs

PHYSICAL OUTPUTS

Database and Dataset Development :

1. Continued refinements and revised weightings for a national social assets database to examine local, regional and national social collaborative capacity;
2. A biomass-to-biofuel stakeholder dataset for the NARA region;
3. Updated US coal-fired electric generating unit population – to examine the market opportunity for activated carbon for mercury and other metals emissions mitigation.
4. Updated and current datasets to identify, classify and locate all US biorefineries (n=412);

Model Development:

1. Bio-PET LCA model was established and completed in GaBi LCA software;
2. Environmental and economic optimization model was established in GAMS optimization software;
3. A revised Community Assets Assessment Model (CAAM) to help explain biomass-to-biojet economic development opportunities in the NARA region.
4. Isobutanol conversion to jet fuel process modeling.
5. Modeling of alternative production pathways (specifically regarding feedstock and pretreatment options).
6. Co-product use and allocation scenarios modeled – including emission credit calculations for co-product scenarios

REFEREED PUBLICATIONS

Rijkhoff, S.A.M., Hoard, S.A., Gaffney, M.J., & Smith, P.M. (2015). Community Asset Attribute Modeling: Applying Social Data to Inform Biofuel Site Selection. Journal of Politics. Submitted.

Martinkus, N., Shi, W., Lovrich, N., Pierce, J., Smith, P., & Wolcott, M. (2014). Integrating Biogeophysical and Social Assets Into Biomass-to-Biofuels Supply Chain Siting Decisions. Biomass & Bioenergy 66,410-418.

Pelton, R.E.O. & Smith, T.M. (2014). Hotspot Scenario Analysis: Comparative Streamlined LCA Approaches for Green Supply Chain and Procurement Decision Making. Journal of Industrial Ecology, doi: 10.1111/jiec.12191.

BOOK CHAPTERS

Dahmann, K. K.S., Fowler, L.B. & Smith P.M. (2014). United States Law and Policy and the Biofuel Industry, included in a Volume on “The Law and Policy of Biofuels” co-editors, Yves Le Bouthillier, Annette Cowie, Paul Martin and Heather McLeod-Kilmurray, Edward Elgar Publishing, as part of the IUCN Academy Series. Submitted June 30, 2014. Accepted and in press.

RESEARCH PRESENTATIONS

Dahmann, K.S., P.M. Smith, and L.B. Fowler. 2014. U.S. Biofuel Law & Policy: An Unsteady Past and an Uncertain Future For Second Generation and Third Generation Biofuels and Beyond. Presentation given at the TAPPI International Bioenergy & Bioproducts Conference 2014, Session on Impacts of Policies and Incentives, Sept. 17-19, Seattle, WA.

Dahmann, K.S., P.M. Smith, and L.B. Fowler. 2014. U.S. BIOFUEL - LAW AND POLICY: An Unsteady Past and an Uncertain Future for 2nd & 3rd Generation Biofuels. Poster presentation at TAPPI International Bioenergy & Bioproducts Conference 2014, Session on Impacts of Policies and Incentives, Sept. 17-19, Seattle, WA.

Dahmann, K.S. L. B. Fowler, and Paul M. Smith. 2014. AVIATION AND ALTERNATIVE FUELS: The Law and Policy of First, Second, and Third Generation Biofuels. Poster presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Martinkus N. 2014. Assessing Existing Plant Assets for Biorefinery Siting. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Chen, L., Pelton, R.E.O, Smith, T. Comparative Life Cycle Analysis of GHG Emissions for Bio-PET Bottles, 2014 NARA Annual Meeting, Seattle WA, September 15, 2014.

Chen, M. 2014. Evolving Structure of U.S. Biorefineries & Market Opportunity of Renewable Chemicals. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Chen, M. and P. Smith. 2014. Evolving Structure of U.S. Biorefineries Industry. Poster presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Chen, M., P. Smith, and P. Venugopal. 2014. Market Opportunities and Challenges Facing the Economically Viable Production of Renewable Chemicals in U.S. Biorefineries. Poster presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Chen, M. and P.M. Smith. 2015. The Competitive Structure of the U.S. Transportation Fuel Industry. Poster presentation at PSU's College of Engineering Research Symposium (CERS). April 2, University Park, PA.

Cline, S.P. and P.M. Smith. 2014. NARA EPP Co-Product Market Opportunity: Lignin-Based Activated Carbon. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Cline, S.P. and P.M. Smith. 2014. The Lignin-Based Activated Carbon Market Opportunity. Poster presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Fowler, L., K. Dahmann, and P. Smith. 2014. "U.S. Biofuel Law & Policy: An Unsteady Past and an Uncertain Future for Second Generation Biofuels. Poster for NEWBio conference." July 31-Aug.1, Geneva, NY.

Laninga, T. 2014. NARA's Approach to Social Sustainability. Moderator. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Laninga, T. and J. Moroney. 2014. Wood to Wing: Stakeholder Perspectives on a Wood-based Biofuels Industry in the Northwest United States. Associated Collegiate Schools of Planning. Philadelphia, PA. November 1. 2014.

Moroney, J., and T. Laninga. 2014. Social Acceptability of a Biomass and Biofuels Supply Chain in the PNW. Abstract proposal accepted for presentation at the Pacific Northwest Wood-based Biofuels and Co-Products Conference. April 28-30, 2014. Seattle, WA.

Moroney, J. and T. Laninga. 2014. The Informed Stakeholder Assessment. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Ibarrola I. P. Smith, S. Hoard, and M. Gaffney. 2014. Refinery-to-Wing Stakeholders Assessment Approach. Poster presentation at the NARA Annual Meeting, Sept. 15-17 in Seattle, WA.

Pelton, R.E.O, Chen, L., Smith, T. Co-Product Implications on the Environmental Preference of Bio-Jet Fuel, 2014 NARA Annual Meeting, Seattle WA, September 15, 2014.

Rijkhoff, S., S. Hoard, M. Gaffney, P. Smith, N. Martinkus, N. Lovrich, J. Pierce and M. Wolcott. 2014. Refining Community Asset and Attribute Modeling: Applying Social Data to Inform Bio-Fuel Project Site Selection in the NARA Region. Poster presentation at the NARA Annual Meeting, Sept 15-17 in Seattle, WA.

Rijkhoff, S., S. Hoard, M. Gaffney, P. Smith, N. Martinkus, N. Lovrich, J. Pierce and M. Wolcott. 2014. Community Asset Assessment Modeling for Informed Biofuel Location Decision-Making. Paper presentation at the TAPPI International Bioenergy & Bioproducts Conf., Sept 17-19, Seattle, WA.

Rijkhoff, S., S. Hoard, M. Gaffney, P. Smith, N. Martinkus, N. Lovrich, J. Pierce and M. Wolcott. 2014. Community Asset and Attribute Modeling: Applying Social Data to Inform Bio-Fuel Site Selection. Presentation at the Pacific NW Political Science Association Annual Meeting, Oct 9-11 in Bend, OR.

Smith, P.M. and T.M. Smith. 2014. EPP Team Co-Product Market Opportunity. Presentation at the NARA Annual Meeting. Sept. 15-17 in Seattle, WA.

Smith, P.M. 2014. Social Assets Assessment and Biorefinery value chain outputs. Presentation at the FAA ASCENT Advisory Board Meeting, Oct. 16-17, Alexandria, VA.

Smith, P.M. 2015. Stakeholders Assessment and Biorefinery value chain outputs. Presentation at the FAA ASCENT Bi-Annually Meeting, Mar. 10-12, Alexandria, VA.

Smith, T.M. User-Inspired Scholarship Toward Sustainable Enterprise: Prioritization & Coordination of Sustainability across the Supply Chain, School of Natural Resources & Environment/Erb Institute, University of Michigan, Ann Arbor, MI, November 13, 2014.

Smith, T.M. Environmental Preferred Products from Biorefineries, 2014 NARA Annual Meeting, Seattle WA, September 15, 2014.

Venugopal. P., P. Smith, and Chen, M. 2014. Potential Technology Pathways for the Production of Alternative Jet Fuel. Poster presentation at NARA-SURE, Washington State University, Pullman, WSU. July 31.

References

1. Advanced Biofuels, A Truly Sustainable Renewable Future. Advanced Biofuels USA, www.AdvancedBiofuelsUSA.org.
2. Alicia Pelaez-Cid, A., M.M. Margarita Teutli-Leon. 2012. Lignocellulosic Precursors Used in the Elaboration of Activated Carbon- Characterization Techniques and Applications in the Wastewater Treatment, Dr. Virginia Hernandez Montoya (Ed.) www.intechopen.com/books/lignocellulosic-precursors-used-in-the-synthesis-of-activated-carbon-characterization-techniques-and-applications-in-the-wastewater-treatment/no-title-specified-. Accessed May 2013.
3. Agusdinata, D. B., Zhao, F., and DeLaurentis, D. A. (2012). Sustainability of Biojet Fuels: A Multiactor Life Cycle Assessment Approach. Potentials, IEEE, 31(1), 27-33.
4. Agusdinata, D. B., Zhao, F., Ileleji, K., and DeLaurentis, D. (2011). Life Cycle Assessment of Potential Biojet Fuel Production in the United States. Environmental Science & Technology, 45(21), 9133-9143. http://pubs.acs.org/doi/abs/10.1021/es202148g
5. Ahmedna, M., Marshall, W. E., and Rao, R. M. (2000). Production of granular activated carbons from select agricultural by-products and evaluation of their physical, chemical and adsorption properties. Bioresource Technology, 71(2), 113 - 123. http://www.sciencedirect.com/science/article/pii/S096085249900070X
6. Bailis, R. E. and Baka, J. E. (2010). Greenhouse Gas Emissions and Land Use Change from Jatropha Curcas-Based Jet Fuel in Brazil. Environmental Science & Technology, 44(22), 8684-8691. http://pubs.acs.org/doi/abs/10.1021/es1019178
7. Baker, C. G. J. and McKenzie, K. A. (2005). Energy Consumption of Industrial Spray Dryers. Drying Technology, 23(1-2), 365-386. http://www.tandfonline.com/doi/abs/10.1081/DRT-200047665.
8. Baltus, W, J. Beckman, D. Carrez, M. Carus, L. Dammer, R. Essel, H. Kaeb, J Ravenstijn, A. Mirabal, L. Scholz, F. Sibilla, and S. Zepnik. 2013. Bio-Based Polymers in the World. Ed. By A.S. Mirabal, L. Scholz, and M. Carus. Nova-Institut GmbH, Huerth, Germany. 365pp.
9. Bardelline, J. (2010, October 6). Improved Standards Needed for Bioplastic Claims. Retrieved from GreenBiz.com: http://www.greenbiz.com/news/2010/10/06/improved-standards-needed-bioplastic-claims?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+Greenbuzz+%28GreenBiz+Feed%29
10. Bayer, P., Heuer, E., Karl, U., and Finkel, M. (2005). Economical and ecological comparison of granular activated carbon (GAC) adsorber refill strategies. Water Research, 39(9), 1719 - 1728. http://www.sciencedirect.com/science/article/pii/S0043135405000655
11. BCAS. (2013). Compressed Air Savings: The cost of compressed air. British Compressed Air Society.. Retrieved from BCAS: http://www.bcas.org.uk/files/pdffiles/16.pdf
12. Bioplastics, C. (2012, April). Bioplastics Industry overview guide-Executive Summary. Retrieved from The Society of the Plastics Industry Bioplastics Council: https://store.plasticsindustry.org/source/orders/index.cfm?section=unknown&task=3&CATEGORY=BPC&PRODUCT_TYPE=SALES&SKU=BPC01&DESCRIPTION=Bioplastics%20Council&FindSpec=&CFTOKEN=19244647&continue=1&SEARCH_TYPE=find&StartRow=1&PageNum=1
13. Biotechnology Industry Organization, "Timeline_Renewable Fuel Standard" - The Renewable Fuel Standard: Timeline of a Successful Policy (Biotechnology Industry Organization (BIO) Powerpoint/Brochure.
14. Bockner, G. (2011, May). Biocontent bottles can still be recycled. Retrieved from Plastics News: http://www.plasticsnews.com/article/20110506/OPINION03/305069990#
15. Bozell, J. J. (2008). Feedstocks for the Future – Biorefinery Production of Chemicals from Renewable Carbon. CLEAN – Soil, Air, Water, 36(8), 641--647. http://dx.doi.org/10.1002/clen.200800100.
16. Buchi Labortechnik AG. (2002). Training Papers-Spray Drying. Version B: 97758. Retrieved from: http://www.buchi.com/sites/default/files/downloads/Set_3_Training_Papers_Spray_Drying_EN_01.pdf
17. Cameron Carbon Incorporated. (2006). Activated Carbon Manufacture, Structure and Properties. Retrieved from: http://www.cameroncarbon.com/documents/carbon_structure.pdf
18. Carter, A. March 26, 2015. Indian River Power Station. Personal Contact.
19. Chakar, F. S. and Ragauskas, A. J. (2004). Review of current and future softwood kraft lignin process chemistry. Industrial Crops and Products, 20(2), 131 - 141. http://www.sciencedirect.com/science/article/pii/S0926669004000664
20. Chiyoda Corporation. 2013. C4/C5 Fractions and Its Derivatives. Available at: http://www.chiyoda-corp.com/technology/en/chemistry/c4c5.html.
21. Cobalt. (2013). Butanols High-value markets. Retrieved from: www.cobalttech.com/biobutanol.html
22. Coca-Cola Co. (2012, January). PlantBottle: Frequently Asked Questions. Retrieved from Coca-Cola Company: http://www.coca-colacompany.com/stories/plantbottle-frequently-asked-questions
23. Colapinto, John, "Hot Grease", The New Yorker, Nov 18, 2013, 32 – 51.
24. Darby, D. (2012). Bioplastics Industry Report. BioCycle. Retrieved from: http://www.biocycle.net/2012/08/15/bioplastics-industry-report/
25. Davis, R., L. Tao, E. Tan, M. Biddy, G. Beckham, C. Scarlata. 2013. Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-acid and enzymatic deconstruction of biomass to sugars and biological conversion to sugars to hydrocarbons. National Renewable Energy Laboratory. Retrieved from: http://www.nrel.gov/docs/fy14osti/60223.pdf
26. Doris, Elizabeth, Joyce McLaren, Victoria Healey, and Stephen Hockett, State of the States 2009: Renewable Energy Development and the Role of Policy, National Renewable Energy Laboratory (U.S. Dept of Energy, Office of Energy Efficiency & Renewable Energy), Technical Report NREL/TP-6A2-4667 October 2009.
27. Energy Information Administration. 2015. Electric Power Monthly with Data for January 2015.

28. EESI, Developing an Advanced Biofuel Industry: State Policy Options for Lean and Uncertain Times, Environmental and Energy Study Institute, February 16, 2010 – www.eesi.org.
29. Environmental Leader. 2013. Gevo, Coke, Toray Partner on Renewable PET Technology. Environmental Leader. Retrieved from: http://www.environmentalleader.com/2013/08/27/gevo-coke-toray-partner-on-renewable-pet-technology/.
30. Erdtman, H. (1972). Lignins: Occurrence, formation, structure and reactions, K. V. Sarkanen and C. H. Ludwig, Eds., John Wiley & Sons, Inc., New York, 1971. 916 pp. $35.00. Journal of Polymer Science Part B: Polymer Letters, 10(3), 228--230. Retrieved from: http://dx.doi.org/10.1002/pol.1972.110100315.
31. Esposito, Frank. 2012. Report emphasizes importance of shale gas to plastics. Plastics News. July, http://www.plasticsnews.com/article/20120717/NEWS/307179974.
32. European Commission, 8.2.2006 “Communication from the Commission: An EU Strategy for Biofuels” Commission OF THE EC, Brussels, COM(2006) 34 final. {SEC (2006) 142} EN.
33. European Commission, Brussels, 21.1.2013, COM(2013) 18 final, 2013/0012 (COD), “Proposal for a Directive of the European Parliament and of the Council on the deployment of alternative fuels infrastructure,” (Text with EEA relevance) {SWD(2013) 5 final}{SWD(2013) 6 final} EN.
34. European Commission, 24.1.2013, “Proposal for a Directive of the European Parliament and of the Council on the deployment of alternative fuels infrastructure,” (Text with EEA relevance), Brussels, COM(2013) 18 final, 2013/0012 (COD) {SWD (2013) 5 final}{SWD (2013) 5 final}.
35. European Commission, 27.3.2013 Brussels, COM(2013) 175 final, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, renewable energy progress report {SWD(2013) 102 final} EN.
36. European Commission, “2 million tons per year: A performing biofuels supply chain for EU aviation” Aug 2013 Update: Update of the version initially published June 2011. (2011 ed. team: Kyriakos Maniatis, Michael Weitz, Alexander Zschocke; contrib. Schroecker et al.).
37. European Commission, “Communication from the Commission to the Council and the European Parliament: The Renewable Energy Progress Report: Commission Report in accordance with Article 3 of Directive 2001/77/EC, Article 4(2) of Directive 2003/30/EC and on the implementation of the EU Biomass Action Plan”, COM(205)628) {SEC(2009) 503 final}, EN.
38. European Commission. Future Transport Fuels: Report of the European Expert Group on Future Transport Fuels, January 2011.
39. Farm Security and Rural Investment Act of 2002. Pub. L. 107-171. 116 Stat. 134. 13 May 2002. United States Statutes at Large. Retrieved from: http://www.gpo.gov/fdsys/pkg/PLAW-107publ171/pdf/PLAW-107publ171.pdf
40. Fesseden J (Norit AC. 2012. Key Factors in Activated Carbon Injection. In: Worldwide Pollution Control Association.
41. FESTO. (2010). Air is money. FESTO. Available at: http://www.festo.com/rep/en-ph_ph/assets/pdf/Air_is_Money_Tia_2.2010.pdf.
42. Food, Conservation and Energy Act of 2008. Pub. L. 110-234. 122 Stat. 923. 22 May 2008. United States Statutes at Large.
43. Freedonia. (2012). US Bioplastics Market. Freedonia.
44. Freudenberg, K. (1959, April 25). Biosynthesis and Constitution of Lignin. Nature, p. 1152.
45. Frosterud, D., M. Wahlberg, J. Sloth, M. Themens. Selected drying technologies and particle engineering for the future Biorefinery. Presented at the Nordic Wood Biorefinery, Stockholm, March 22-24.
46. Gevo. (2010). An Alternative Solution for Plant Owners. Retrieved from: www.bioenergyinstitute.com/pastevents/ethanolBankruptcies/Presentation%2010%20-%20Mark%20Smith.pdf
47. Gevo. (2011). Bio-based Isobutanol to Enable Coca-Cola to Develop Second Generation PlantBottle^a Packaging. Retrieved from GEVO: http://gevo.com/?casestudy=bio-based-isobutanol-to-enable-coca-cola-to-develop-second-generation-plantbottle-packaging
48. Gevo. (2011). Isobutanol- A renewable solution for the Transportation Fuels Value Chain. White Paper. Retrieved from: http://www.gevo.com/assets/pdfs/GEVO-wp-iso-ftf.pdf.
49. Gevo. 2013. Markets – Isobutanol (http://www.gevo.com/our-markets/isobutanol). Accessed 1/9/14.
50. Glasser, W. G. (1999). Classification of Lignin According to Chemical and Molecular Structure. In W. Glasser, In Lignin: Historical, Biological and Materials Perspectives (p. 216). Washington, DC: American Chemical Society.
51. Glenz WW, Polyethylene terephthalate (PET). Kunststoffe (2007). Carl Hanser Verlag GmbH & Co. KG. Munich, Germany. 10/2007:76-80. Retrieved from: https://www.kunststoffe.de/en/journal/archive/article/continued-growth-trade-fair-report-k-2007-polyethylene-terephthalate-pet-586284.html
52. Gonugunta, P.(2012). Synthesis and Characterization of Biobased Carbon Nanoparticles from Lignin. University of Guelph (Thesis). Retrieved from: https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/3608/Synthesis%20and%20Characterization%20of%20Biobased%20Carbon%20Nanoparticles%20from%20Lignin.pdf?sequence=1. Accessed May 2013.
53. Gosselink, R. J. A., de Jong, E., Guran, B., and Abächerli, A. (2004). Co-ordination network for lignin—standardisation, production and applications adapted to market requirements (EUROLIGNIN). Industrial Crops and Products, 20(2), 121 - 129. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0926669004000652
54. Greiner, E., Kalin, T., Inoguchi, Y. (2010). Marketing Research Report: Activated Carbon. Chemical Economics Handbook. Rep no. 731.2000.
55. Highson, A., Smith, C. (2011, December 12). NNFCC Renewable Chemicals Fact sheet: lignin. Retrieved from NNFCC The Bioeconomy Consultants: http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-lignin
56. Hileman, Jim. Power Point Presentation - “Alter-

native Jet Fuel Activities” By Dr. Jim Hileman Office of Environment and Energy, FAA, To Biomass R & D Technology Committee (Wash. D.C.), Aug 2013.

57. Holladay, J. (2007). Top Value Added Chemicals from Biomass. Retrieved from www.pnl.gov/main/publications/external/technical_reports/PNNL-16983.pdf

58. Humbird, D., R. Davis, L. Tao, C. Kinchin, D. Hsu, A. Aden. 2011. Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover. National Renewable Energy Laboratory. Retrieved from: http://www.nrel.gov/biomass/pdfs/47764.pdf

59. Humphreys, J. M. and Chapple, C. (2002). Rewriting the lignin roadmap. Current opinion in plant biology, 5(3), 224--229. Retrieved from: http://www.sciencedirect.com/science/article/pii/S1369526602002571

60. Hung, J.J. (2012). The Production of Activated Carbon From Coconut Shells Using Pyrolysis and Fluidized Bed Reactors. University of Arizona (thesis). Retrieved from: http://arizona.openrepository.com/arizona/bitstream/10150/243968/1/azu_etd_mr_2012_0079_sip1_m.pdf.

61. ICCT, Measuring and Addressing Investment Risk in the Second-Generation Biofuels Industry, December 2012, The International Council on Clean Transportation – www.theicct.org.

62. ICIS. (2013). Butyl Acetate: Market Overview. ICIS. Retrieved from: www.icis.com/chemicals/butyl-acetate/?tab=tbc-tab2

63. ICIS. (2013). US gulf n-butane drops on shale production and low gasoline demand. Retrieved from: http://www.icis.com/Articles/2012/05/10/9558592/us-gulf-n--butane-drops-on-shale-production-and-low-gasoline.html

64. Imre, B. and Pukánszky, B. (2013). Compatibilization in bio-based and biodegradable polymer blends. European Polymer Journal, 49(6), 1215 - 1233. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0014305713000372

65. Ioannidou, O. and Zabaniotou, A. (2007). Agricultural residues as precursors for activated carbon production—A review. Renewable and Sustainable Energy Reviews, 11(9), 1966 - 2005. http://www.sciencedirect.com/science/article/pii/S136403210600061X

66. Jebens, A., Janshekar, H., Yokose, K. (2012). Lignosulfonates. Chemical Economics Handbook Report. Retrieved from: www.sriconsulting.com/CEH/Public/Reports/671.5000

67. Johnson, L., Lippke, B., and Oneil, E. (2012). Modeling Biomass Collection and Woods Processing Life-Cycle Analysis. Forest Products Journal, 62(4), 258--272. http://dx.doi.org/10.13073/FPJ-D-12-00019.1

68. Kaeb, H. (2009, November 10-11). Bioplastics: Technology, Markets, Policies. Retrieved from Ecoembes: http://www.ecoembes.com/es/gestion-de-empresas-adheridas/prevencion/documents/haraldkaeb.pdf

69. Keller, Anne.(2012). NGL 101-The basics. Retrieved from: http://www.yumpu.com/en/document/view/10154703/ngl-101-the-basics-eia

70. Kolodzieg, R., Scheib, J. (2012) Bio-isobutanol: The Next-generation Biofuel. Hydrocarbon Processing. Retrieved from: http://www.hydrocarbonprocessing.com/Article/3081332/Bio-isobutanol-The-next-generation-biofuel.html

71. Laing, Keith. (2012, Nov.). Obama quietly signs bill shielding airlines from carbon fees in Europe. The Hill. Retrieved from: http://thehill.com/blogs/transportation-report/aviation/269603-obama-quietly-signs-airline-emission-trading-ban-.

72. Lane, Jim. 2014. Top 10 Biofuels & Biobased Predictions for 2014. Biofuels Digest (http://www.biofuelsdigest.com/bdigest/2014/01/06/top-10-biofuels-biobased-predictions-for-2014/). Jan. 6.

73. Lane, J. (2013, August 7). EPA sets final 2013 US renewable fuel mandate. Retrieved from BiofuelsDigest: http://www.biofuelsdigest.com/bdigest/2013/08/07/epa-sets-final-2013-us-renewable-fuel-mandate/

74. Lane, Jim. (2013). 4C-able future: Biobased butanol, butadiene and BDO are having a hot year. Biofuels Digest. Retrieved from: http://www.biofuelsdigest.com/bdigest/2013/08/21/4c-able-future-biobased-butanol-butadiene-and-bdo-are-having-a-hot-year/.

75. Encyclopedia Britannica. (n.d.)Lignin (Organic material). Retrieved from Encyclopedia Britannica: http://www.britannica.com/EBchecked/topic/340820/lignin

76. Lane, Jim, The Dew Drop Inn – Who’s Dropping in What in Biofuels?, Jim Lane, Biofuelsdigest.com.

77. Marketing Study for Biomass Treatment Technology. (n.d.). Retrieved from Report for North East Process Industry Cluster by NNFCC: www.northeastbiofuels.com/_assets/file/marketingstudynnfcc.pdf

78. MASBI Report, Fueling a Sustainable Future for Aviation 2013, Midwest Aviation Sustainable Biofuels Initiative.

79. Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., and Kaminuma, T. (2001). Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment. Environmental Science & Technology, 35(2), 318-324. Retrieved from: http://pubs.acs.org/doi/abs/10.1021/es0010498

80. McCarthy, J. L. and Islam, A. (1999). 2. In , Lignin Chemistry, Technology, and Utilization: A Brief History (pp. 2-99). Retrieved from: http://pubs.acs.org/doi/pdf/10.1021/bk-2000-0742.ch001

81. Mind, A. R. (2012, December). Bioplastics - a global market watch, 2011 - 2016. Retrieved from Research and markets: http://www.researchandmarkets.com/research/gzcgr2/bioplastics_a

82. Moller, J.T., S. Fredsted. (2009). A primer on Spray Drying. Chemical Engineering 34-40. Retrieved from: www.niro.com/niro/cmsresources.nsf/filenames/A-primer-on-Spray-Drying-Chemical-Engineering-Nov09.pdf/$file/A-primer-on-Spray-Drying-Chemical-Engineering-Nov09.pdf

83. Muñoz, I., Peral, J., Antonio Ayllón, J., Malato, S., José Martin, M., Yves Perrot, J., Vincent, M., and Domènech, X. (2007). Life-Cycle Assessment of a Coupled Advanced Oxidation-Biological Process for Wastewater Treatment: Comparison with Granular Activated Carbon Adsorption.. Environmental Engineering Science, 24(5), 638 - 651. Retrieved from: https://proxy.tamuc.edu:2048/login?url=http://search.ebscohost.com/login.aspx?di-

rect=true&db=a9h&AN=25138418&site=ehost-live

84. Mussatto, S. I., Fernandes, M., Rocha, G. J., Órfão, J. J., Teixeira, J. A., and Roberto, I. C. (2010). Production, characterization and application of activated carbon from brewer's spent grain lignin. Bioresource technology, 101(7), 2450--2457.

85. National Research Counsel, Transitions to Alternative Vehicles and Fuels, The National Academies Press at http://www.nap.edu/catalog.php?record_id=18264, Committee on Transitions to Alternative Vehicles and Fuels; Board on Energy and Environmental Systems; Division of Engineering and Physical Science; National Research Counsel; 2013.

86. National Resources Defense Council. (n.d.) Mercury Contamination in Fish - Learn About Mercury and Its Effects. Retrieved from: http://www.nrdc.org/health/effects/mercury/effects.asp

87. Nexant. (2012). Biobutanol and Downstream Markets: Will you be buying bio? Retrieved from: www.chemsystems.com/reports/search/docs/prospectus/STMC12_Biobutanol_Pros.pdf.

88. Nimz, H. (1968). The Chemistry of Lignin. Von I. A. Pearl. Edward Arnold (Publishers) Ltd., London 1967. Marcel Dekker, Inc., New York 1. Aufl., XI, 339 S., 24 Abb., geb. $ 15.75. Angewandte Chemie, 80(8), 328--328. Retrieved from: http://dx.doi.org/10.1002/ange.19680800831

89. Norit. (n.d.) What is Activated Carbon? Cabot. Retrieved from: http://www.norit.com/carbon-academy/introduction/.

90. Noyes, Graham, and Sara E. Bergan, Fortifying the RPS EPA's Proposed RIN Quality Assurance Program, Stoel Rives LLP, Attorney at Law – White Paper.

91. Owen, B., Lee, D. S., and Lim, L. (2010). Flying into the Future: Aviation Emissions Scenarios to 2050. Environmental Science & Technology, 44(7), 2255-2260. Retrieved from: http://pubs.acs.org/doi/abs/10.1021/es902530z

92. Pan, Ingrid. (2013). Why ethane stopped trading like crude and started trading like nat gas (part 2). Market Realist. Retrieved from: http://marketrealist.com/2013/03/why-ethane-stopped-trading-like-crude-and-started-trading-like-nat-gas-part-ii/.

93. Panoutsou, Calliope and Ausilio Bauen, and Jim Duffield, Review: Policy regimes and funding schemes to support investment for next-generation biofuels in the USA and the EU-27 (biofpr: biofuels bioproducts & biorefining), 2013 - wileyonlinelibrary.com.

94. PepsiCo. (2011, March 15). PepsiCo develops world's first 100 percent plant-based, renewably sourced PET bottle. Retrieved from PEPSICO: www.pepsi.com/pressrelease/pepsico-develops-worlds-first-100-percent-plant-based-renewably-sourced-pet-bott03152011.html

95. Peters, M. W., et al. (2010). Integrated process to selectively convert renewable isobutanol to p-xylene, Google Patents.

96. PRWEB. (2013). Global Activated Carbon Market Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 2019. Transparency Market Research. Retrieved from: http://www.prweb.com/releases/2013/9/prweb11160954.htm

97. Ragan, S.,Megonnell, N. (2011). Activated Carbon from Renewable Resources-Lignin. Cellulose Chemistry and Technology 45(7-8): 527-531. Retrieved from: http://www.cellulosechemtechnol.ro/pdf/CCT45,7-8(2011)/p.527-531.pdf

98. Ragauskas, A. J. (2004). Lignin Overview. Retrieved from Georgia Institute pf Paper Science Tech and Technology: http://www.ipst.gatech.edu/faculty/ragauskas_art/technical_reviews/Lignin%20Overview.pdf

99. Reid, T. (2013). White Paper: Plastics vs. Bioplastics. Retrieved from awareness into action: http://www.awarenessintoaction.com/whitepapers/bioplastics-recycled-plastics.html

100. REN21. 2014. Renewables 2014 Global Status Report.

101. Renewable Fuel Standard. (2011). Potential Economic and Environmental Effects of U.S. Biofuel Policy. The National Academic Press, 250.

102. Rivas, S. A., Galia, M. B. (2010). Biopolymers from sunshine. In K. N. Timmis, Handbook of hydrocarbon and lipid microbiology. Springer-Verlag Berlin Heidelberg.

103. Rossi, Andrew, Ed., Good Environmental Practices in Bioenergy Feedstock Production: Making Bioenergy Work for Climate and Food Security, BEFSCI – Bioenergy and Food Security Criteria and Indicators, Bioenergy and Food Security Criteria and Indicators project (Food and Agriculture Organization of the United Nations (FAO)), 2012 – Environment and Natural Resources Management Working Paper(Environment Climate Change [Energy] Monitoring and Assessment), 49.

104. Sabourin, D. (2011, May 3). Degradable additives provide poor end-of-life option for PET packaging, says NAPCOR. Sonoma, CA: NAPCOR. Retrieved from National Association for PET Container Resources (NAPCOR).

105. SAFN, Executive Summary RE SAFN Part 1 of 1 - Regional leader group document - Sustainable Aviation Fuels Northwest: Powering the Next Generation of Flight.

106. SAFN 2011 Report Regional leader group document - Sustainable Aviation Fuels Northwest: Powering the Next Generation of Flight. 2011 Report – complete report available at www.safnw.com.

107. Schut, J. H. (2012, August 13). The race to 100% bio PET. Retrieved from Plastics Engineering Blog: http://www.plasticsengineering blog.com/2012/08/13/the-race-to-100-bio-pet

108. Setyawan, E. (2011). Manufacturing Activated Carbon in Biomass Rich Countries. JFE Project. Retrieved from: http://www.slideshare.net/ekosbsetyawan/manufacturing-activated-carbon

109. Shen, L., Haufe, J., & Patel, M. K. (2009). Product overview and market projection of emerging bio-based plastics . The Netherlands: European Bioplastics.

110. Simon, CJ., Schnieders F. (2009). Business Data and Charts 2007. PlasticsEurope Market Research Group (PEMRG). Retrieved from: http://www.plasticseurope.org/Content/Default.asp? PageID=989.

111. Singh, B.B. and J.N. Swamy. 2012. Shale impact on C2, C3 and C4 derivitives. Chemical Market Resources, Inc., www.CMRHou.Tex.Com. (http://cmrhoutex.com/media/The%20Shale%20Gas%20Impact%20on%20C2%20C3%20and%20C4%20Downstream%20Derivatives.pdf).

112. Sjostrom, S., Durham, M., Bustard, C. J., and Martin, C. (2010). Activated carbon injection for

mercury control: Overview. Fuel, 89(6), 1320 - 1322. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0016236109005250

113. SPI, C. B. (2013, January). Position paper on degradable additives. Retrieved from The Society of the Plastics Industry Bioplastics Council: http://www.plasticsindustry.org/files/about/BPC/Position%20Paper%20on%20Degradable%20Additives%20-%20012113%20-%20Final.pdf
114. SPI. (2013). Development of biobased plastics independent of the future biofuels. Retrieved from: http://www.plasticsindustry.org/files/about/BPC/Development%20of%20Biobased%20Plastics%20-%20August%2026%202013%20-%20FINAL.pdf
115. Srivastava, R. K., Hutson, N., Martin, B., Princiotta, F., and Staudt, J. (2006). Control of Mercury Emissions from Coal-Fired Electric Utility Boilers. Environmental Science & Technology, 40(5), 1385-1393. Retrieved from: http://pubs.acs.org/doi/abs/10.1021/es062639u
116. Starksy, Valarie, The Renewable Fuel Standard and Cellulosic Biofuels: Prospects and Challenges, Biomass Program, Energy Efficiency and Renewable Energy Department of Energy, Lead Platform R & D.
117. Steeman, A. (2011, July 13). PET is PET - Petro-PET or Bio-PET. Retrieved from Best in Packaging: http://www.bestpackaging.com/2011/07/13/pet-is-pet-petro-pet-or-bio-pet
118. Stevens, G. (2010, October 07). Bioplastic Standards 101. Retrieved from Green Plastics: http://green-plastics.net/news/45-science/107-bioplastic-standards-101
119. Suhas, Carrott, P. J. M., and Carrott, M. M. L. R. (2007). Lignin – from natural adsorbent to activated carbon: A review. Bioresource Technology, 98(12), 2301 - 2312. http://www.sciencedirect.com/science/article/pii/S0960852406004056
120. The Babcox and Wilcox Company. 2015. Powdered Activated Carbon (PAC) Injection Overview.
121. The Freedonia Group. (2012). World Activated Carbon to 2016. Retrieved from: www.freedoniagroup.com/DocumentDetails.aspx?ReferrerId=FG-01&studyid=2878.
122. Thielen, M. (2012, April). Bioplastics: Basics. Applications. Markets. Retrieved from bioplastics magazine: http://www.bioplasticsmagazine.com/en/books/bioplastics.php
123. Transparency Market Research. (2012). Butanediol, 1,3 Butadiene and Methyl Ethyle Ketone Market: Application, Bio-based alternatives, Downstream Potential, Market Size and Forecast. Retrieved from: http://www.transparencymarketresearch.com/butanediol-butadiene-and-mek-market.html.
124. Tsai, W. T., Chang, C. Y., Wang, S. Y., Chang, C. F., Chien, S. F., and Sun, H. F. (2001). Preparation of activated carbons from corn cob catalyzed by potassium salts and subsequent gasification with \ {CO_2\}. Bioresource Technology, 78(2), 203 - 208. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0960852400001115
125. United States Department of Agriculture. (n.d.) Biopreferred Home. USDA. Retrieved from: http://www.biopreferred.gov/Default.aspx
126. United States, Department of Agriculture, Agriculture and Aviation: Partners in Prosperity, January 2012 – published by the U.S. Department of Agriculture in conjunction with Airlines for America (A4A, formerly the Air Transport Association of America) and the Boeing Company – USDA, Airlines for America, and Boeing.
127. United States Department of Agriculture BCAP: Biomass Crop Assistance Program – Energy Feedstocks From Farmers & Foresters, A Report by the U.S. Department of Agriculture: Farm Service Agency, October 2012.
128. United States Department of Agriculture. (2009). Public Meeting on BioPreferred Voluntary Labeling Program. Departmental Management. Office of Procurement and Property Management. Federal Register 74(240). Retrieved from: http://www.gpo.gov/fdsys/pkg/FR-2009-12-16/html/E9-29957.htm
129. United States Department of Agriculture. (2012). Guidelines for Designating Biobased Products for Federal Procurement. Office of Procurement and Property Management. Federal Register 77(84). Retrieved from: http://www.gpo.gov/fdsys/pkg/FR-2012-05-01/pdf/2012-10420.pdf
130. United States Department of Energy. (2010). Current State of the U.S. Ethanol Industry. New Castle: Cardno ENTRIX. Retrieved from: https://www1.eere.energy.gov/bioenergy/pdfs/current_state_of_the_us_ethanol_industry.pdf
131. United States, Department of Energy: U.S. Billion-ton Update; Biomass Supply for a Bioenergy and Bioproducts Industry, August 2011.
132. United States Energy Information Administration. (2010, July 8). The Ethanol Blend Wall. Retrieved from U.S. Energy Information Administration: http://www.eia.gov/oog/info/twip/twiparch/100708/twipprint.html
133. United States Energy Information Administration. (2013). Short-term Energy Outlook. EIA. Retrieved from: http://www.eia.gov/forecasts/steo/
134. United States Energy Information Administration(a). (2013). Natural gas prices. U.S. Energy Information Administration. Retrieved from: www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.
135. United States Energy Information Administration(b). 2013. Electric Power Monthly. U.S. Energy Information Administration. Retrieved from: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.
136. United States Energy Information Administration(c). 2013. Short Term Energy Outlook: Coal. U.S. Energy Information Administration. Retrieved from: http://www.eia.gov/forecasts/steo/report/coal.cfm.
137. United Nations Environment Programme. (2013). Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport. UNEP Chemicals Branch. Retrieved from: http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf
138. United State Environmental Protection Agency. (2011) Fact Sheet: Mercury and Air Toxic Standards for Power Plants. Retrieved from: http://www.epa.gov/mats/pdfs/20111221MATSsummaryfs.pdf
139. United State Environmental Protection Agency. (2013). Regulation of Fuels and Fuel Additives: Identification of Additional Qualifying Renewable Fuel Pathways Under the Renewable Fuel Standard Program. Federal Register 78(43): 14198. Retrieved from: https://www.federalregister.gov/

articles/2012/03/05/2012-5256/regulation-of-fuels-and-fuel-additives-identification-of-additional-qualifying-renewable-fuel

140. United States Environmental Protection Agency. (2011) The Toxics Rule Facilities. National Electric Energy Data System Retrieved from: http://www.epa.gov/mats/pdfs/20111221facilitiesmap.pdf
141. United States Environmental Protection Agency. (n.d.) Basic Information. Retrieved from: http://www.epa.gov/hg/about.htm
142. United States Environmental Protection Agency. (n.d.) Guidance on New Fuel Pathway Approval Process. Retrieved from: http://www.epa.gov/otaq/fuels/renewablefuels/compliancehelp/rfs2-lca-pathways.htm
143. United States Environmental Protection Agency, “Regulatory Announcement: EPA Proposes 2014 Renewable Fuel Standards, 2015 Biomass-Based Diesel Volume” (U.S. Environmental Protection Agency: Office of Transportation and Air Quality), EPA-420-F-13-048, November 2013.
144. United States Environmental Protection Agency. (n.d.) Questions and Answers on Changes to the Renewable Fuel Standard Program (RFS2). Retrieved from: http://www.epa.gov/otaq/fuels/renewablefuels/compliancehelp/rfs2-aq.htm
145. Vanholme, R., Morreel, K., Ralph, J., and Boerjan, W. (2008). Lignin engineering. Current Opinion in Plant Biology, 11(3), 278 - 285. Retreived from: http://www.sciencedirect.com/science/article/pii/S1369526608000459.
146. Voegele, Erin. 2010. Filling a Void. Biomass Magazine. (http://biomassmagazine.com/articles/6544/filling-a-void). Oct. 7.
147. Washington State, Biennial Energy Report: Issues, Analysis and Updates - Department of Commerce: State of Washington. December 2012, Report to the Legislature, Rogers Weed, Director.
148. Welle, F. (2011). Twenty years of \{PET\} bottle to bottle recycling—An overview. Resources, Conservation and Recycling, 55(11), 865 - 875. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0921344911000656
149. Wikipedia. (2013, August 6). Lignin. Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Lignin
150. Williams, P. R. D., Inman, D., Aden, A., and Heath, G. A. (2011). Correction to Environmental and Sustainability Factors Associated With Next-Generation Biofuels in the U.S.: What Do We Really Know?. Environmental Science & Technology, 45(22), 9820-9820. Retrieved from: http://pubs.acs.org/doi/abs/10.1021/es2035043
151. Yahoo Finance. (2013). US Activated Carbon Market. PRNewswire. Retrieved from: http://finance.yahoo.com/news/us-activated-carbon-market-154600355.html
152. Yoder, J. (2010) Biofuel Economics and Policy for Washington State. WSU School of Economic Sciences. Retrieved from: http://cru.cahe.wsu.edu/CEPublications/XB1047E/XB1047E.pdf
153. Zhang, F., Johnson, D. M., and Sutherland, J. W. (2011). A GIS-based method for identifying the optimal location for a facility to convert forest biomass to biofuel. Biomass and Bioenergy, 35(9), 3951 - 3961. http://www.sciencedirect.com/science/article/pii/S0961953411003308

SYSTEMS METRICS

LCA AND COMMUNITY IMPACT TEAM

TASK 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

Task Description

This research module will provide a definitive assessment of the technical, economic, environmental, and social impacts of using woody biomass for the production of jet fuel. Understanding the consequences of this technology is necessary if forest 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 based 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 green house gases (GHG) and other environmental performance indices for comparisons between cellulosic jet fuel and fossil fuels. Alternative technologies, with 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 independence 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.

Activities and Results

Task SM-LCA-1.1. Soil Carbon Analysis (Tasks 4 thru 10)

DEEP SOIL CARBON AND NITROGEN

We continue to work on the role of deep soil carbon, nutrients, water and other resources in determining the resilience of ecosystems to additional biomass harvesting and nutrient removal for biofuel feedstocks. The specific objectives of our current work are:

1. To determine the effect of systematic sampling to variable depths on estimates of forest soil carbon (C) and nitrogen (N).
2. To evaluate the ability of mathematical models to accurately predict total soil C and N in soil horizons up to 300 cm depth.
3. To assess which soils are most important to sample more deeply.
4. To investigate the vertical distribution of exchangeable cations (calcium (Ca), magnesium (Mg), potassium (K)) and their relationship with other soil and stand variables.

As mentioned in previous reports, 22 deep soil sampling sites from the Stand Management Cooperative nutrition study of 73 sites representing the entire coastal Douglas-fir production region from north Vancouver Island, Canada to southern Oregon were sampled. During the summer of 2014, 20 more deep soil excavations were completed. The sites were selected from remaining Type V stands that were not previously sampled, as well as a subset of the Type I installations. At the Type I stands, pits will be dug in both fertilized and unfertilized plots. At 10 sites, in addition to soil samples, moisture probes were installed at depths of 10, 50, 100, and 200 cm. A temperature probe was also deployed at 50 cm depth. Data loggers are collecting data once every hour in order to give enough temporal resolution to examine whether hydraulic redistribution (the passive movement of water from deep soils to the surface through plant roots) is an important process during the dry summer season across a variety of sites and soils in the Pacific Northwest. A paper on the distribution and modeling of forest soil C was published in the Soil Science Society of America Journal (James et al. 2014a). A second paper was recently published, also in 2014 (James et al. 2014b).

NARA LONG-TERM SOIL PRODUCTIVITY (LTSP) SITE - LYSIMETERS STUDY

Lysimeters were installed in 2013: the 100-cm depth lysimeters were installed in July 8-10/2013. Those with 20-cm depth were installed in September 26-27/2013. Soil solution samples were collected monthly (from February/2014), but collections continued to be small and irregular. Unfortunately, the collections from this study were insufficient to construct a nutrient budget for this site, as was done earlier for the similar site a Fall River LTSP.

RESIDENCE TIME OF CARBON AND DECOMPOSITION OF DOUGLAS-FIR STUMPS FOR LCA CARBON MODEL

We are working with Indroneil Ganguly to make sure that our work helps him complete the carbon life-cycle assessment (LCA). All samples for the LCA – Douglas-Fir Stump Decay project have been collected, and preliminary data results are promising. Samples were taken at five sites from stumps cut in 2013, 2012, 2010, 2006, 1999 and 1992; totaling roughly 160 stumps. For each of those stumps we collected at least two density and two resistograph measurements to estimate density; two samples for carbon and nitrogen analysis; and various field observations including diameter, height and perceived decay class (based upon a decay classification system that we developed for Douglas-fir stumps). We are currently analyzing the woody material for carbon and nitrogen and analyzing the other field data. We are building a model for decomposition that accounts for loss of density as a function of time, climate and other factors. We currently have a detailed report on progress, but it is too long to present here. The report can be downloaded at http://soilslab.cfr.washington.edu/publications/NARA-StumpDecomposition-150201.pdf

Task SM-LCA-1.2. Life Cycle Assessment (Tasks 12 thru 34)

During the 2014-2015 reporting period, the LCA team has made significant progress towards the successful attainment of the proposed project goals. The research undertaken by the LCA team not only met the requirements underlined in the specific task areas, but went above and beyond the basic requirements. In the initial phases of the project, the LCA team developed a 'hybrid NARA woody biomass to biojet fuel framework model' using surrogate modules available in established literature (namely, National Renewable Energy Laboratory (NREL) and the Consortium for Research on Renewable Industrial Materials (CORRIM)). During the reporting period, the LCA team was able to successfully replace a majority of those surrogate processes with the modules developed by NARA team members. The LCA team also established a final model integration plan to be implemented once all the bio-refinery and co-product processes are developed by the relevant research teams.

The Life Cycle Assessment (LCA) requires detailed data from all the subcomponents of the NARA biofuels project; effective collaboration between the NARA team members determines the success of the LCA work. During the reporting period, the LCA team members conducted multiple meetings with all the relevant NARA researchers to ensure timely delivery of all required data. The following section summarizes the meetings held on the various aspects of NARA LCA work.

FEEDSTOCK LOGISTICS: Oregon State University (OSU) is heading the feedstock economic and logistic analysis for the west of cascades region. Following up on the preliminary discussion during the 2014 annual meeting, Dr. Ivan Eastin and Dr. Indroneil Ganguly visited Corvallis on the 5th and 6th of November to coordinate with the OSU researchers on their research project. Meetings were held with Dr. Kevin Boston, Dr. John Sessions, Dr. Darius Adams and Dr. Greg Latta. Following that meeting, updated data was provided to the LCA group by the aforementioned researchers.

AIR QUALITY MODELING: A pre-annual coordination meeting on LCA and air quality impacts was held in Pullman on the 10th of September. Dr. Ganguly and Cody Sifford (graduate student) from the University of Washington (UW) attended the meeting. The meeting was extremely successful in terms of understanding the nature of data that will be available to the LCA team from the Washington State University (WSU) air quality team. A follow-up meeting was held at the U.S. Forest Service fire lab in Seattle, where, Dr. Lamb, Vikram Ravi (WSU PhD student), and Dr. Vaughn of WSU attended the meeting along with all the members of the UW-LCA team.

PRE-TREATMENT AND BIO-REFINERY: A meeting was held in Seattle on August of 2014, which was attended by, the ASPEN modeling group, NARA leadership, Gevo Inc. representatives, Co-products LCA group, and the UW-LCA group. The focus of this meeting was the pretreatment through jet fuel component of the LCA. The purpose of the meeting was to coordinate the data acquisition between the LCA team and our partners at Gevo Inc. and within the NARA pretreatment, ASPEN, techno-economic analysis (TEA) and co-products groups. The meeting emphasized the need to have a completed LCA of the entire wood-to-biofuel/co-product process ready for submission for a technical review by the end of June 2015. The discussion focused on the status of the ASPEN modeling and delineating the boundaries of the Gevo Inc.'s "proprietary black box" (essentially the fermentation and oligomerization process). The discussion also touched on the inputs/outputs for the GIFT™ process, including the power requirements. A follow-up discussion session was held at the 2014 NARA annual meeting, and roles and responsibilities, as is explained in Figure SM-LCA-1.1, were finalized for the NARA-LCA project.

Task SM-LCA-1.3. Community Economic Impact Assessment (Tasks 36 through 39)

We continued with the literature review focusing on studies with biorefinery direct employment estimates. The review will become part of the Preliminary Economic Impact Report (Task 38). Spreadsheet models to produce a sensitivity analysis with respects to commodity versus industry assumptions were completed and commodity versus industry production differences on economic impacts were populated with IMPLAN data. We began the analysis that describes the relationships between a commodity by commodity total requirements matrix, a commodity by industry total requirements matrix, an industry by commodity total requirements matrix, and the industry by industry total requirements matrix and how these results differ in the economic impact assessment.

Adaption of the Western Montana Corridor (WMC) spreadsheet model to western Washington was made using biomass supply data from the Washington Biomass Assessment and preliminary supply data from the NARA supply model, recently obtained from Darius Adams at Oregon State University. Data on supply estimates are presented tables SM-LCA-1.1 and SM-LCA-1.2 respectively, first from the Washington Biomass Assessment, followed by data from the NARA supply model. Figure SM-LCA-1.2 compares the mill values in the two data sets.

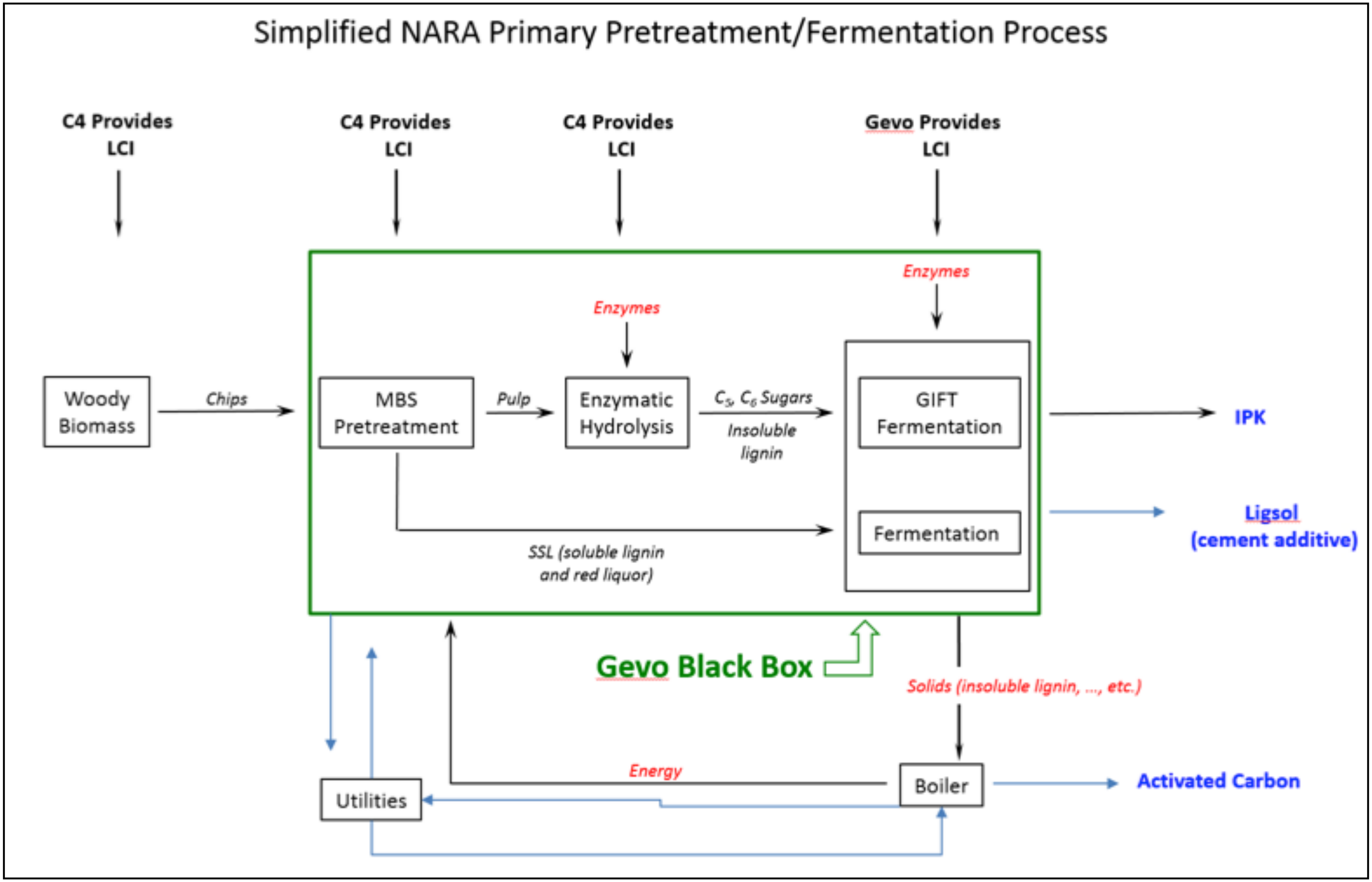


Figure SM-LCA-1.1. NARA-LCA layout

Table SM-LCA-1.1. Values using the Washington Biomass Supply Assessment

County	Mill value	Forest Value	Transport Value
Clallam	$7,367,696	$2,488,314	$4,879,383
Clark	$943,015	$324,192	$618,824
Cowlitz	$4,569,030	$1,668,931	$2,900,099
Grays Harbor	$2,869,573	$1,088,807	$1,780,765
Island	$51,240	$11,869	$39,371
Jefferson	$3,225,590	$1,235,311	$1,990,280
King	$2,809,239	$970,488	$1,838,751
Kitsap	$449,250	$157,203	$292,048
Lewis	$6,019,453	$1,985,090	$4,034,363
Mason	$2,629,480	$873,636	$1,755,843
Pacific	$460,167	$157,843	$302,324
Pierce	$3,417,444	$1,146,155	$2,271,289
Skagit	$1,558,853	$549,736	$1,009,117
Skamania	$638,577	$233,743	$404,833
Snohomish	$2,161,982	$813,260	$1,348,722
Thurston	$900,160	$280,169	$619,991
Wahkiakum	$337,145	$115,521	$221,624
Whatcom	$977,687	$335,169	$642,517
San Juan	$4,215	$304	$3,911
Grand Total	$41,389,797	$14,435,741	$26,954,056

Table SM-LCA-1.2. Values using the NARA Supply Model

County	Mill Value	Forest Value	Transport Value	Haul Value	Processing Value
Clallam	$0	$0	$0	$0	$0
Clark	$0	$0	$0	$0	$0
Cowlitz	$0	$0	$0	$0	$0
Grays Harbor	$19,629,215	$3,145,491	$16,483,724	$5,159,177	$11,324,547
Island	$0	$0	$0	$0	$0
Jefferson	$0	$0	$0	$0	$0
King	$0	$0	$0	$0	$0
Kitsap	$0	$0	$0	$0	$0
Lewis	$2,140,439	$53,083	$2,087,356	$852,487	$1,234,869
Mason	$3,806,120	$340,644	$3,465,477	$1,269,638	$2,195,839
Pacific	$21,563,754	$2,585,785	$18,977,968	$6,537,341	$12,440,627
Pierce	$0	$0	$0	$0	$0
Skagit	$0	$0	$0	$0	$0
Skamania	$0	$0	$0	$0	$0
Snohomish	$0	$0	$0	$0	$0
Thurston	$4,486,092	$589,531	$3,896,561	$1,308,431	$2,588,130
Wahkiakum	$3,335,130	$84,454	$3,250,608	$1,326,534	$1,924,074
Whatcom	$0	$0	$0	$0	$0
San Juan	$0	$0	$0	$0	$0
Grand Total	$54,960,750	$6,798,988	$48,161,694	$16,453,608	$31,708,086

Differences include 1) greater biomass supply under the NARA supply model at $65/BDT, and 2) greater geographical distribution of where the supply comes from under the Washington Biomass Supply Assessment. The Washington Biomass Supply Assessment secured less volume (~83%) at $65/BDT than the NARA Supply Model. The Washington Biomass Supply Assessment supply region is more evenly spread across surrounding counties. The majority of the supply and hence economic impacts from the NARA Supply Model are in Grays Harbor and Pacific counties. Total sector economic impact differences are relatively small: $244 million (WA Biomass Assessment) versus $258 million (NARA Supply Model).

A discussion regarding the differences between the two models occurred during the NARA annual meeting. Possible reasons for the discrepancies were mentioned. We decided to continue with the use of the NARA model since the WA biomass assessment model does not include Oregon counties in its database. Differences are thought to arise from variances in scale and inventory assumptions. Scale variance may operate as follows: 1) the biomass calculator uses parcel sizes that are significantly smaller than FIA plot representative areas that are in the NARA Supply model; 2) the smaller sized parcels contain less volume; hence supply requirements of the same fixed amount require more parcels than FIA plot areas; 3) the effect of requiring more parcels supplying the required supply is a larger and more diverse geographic distribution of the supplying counties. Inventory assumption differences are particularly relevant with respects to Pacific County, Washington. Inventory variance is thought to be related to different estimates of Pacific County inventory. Inventory, and its potential to attain a specified harvest level, in the biomass calculator is low relative to surrounding counties due to major wind storm damages that occurred there during December 2007.

Conversion of the Western Montana Corridor (WMC) Community Impacts spreadsheet model to western Washington, western Oregon (WWO) county data was made available to Natalie Martinkus for her

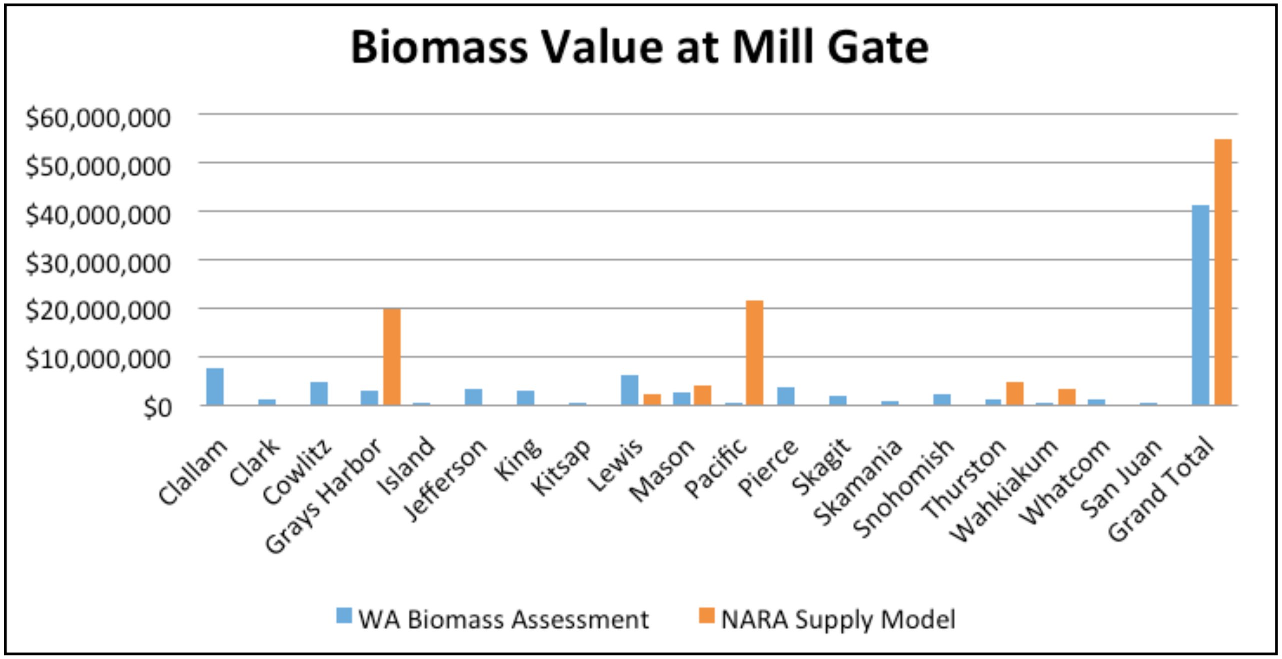


Figure SM-LCA-1.2. Comparison of the Washington Biomass Supply Assessment and NARA Supply Model data

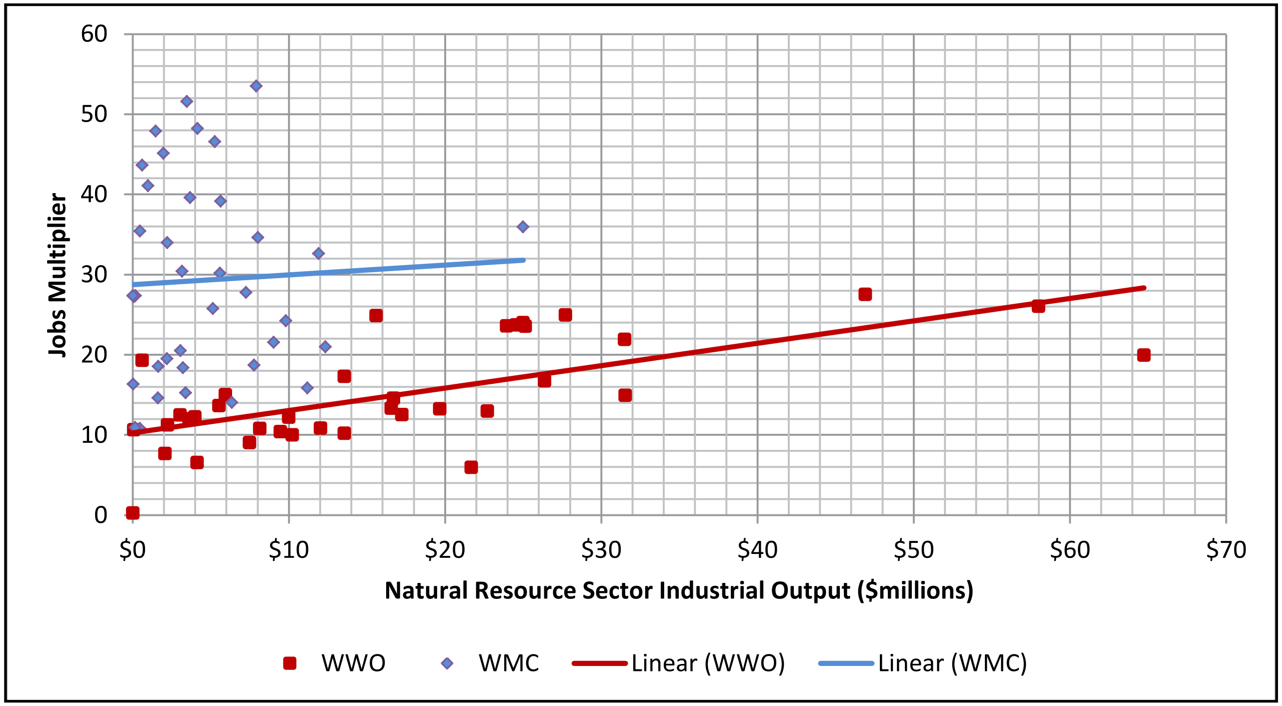


Figure SM-LCA-1.2. Jobs multiplier for WMC and WWO regions

NARA-related dissertation research, which is creating a biorefinery siting model for the WWO region.

Differences in the calculated county multipliers for the two regions (WMC and WWO) are being studied. For instance, Figures SM-LCA-1.3 and SM-LCA-1.4 below indicate significant differences in both job and induced-effect multipliers for the two regions. The figures relate these county level multipliers with the size of the natural resource sectors in each county and are colored coded for each region. Note the higher job multipliers associated with the smaller sized sectors found in the WMC counties versus those found in the WWO counties. Additionally, the WMC county induced-effect multipliers, while lower than WWO counties, show a potential increasing trend with sector size versus those counties in WWO.

Recommendations | Conclusions

Progress on the deep soils and sustainability analysis relative to nutrients, earlier recognized as a critical component of our assessment of sustained productivity of additional harvest for biofuels, is going well, with far greater than earlier anticipated progress, and we will continue to pursue this aspect of biofuel production. We have managed to leverage all of the graduate student stipends from other sources such as fellowships and teaching assistantships, and we should be able to continue this. Graduate students Jason James and Christiana Dietzen are the primary students, with Dr. Kim Littke and others working as well on the project.

We mentioned concern that the lysimeters at the NARA Long-Term Soil Productivity study do not seem to be collecting large amounts of percolating water. This is often a problem when they are first installed, so the fall rains arriving in September will hopefully solve this problem. Collections do not seem to be improving, and we will continue to try and improve this, but since they are in the ground, it is hard to understand why this is occurring. It may be that there is an incompatibility between soil properties and the porous media that is supposed to make intimate contact and allow water flow. Graduate student Marcella Menegale will continue work on this project, helped by Dr. Kim Littke and Dr. Scott Holub from Weyerhaeuser.

We will continue to expand the results of the four Long-Term Soil Productivity studies to the Pacific Northwest (PNW) region as a whole through our modeling effort using biogeoclimatic and stand factors as model inputs. These can also be used in a crude assessment of the impacts of climate change on potential productivity. Dr. Kim Littke will continue this effort. Dr. Marcia Ciol has contributed substantially to the direction of this effort, but has moved off of the grant for now.

The Stump Decomposition Project, after some problems, has made strong progress, and the data should prove highly useful in completing the carbon LCA. Graduate student Matt Norton will continue this work with help from Dr. Kim Littke, Dr. Indroneil Ganguly and others.

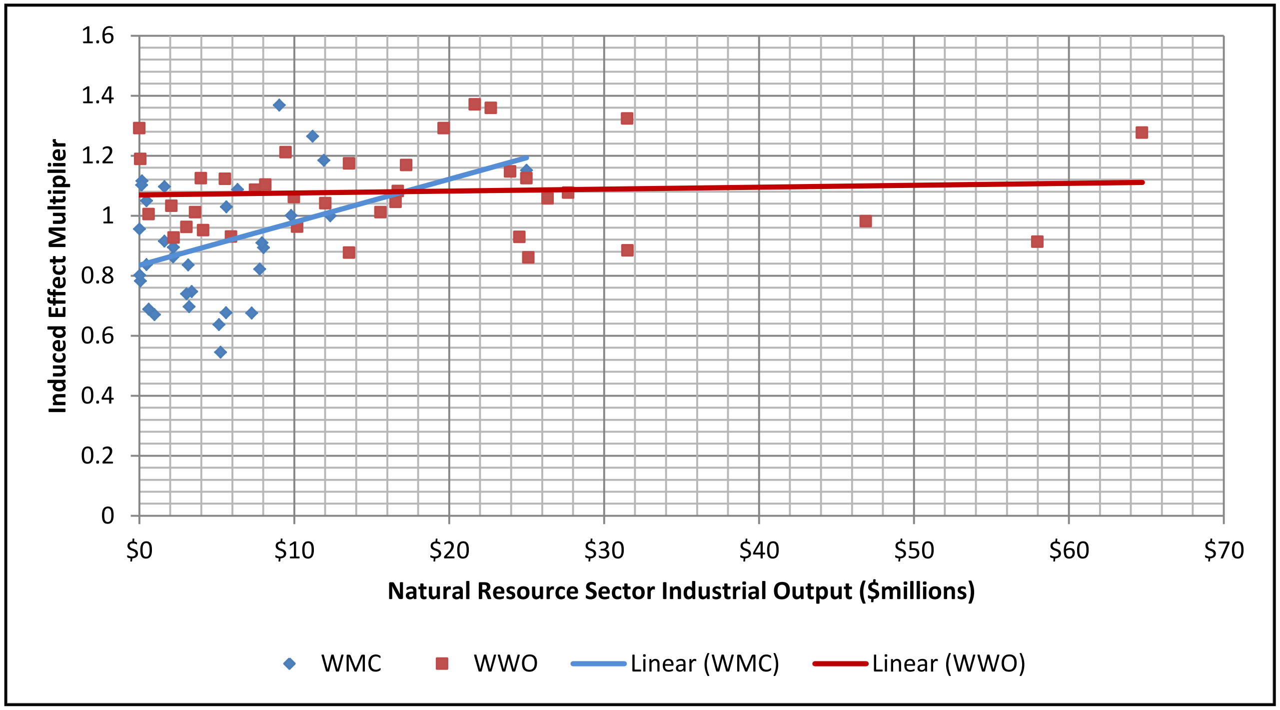


Figure SM-LCA-1.3. Induced effect multiplier for WMC and WWO regions.

The preliminary research results obtained from the LCA, using NREL surrogate modules, show that under most scenarios, NARA-biojet fuel meets the required 60% global-warming potential (GWP) reduction criterion. The LCA team has already developed the individual modules necessary to be able to switch out the NREL surrogate pretreatment (dilute acid) process and incorporate the NARA-mild-bisulfite (MBS) pretreatment. The ASPEN modeling team has already provided the data to our corporate partners (Gevo, Inc.) responsible for the isobutanol (IBA) aspect of the modeling. As soon as Gevo Inc. is ready to share their data with the LCA team, a complete baseline NARA biojet fuel LCA will be made available. All the details have already been iron out, and the final LCA documents should be ready for submission for International Organization for Standardization (ISO) approval by the end of summer of 2015. Following are the planned action plan for the next 12 months, in chronological order:

1. Verify and cross-check all the data obtained from the ASPEN modeling group and make sure none of

the details have been overlooked.

2. Provide necessary input to Gevo Inc. so that they can integrate Gevo's black-box Life cycle inventory (LCI) with the rest of the process
   a. Provide pretreatment, boiler and utilities LCI to Gevo Inc.
3. Obtain Feedstock Scenario Logistics data from different groups at OSU and complete Feedstock Scenario Logistics Data with the selected (or hypothetical) pretreatment facility in the Mid Cascade to Pacific (MC2P) region.
   a. The data may include the following aspects:
      i. Logistics scenarios
      ii. Corresponding slash recovery rates (Kevin Boston)
      iii. Determination of supply zone assuming one million bone-dried tons (BDT) per year (Darius Adams)
4. Finalize the LCI of pre-treatment-gate to iso-paraffinic kerosene (IPK) in storage by integrating the LCIs provided by Gevo Inc.
5. Obtain activated charcoal and cement additive LCIs from Tim Smith's group and integrate it with the biofuels LCA
6. Complete the integrated LCA for ISO (add distribution LCA from Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use model (GREET)
7. Complete the full ISO documentation for technical review, in collaboration with Gevo Inc.
8. Along the way publish peer reviewed journal articles.

Spatial economic impacts depend on the definition of the supply region. We will illustrate how economic impacts change as assumptions about the supplying region are formed. Changes in the supply region occur over time. The NARA Supply model develops supply data over several decades. We will compare changing supply regions over time between the Washington Biomass Supply Assessment data and the NARA Supply Model. We will continue to evaluate alternative locations for biomass facility sites in Washington and Oregon with the NARA Supply Model.

Regional economic impacts differences exist between WMC and WWO. We will continue to document these differences and how they are likely to affect community impacts. Also, we expect to see differences in the commodity by industry accounts. Further development of these accounts will be pursued, including insertion of the biofuels production sector in the input-output model. Finally, a further breakout of the sectors will allow more precise multiplier estimates associated with the forestry sector. We continue to develop spreadsheet models that allow for a sensitivity analysis of industry by industry multipliers versus commodity by industry multipliers. In addition, we have disaggregated the 67-sector model to a 440 sector model. We also have zip-code level data for Washington counties. Models built upon zip-code level data will be used to characterize the rural economic impacts that occur in Washington State and generalized for the NARA region. Current spreadsheet input-output models assume the traditional industry-by-industry matrix analysis with industries aggregated into standard U.S. Bureau Economic Analysis sixty-seven sectors. Given that outputs from the proposed bio-jet fuel process will include several commodities, we are developing the commodities by industry framework, as well as disaggregating the sixty-seven sectors. Discussions were held at the NARA annual meeting with Tom Spink, Gevan Marrs and the rest of the TEA team to share data that will allow measures of the production function for the different commodities to be produced. Data to construct the biofuels sector within the transactions table is expected to be available in April 2015.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

James, J., Devine, W., Harrison, R & Terry T. (2014a). Deep Soil Carbon: Quantification and Modeling in Subsurface Layers. Prepublished Soil Sci. Soc. Am. J. doi:10.2136/sssaj2013.06.0245nafsc. Available at: http://soilslab.cfr.washington.edu/publications/James-etal-2014a.pdf

James, J., Knight, E., Gamba, V., & Harrison, R. (2014b). Deep soil: Quantification, modeling, and significance of subsurface nitrogen. Forest Ecology and Management, 336,194-202. doi:10.1016/j.foreco.2014.10.010

Jandl, R., Rodeghiero, M., Martinez,C., Cotrufo, M.F., Bampa, F., van Wesemael, B., Harrison, R.B., Guerrini, I.A., Richter, D.D., Rustad, L., Lorenz, K., Chabbi, A., & Miglietta, F. (2014). Current status, uncertainty and future needs in soil organic carbon monitoring. Science of the Total Environment, 468,376-383. doi:10.1016/j.scitotenv.2013.08.026

Knight, E., Footen, P., Harrison, R.B., Terry, T., & Holub, S.. 2014. Competing vegetation effects on soil carbon and nitrogen 12 years post-harvest in a Douglas-fir plantation on a highly productive site. Prepublished Soil Sci. Soc. Am. J. doi:10.2136/sssaj2013.07.0320nafsc.

Littke, K., Harrison, R.B., Zabowski, D. & Briggs, D.G. (2014a). Assessing Nitrogen Fertilizer Response of Coastal Douglas-fir in the Pacific Northwest using a Paired-tree Experimental Design. Forest Ecology and Management, 330,137-143. doi:10.1016/j.foreco.2014.07.008

Littke, K.M., Harrison, R.B., Zabowski, D., Ciol M.A. & Briggs D.G. (2014b). Prediction of Douglas-fir Fertilizer Response Using Biogeoclimatic Properties in the Coastal Pacific Northwest. Canadian Journal of Forest Research, 44(10), 1253-1264.

Littke, K.M., Harrison, R.B., Zabowski, D., & Briggs, D.G. (2014c). Effects of geoclimatic factors on soil water, nitrogen, and foliar properties of Douglas-Fir plantations in the Pacific Northwest. Prepublished in Forest Science doi:10.5849/forsci.13-141.

Shryock, B., Littke, K., Ciol, M., Briggs, D. & Harrison, R.B.. (2014). The effects of urea fertilization on carbon sequestration in Douglas-fir plantations of the coastal Pacific Northwest. Forest Ecology and Management, 318, 341-348. doi:10.1016/j.foreco.2014.01.040

Pierobon, F., I. Ganguly, T. Anfodillo and I. Eastin. 2014. Evaluation of Environmental Impacts of Harvest Residue-based Bioenergy Using Radiative Forcing Framework. Forestry Chronicle. V90 N(5), pp:577-585

CONFERENCE PROCEEDINGS AND ABSTRACTS FROM PROFESSIONAL MEETINGS

Ganguly, I., I. Eastin, F. Pierobon, and T. Bowers. 2014. "Environmental Assessment for Woody Biomass Feedstock for Bio-jet Fuel Production." In Proceedings of the Seventh National New Crops Symposium New Crops: Bioenergy, Biomaterials, and Sustainability. Washington D.C.: AAIC

RESEARCH PRESENTATIONS

Presentations

Ganguly I., Sifford C., Ravi V., Alvorado E., Eastin I., Lamb B. and Pierobon F. (2014). Local Air Quality as a Result of Prescribed Biomass Burns. 24th IUFRO World Congress, International Union of forest Research Organization. October 5th-11th, 2014, Salt Lake City, USA.

Pierobon F., Ganguly I., Eastin I., Bowers T. and Anfodillo T. (2014). Incorporating Carbon Sequestration into the Feedstock LCA for residual woody biomass. 24th IUFRO World Congress, International Union of forest Research Organization. October 5th-11th, 2014, Salt Lake City, USA.

Ganguly I., Eastin I., Bowers T., Nwaneshiudu I., Pierobon F., Chen C., Sifford C. and Sasatani D. (2014). LCA based environmental assessment of NARA bio-jet fuel. NARA Annual Meeting. Seattle, September 15-17, 2014.

Ganguly, I, I Eastin, F Pierobon, and T Bowers. 2014. "Environmental Assessment for Woody Biomass Feedstock for Bio-jet Fuel Production." In Proceedings of the Seventh National New Crops Symposium New Crops: Bioenergy, Biomaterials, and Sustainability. Washington D.C.: AAIC.

Francesca Pierobon, Indroneil Ganguly, Tait Bowers, Tommaso Anfodillo and Ivan L. Eastin. Feedstock LCA for Bio-Jet Fuel in Temperate Mountain Systems: Incorporating Carbon Sequestration. 2014 IUFRO conference, Salt Lake City, Utah

Indroneil Ganguly, Ivan L. Eastin, Francesca Pierobon, and Tait Bowers. Local Air Quality Impacts of Advanced Biofuels in the Pacific Northwest: A Consequential LCA Approach. 2014 IUFRO conference, Salt Lake City, Utah

Harrison, Rob, Kim Littke, Jason James, Stephani Michelsen-Correa, Marcella Menegale and Matt Norton. NARA nutrition and soil research for sustained biomass productivity. NARA Annual Meeting, September 15-17, 2014.

Littke, Kim and R.B. Harriso.n Fertilizer research for increased and sustained biomass productivity. NARA Annual Meeting, September 15-17, 2014.

James, Jason and R.B. Harrison. Nitrogen and carbon cycling research at NARA Long-term soil productivity study. NARA Annual Meeting, September 15-17, 2014.

Menegale, Marcella and R.B. Harrison. Dep soil impacts on forest soil productivity for biomass feedstock. NARA Annual Meeting, September 15-17, 2014.

Norton, Matt and R.B. Harrison. Fate and decomposition of stumps after forest cutting for biomass feedstock. NARA Annual Meeting, September 15-17, 2014.

Dietzen, Christiana. 2014. Andisol deep soil carbon pool response to silvicultural treatments. Presented at the Northwest Forest Soils Council Winter meeting, March 14, 2015. Hood River, Oregon.

James, Jason. 2014. Profiles and Chemistry of deep forest soils in the Pacific Northwest. Presented at the Northwest Forest Soils Council Winter meeting, March 14, 2015. Hood River, Oregon.

Norton, Matt. 2014. Decomposition and stump carbon in cut Douglas-fir plantations with time. Presented at the Northwest Forest Soils Council Winter meeting, March 14, 2015. Hood River, Oregon.

Posters

C. Dietzen, R. Harrison, J. James, and M. Ciol. 2014. "Anion Exchange Capacity as a Mechanism for Deep Soil Carbon Storage". American Geophysical Union Fall Meeting San Francisco, CA. December.

R. Harrison, Kim Littke, Austin Himes, Erika Knight, Jason James, Christiana Dietzen, Stephani Michelsen-Correa. 2014. "Nutrient Limitations on Intensive Biomass Production in PNW Douglas-fir Plantations". Soil Science Society of America, Los Angeles, CA. November.

J. James, R. Harrison and T. Bonassi. 2014. "The Relationship Between Exchangeable Base Cations, Soil Carbon and Soil Nitrogen in Deep Forest Soils of the Pacific Northwest". Soil Science Society of America, Los Angeles, CA. November.

S. Michelsen-Correa and Robert Harrison. 2014. "Uptake efficiency and transport of applied nitrogen fertilizers in Douglas-fir forests of the Pacific Northwest". Soil Science Society of America Annual Meeting. Long Beach, CA. November.

C. Dietzen, J. James, R. Harrison, K.Littke, S. Holub, and M. Ciol. 2014. "Effects of Forest Management on Deep Soil Carbon and Nitrogen in a Highly Productive Pacific Northwest Andisol" (Poster). Soil Science Society of America Long Beach, CA. November.

R. Harrison, Austin Himes, Jason James, Christiaa Dietzen, Kim Littke and Eric Turnblom. 2014. "Bioenergy Production and Soil Sustainabililty in the Pacific Northwest, USA". International Union of Forest Research Organizations, Salt Lake, UT. October.

J. James, W. Devine, R. Harrison and T. Terry. 2014. "Deep Soil: Modeling and Understanding Carbon Storage". International Union of Forest Research Organizations, Salt Lake, UT. October.

I. Calleson, Robert Harrison, Darlene Zabowski, Karsten Raulund-Rasmussen, Inge Stupak, Jim Boyle and Jeff Hatten. 2014. "Tree Root Systems and Nutrient Mobilization: Carbon Storage and Mineral Weathering by Rhizospheres and Deep Roots". IUFRO, Salt Lake City, UT. October.

K.M. Littke, R. Harrison, D. Zabowski, and D. Briggs. 2014. Effects of geoclimatic factors on soil nutrients and site productivity of Douglas-fir. NARA Annual meeting. Seattle, WA. September.

S. Holub, J. Hatten and R. Harrison. 2014 How do removals affect long-term productivity. NARA's approach to sustainability. Northwest Advanced Renewables Alliance Meeting, Seattle, WA. September.

D. Maguire, D. Mainwaring, A. Bluhm, K. Coons, Rob Harrison and Eric Turnblom. 2014. Sustainability of biofuel feedstock production: Above-ground nutrient pools and removals. Northwest Advanced Renewables Alliance Meeting, Seattle, WA. September.

R. Harrison, D. Briggs, K. Littke and E. Turnblom. 2014. Forest Fertilization to Increase Biofuel Feedstock and Soil C Sequestration in Coastal PNW Forests. Northwest Advance Renewables Alliance Annual Meeting. Museum of Flight, Boeing Field, Seattle WA. September.

M. Norton. 2014. "Douglas Fir Stump Decomposition: Modeling Carbon Residence Times". Northwest Advance Renewables Alliance Annual Meeting. Museum of Flight, Boeing Field, Seattle WA. September.

K.M. Littke. 2014. Mapping fertilizer response across the region. Stand Management Cooperative Fall 2014 Meeting. Corvallis, OR. September.

K.M. Littke and M. Norton. 2014. "Residence Time of Carbon and Decomposition of Douglas fir Stumps." Stand Management Cooperative Fall Meeting and Field Trip. OSU, LaSells Stewart Center, Corvallis, OR. September.

T. Bowers, I. Ganguly, R. Zamora, C. Chen, J. Sessions and I. Eastin. 2014. Comparative Life Cycle Assessment of the Biomass Logistics Model: Mid-Cascade to Pacific Region. Northwest Advance Renewables Alliance Annual Meeting. Museum of Flight, Boeing Field, Seattle WA. September.

F. Pierobon, I. Ganguly, T. Bowers and I. Eastin. 2014. Evaluation of Environmental Impacts of Harvest Residue Based Bio-energy Using Radiative Forcing Analysis. Northwest Advance Renewables Alliance Annual Meeting. Museum of Flight, Boeing Field, Seattle WA. September.

C. Sifford, I. Ganguly, E. Alverado and I. Eastin. 2014. Developing an Impact Assessment of Local Air Quality as a Result of Biomass Burns. Northwest Advance Renewables Alliance Annual Meeting. Museum of Flight, Boeing Field, Seattle WA. September.

Ikechukwu Nwaneshiudu, Francesca Pierobon, Indroneil Ganguly, Ivan Eastin. (2014). Environmental Assessment of Wet Oxidation and Mild Bisulfite Pretreatments for Converting Forest Slash Residues to Sugar. NARA Annual meeting. Seattle, September 15-17, 2014.

Bowers, T., Ganguly, I., Eastin, I, Pierobon, F., Chen, C., & Sifford, C. 2014. Woody biomass feedstock logistics: LCA scenarios for forest harvest residuals in the Mid-Cascade to Pacific region. Northwest Wood-Based Biofuels and C0-Prodcuts Conference, Seattle, WA. April 2014.

OTHER PUBLICATIONS

Indroneil Ganguly, Ivan Eastin, Tait Bowers and Francesca Pierobon. Environmental Implications of Advanced Biofuels in the Pacific Northwest: An LCA Approach. CINTRAFOR Newsletter, 2014.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

Bowers, C.T., Pierobon, F., 2014. MOSS: Biofuels LCA: Study overview and implications. March 13th 2014.

Indroneil Ganguly. 2014. "Overview on Life Cycle Assessment (LCA) of Renewable Energy & Environmental Implications of Bio-Jet Fuel: Using Logging Residue as Feedstock". University of Washington: School of Environmental and Forest Sciences (SEFS) seminar series, February 12, Seattle, WA.

SYSTEMS METRICS

SUSTAINABLE PRODUCTION TEAM

TASK SM-SP-1: SUSTAINABLE FEEDSTOCK PRODUCTION SYSTEMS

Key Personnel	Affiliation
Scott Holub	Weyerhauser
Greg Johnson	Weyerhauser

Task Description

The importance of ensuring environmental sustainability and carbon benefits of biofuel production cannot be understated. 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 detriment 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.

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, through our collaborations, we also plan to investigate wildlife and water quality effects following biomass removal and compaction treatments to round out environmental sustainability objectives on site.

Activities and Results

The Sustainable Feedstock Production Systems team through our work at NARA LTSP has made significant headway toward our goal of providing needed information on the sustainability of residual biomass removal on the forested landscape. Harvest was completed on the 83-acre site and 28 1-acre plots were treated with a factorial of biomass removal and soil-compaction treatments (Figure SM-SP-1.1 and Figure SM-SP-1.2). We measured and recorded immediate post-treatment soil and biomass effects (Figure SM-SP-1.3). We installed weather stations and plot level soil moisture and temperature monitoring equipment. Fencing was installed in November 2013 to keep deer and elk away from the young seedlings, and in March 2014 30,000 seedlings were planted across the site, 5000 of which will serve as our primary indicator of productivity sustainability for the various treatments. We have measured the trees after one growing season, but data has not been closely analyzed. Our university collaborators have also begun projects using the study site to examine carbon and nutrient cycling mechanisms, nutrient leaching, wildlife (pollinator abundance) and water effects.

This fiscal year we also measured another existing LTSP site, Fall River LTSP near Olympia, Washington, which has reached age 15. Those data provide a fast-forward view of what we might expect to see at the new NARA LTSP. So far results at Fall River LTSP indicate a small (and borderline-statistically-significant) decline in tree volume growth at the 3rd most severe biomass removal, but no significant decline was observed at the most severe biomass removal level (Figure SM-SP-1.4).

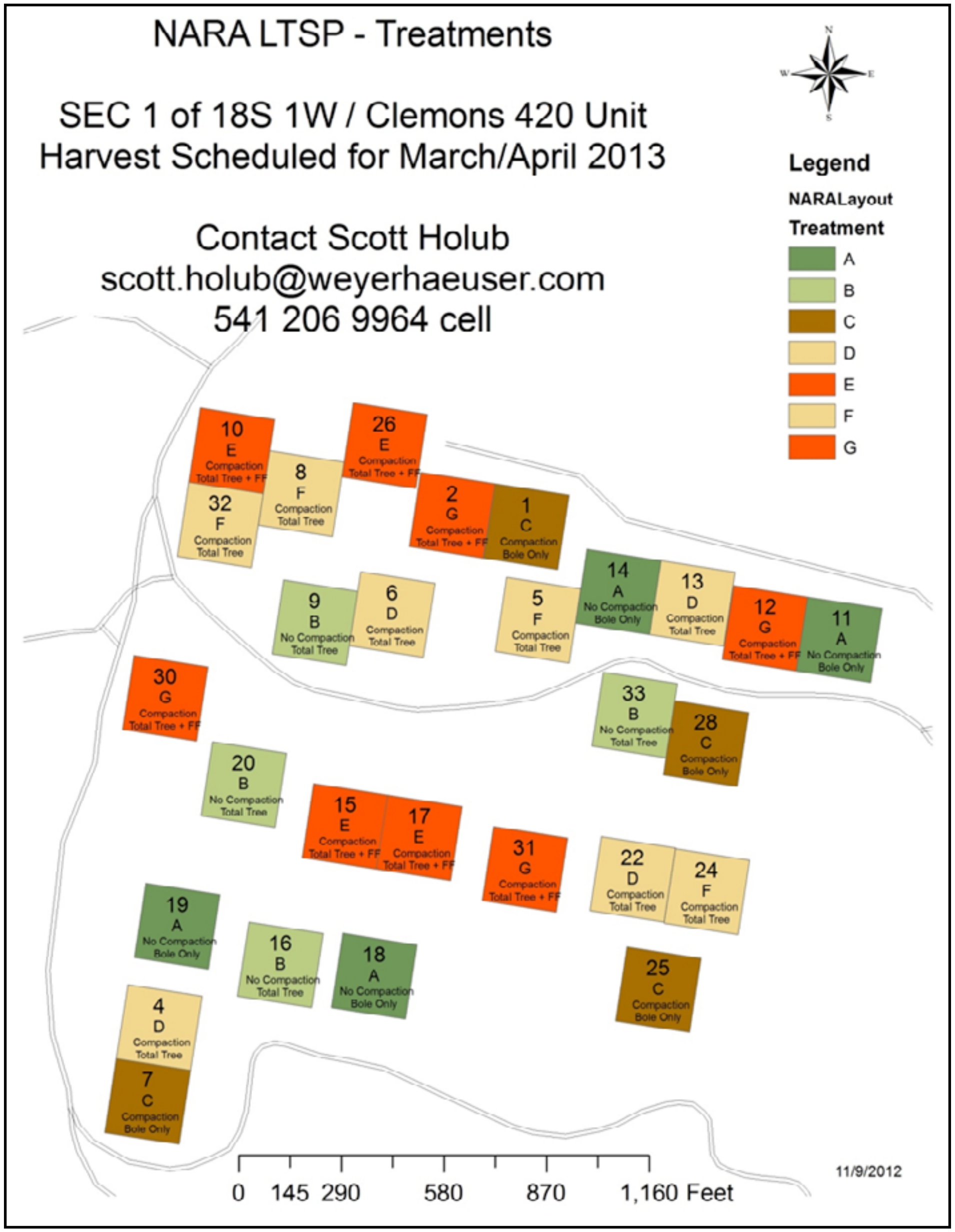


Figure SM-SP-1.1. NARA LTSP Treatment map

Figure SM-SP-1.2. NARA LTSP aerial photo June 2014

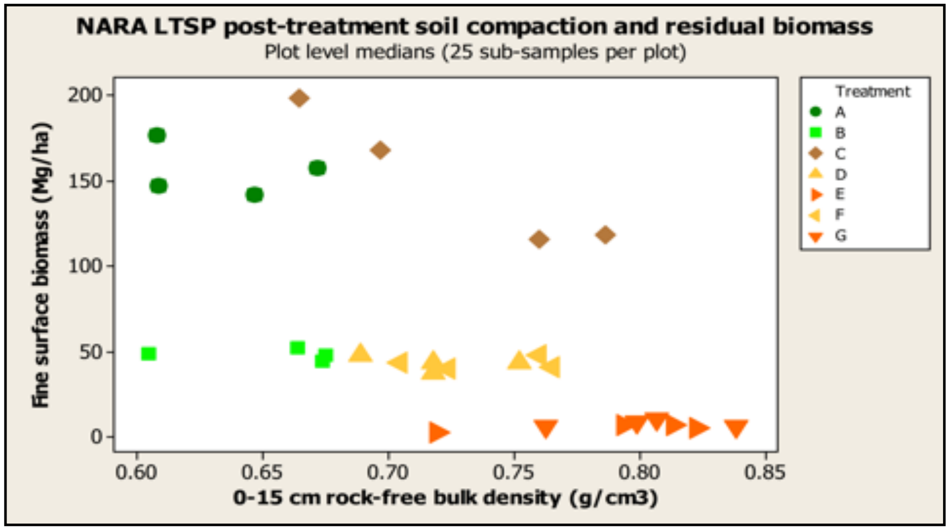


Figure SM-SP-1.3. Post-treatment assessment of compaction and remaining biomass – NARA LTSP

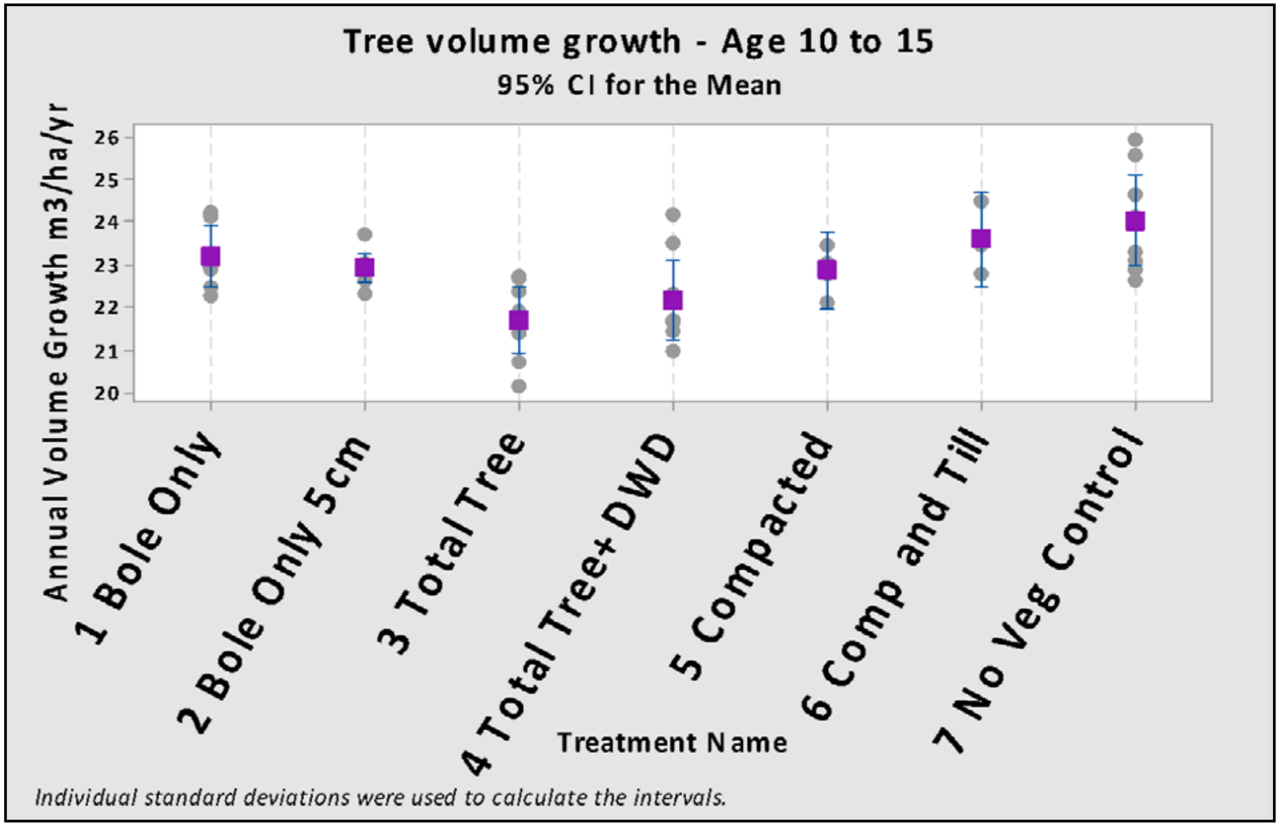


Figure SM-SP-1.4. Preliminary plot-level wood-volume annual growth rates by biomass removal and compaction treatment at the Age 15 Fall River LTSP near Olympia, Washington. Measurements were taken in Fall 2014. Note: All treatments had vegetation controlled with herbicide, except No Veg Control. All treatments were non-compacted, except Compacted and, Compacted and Tilled. No Veg Control, Compacted and, Compacted and Tilled were Bole Only biomass removal.

Recommendations | Conclusions

Preliminary findings indicate that the different treatments we implemented at NARA LTSP were successful at creating a range of conditions in residual biomass remaining and soil compaction. As the projects continue we will monitor environmental conditions, maintain the plots and fence, and support student projects to examine the effects of the treatments.

15-year results from the Fall River LTSP indicate that biomass removal effects on tree growth were small at that site so far. Additional sites and continued study and monitoring are still needed before firm conclusions can be drawn.

Physical and Intellectual Outputs

PHYSICAL

- Harvest was completed on the 83 acre site and applied biomass removal and compaction treatments were applied to 28 1-acre plots .
- Post-treatment soil and biomass effects were measured and recorded from 25 locations per plot (Figure SM-SP-1.3).
- Weather stations and plot level soil moisture and temperature monitoring equipment was installed; data shared with collaborators.

RESEARCH PRESENTATIONS

Holub, S., Terry, T., Harrison, R., Harrington, C. (2015) .Site Productivity Following Various Levels of Biomass Removal, Compaction, and Vegetation Control at Fall River LTSP: 15-year Tree Data. Invited Oral presentation, Northwest Forest Soils Council Winter Seminar, Hood River, Oregon March 14, 2015.

Holub, S., Hatten, J., Harrison R. (2014). How do removals affect long-term productivity?: Long-Term Soil Productivity (LTSP) studies. Oral Presentation at NARA annual meeting, Seattle, WA. September 15-17, 2014.

Holub, S., Meehan, N., Meade, Johnson, R. G., Harrison, R., Menegale, M., Hatten, J., & Gallo, A. (2014). NARA Long-term Soil Productivity (LTSP) Project – 2014 Update. Poster Presentation at NARA annual meeting, Seattle, WA. September 15-17, 2014.

OTHER PUBLICATIONS

Harrington, T.B. & Holub, S.M. (2014, Summer). Managing for long-term soil productivity in Pacific Northwestern forests. Western Forester. 59(3), 1-4. http://www.forestry.org/media/docs/westernforester/2014/WF_June_July_Aug2014.pdf

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

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-2.3. Establish Large-Scale ("iFLAMES")

We successfully established Site #1 (Warm Springs) of the integrated Fireshed-Level Adaptive Management Evaluation Sites (IFLAMES) network, with pre-treatment measurements completed and summarized; the nine areas, range from 125 to 270 ft2 of basal area/acre and are representative of mixed-conifer stands in this area. All stands are mixtures of Douglas-fir and ponderosa pine, and some of the stands have incense-cedar. We continue to plan for additional sites on tribal lands (e.g. Salish-Kootenai and Yakama tribal lands) and to coordinate with regional CFLRP projects over potential sites on federal lands (e.g. Lakeview). This requires regular attendance of meetings and conferences, site visits, and conversations.

Kevin Vogler's thesis work is moving forward to publication in two manuscripts:

- "Sustainable Biomass supply from Fuel reduction treatments: A Biomass Assessment of Forest Service lands in the Blue Mountains, USA" to be submitted to Biomass & Bioenergy
- "Wildfire hazard in dry forests of Eastern Oregon: Are fuel treatments appropriately scaled to address the problem?" to be submitted to Journal of Forestry

Along with other related research, as well as experiences with iFLAMES, we were able to foster greater participation from land managers and collaborators within the region; these efforts are supported by research examining:

- Ecosystem resiliency and fuel model recovery following fuels treatments in dry-forest ecosystems, primarily examining post-treatment regeneration within established plots. An analysis of the current state of previously treated stands should give an indication of the effective lifecycle for each treatment.
- Revision/expansion of our understanding of the historic role of fire, insects and climate variability in these ecosystems; reconstructions for approximately 500 years on ten different sites on the Malheur National Forest in central-eastern Oregon. Data about historical successional and disturbance dynamics over long periods of highly variable climate periods will inform restoration treatments that create resilient forest structure and composition in the face of future change.

Recommendations | Conclusions

Intensity and extent of silvicultural treatments across an expanse of Eastside federal lands (in need of restoration) influences the amount of material available for biomass/bioenergy, and there are compelling reasons to pursue those ventures to support restoration and sustainable land management; however, our analysis concludes that available supply is insufficient to support the NARA facility currently envisioned.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Spies, T. A., E. M. White, J. D. Kline, A. Paige Fischer, A. Ager, J. Bailey, J. Bolte, J. Koch, E. Platt, C. S. Olsen, D. Jacobs, B. Shindler, M. M. Steen-Adams and R. Hammer. 2014. Examining fire-prone forest landscapes as coupled human and natural systems. Ecology and Society 19(3): 9.

CONFERENCE PROCEEDINGS AND ABSTRACTS FROM PROFESSIONAL MEETINGS

J.D. Bailey. 2014. Overuse and misuse of "thinning" in modern silviculture. Presentation at: Society of American Foresters National Convention. October 8-11 in Salt Lake City, UT.

RESEARCH PRESENTATIONS

James Johnston gave presentations to the Blue Mountains Forest Partners and the Malheur National Forest on August 21 and October 16 about historical successional and disturbance dynamics on forests targeted for restoration treatments under the CFLRP program.

Vogler, K. and J. Bailey. Sustainable Biomass Supply from Fuel Reduction Treatments: A Biomass Assessment of Federally Owned Land in Eastern Oregon. Oral Presentation at Large Wildland Fires Conference, April 19-23, 2014, Missoula, MT.

Vogler, K. and J. Bailey. Sustainable Biomass Supply from Fuel Reduction Treatments: A Biomass Assessment of Federally Owned Land in Eastern Oregon. Poster prepared for Central Oregon Fire Science Symposium, April 7-10, 2014, Bend, OR.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

"Living with Fire" Pacific Northwest Science and Management Team Retreat, June 5-6, 2014 in Skamania, WA. (Speaker)

THESIS AND DISSERTATIONS

Vogler,K. Sustainable Biomass Supply from Fuel Reduction Treatments: A Biomass Assessment of Federally Owned Land in Eastern Oregon. Masters Defense, June 20, 2014, Corvallis, OR.

TASK SM-SP-3: BIOMASS MODELING AND ASSESSMENT

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

Task Description

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 ID and MT 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 OR and WA 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: (a) biomass processing plant locations and capacities and (b) biomass supply volumes under alternative biomass prices.

Activities and Results

We further refined the NARA biomass supply model and began preparation of a manuscript for submission to a peer-reviewed journal documenting the model and applying it to develop projections of supply curves for biomass suitable for use in liquid biofuel production. We also examined the impacts of variation in supply functions with changes in two key public policies: (i) RIN credits expanded to include material from federal lands, (ii) changes in public harvests.

Recent work also includes preparation of a manuscript refining the NARA-based work from Mindy Crandall's doctoral thesis for submission to a peer-reviewed resource economics journal. The work is based on a variant of the NARA biomass supply model adapted to utilize specific potential depot locations along with transport, processing, capital establishment, and operating costs to determine optimal depot locations and capacities and market clearing biomass flows from woods to the depots. Portions of this work was also presented at the Southern Regional Science Association Annual Meeting March 26 - 28 in Mobile, AL and accepted for oral presentation at the combined Western Forest Economists and International Society of Forest Resource Economics meeting May 31 – June 2 in Vancouver, BC.

After meeting with Indroneil Ganguly and Ivan Easton, we expanded our Forest Vegetation Simulator (FVS) yield and biomass model to provide additional outputs for the Mid Cascade to Pacific (MC2P) region under an array of silvicultural options for use in their Life Cycle Inventory analyses. We continue to work on final development of FVS yield and biomass data for eastern OR and WA along with ID and MT enabling completion of biomass supply relations for example refinery areas in the Missoula Corridor area.

Work continues in partnership with Natalie Martinkus shifting our transportation cost computation methods to a new ARCGIS Network Analyst-based approach. This new approach promises to be faster and more flexible than the scheme we have used to date.

Recommendations | Conclusions

Work will begin this summer on a multi-NARA group synthesis paper covering the sustainability of the use of forest residuals for bio-fuel production. This work will require:

- incorporation of completed John Sessions led Collection, Processing, and Transport Logistics group findings into the NARA biomass supply model (Task SM-SP-3.2).
- inclusion of wildlife metrics from Matt Betts led Wildlife Impacts group into the FVS growth and yield generation program.
- evaluation for potential inclusion of Doug Maguire and Jeff Hatten led Long-Term Site Productivity group findings into the FVS growth and yield generation program.
- Refinement of FVS growth and yield output to provide Indroneil Ganguly and Ivan Eastin of the Life Cycle Assessment group detailed data for use and input in their modeling.

We are also in the process of submitting a proposal for an AFRI Foundational Program Grant in the Agriculture Economics and Rural Communities (AERC) program area. The proposal's Duke University led research team seeks to coordinate, leverage and extend three NIFA Bioenergy Bioeconomy Bioproducts (B3) projects. The proposed project seeks to align two AFRI "Policy Options for, and Impacts on, Regional Biofuels Production Systems" program area projects:

- CRIS Number 229908 "The Effect of Existing and Novel Policy Options on the Sustainable Development of Regional Bioenergy Systems" and
- CRIS Number 230883 "Regional Bioenergy Policy Effectiveness: Compatibility, Innovation, and Coordination across the Supply Chain",

plus the proposed project will investigate the applicability of identified policy options to AFRI large cap projects. In addition to utilizing existing established forest sector models to simulate emerging bioenergy opportunities across the U.S., the project would use the NARA biomass supply model to evaluate the potential effectiveness of project identified novel policy options for fostering development of bioenergy markets in the U.S. Pacific Northwest. The proposed project timeline for integration of the NARA biomass supply model with these policy-based AFRI efforts includes an overlap with NARA year 5 providing additional bioenergy policy support through leading up to our final reporting for the Sustainable Feedstock Production Group.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Crandall M, DM Adams, CA Montgomery. The potential for biomass use and increased federal harvests to aid rural development in western Oregon. (in preparation)

RESEARCH PRESENTATIONS

Crandall, M., C. Montgomery, and D. Adams. 2015. Potential Rural Development Impacts of Increased Utilization of Forest Resources. Presented at Southern Regional Science Association Annual Meeting, March 26 - 28, Mobile, AL

THESIS AND DISSERTATIONS

Crandall, Mindy. "The effects of increased supply and emerging technologies in the forest products industry on rural communities in the northwest U.S." Doctoral dissertation in the Department of Forest Engineering, Resources and Management, submitted to the Graduate School, Oregon State University, September 26, 2014. https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/52556/CrandallMindyS2014.pdf

TASK SM-SP-4: LONG TERM PRODUCTIVITY STUDIES

Key Personnel	Affiliation
Doug Maguire	Oregon State University

Task Description

We will 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 both 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

Task SM-SP-4.2. Estimate nutrient and carbon removals under various levels of biomass harvesting

This task has been completed. Tree lists from four SMC type 1 plantations (~15 yrs plantation age), representing a range of site productivities (SI50=78.3, 99.7, 124.7, and 143.6 ft) were grown to 80 years of age using the geographically appropriate version of ORGANON, a regional growth model. Examining fire-prone forest landscapes as coupled human and natural systems

Task SM-SP-4.3. Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities

We have accumulated estimates of soil nutrient replenishment rates, atmospheric deposition rates, and nutrient release rates of various parent materials found within westside Douglas-fir stands. Based on the soil nutrient capital at the four SMC-type 1 sites sampled during the construction of soil biomass equations, and application of the Evans stability ratio, we have determined sustainable levels of bioenergy feedstock production.

Task SM-SP-4.4. Estimate changes in long-term site productivity under different climate change scenarios

Based on future estimates of climate change (using climate-FVS) at the four SMC type-1 sites that were sampled during the construction of biomass equations, Douglas-fir is predicted to be a non-viable species in the future. This would suggest that there is no long-term Douglas-fir productivity on the basis of that specific model. We are currently exploring the use of other models in answering this question.

Recommendations | Conclusions

Differences in nutrient removals by harvest intensity are most pronounced in low productivity stands, where a bole-only harvest takes a much smaller % of aboveground nutrient content relative to a whole-tree harvest. Given that low productivity stands have greater nutrient limitations than their high productivity counterparts, and also due to inherently greater biomass production, biomass harvesting would be best focused within high productivity stands.

Of the five macronutrients for which published rates of weathering, deposition, and leaching are available (N, P, K, Ca, Mg), calcium is the nutrient that has the highest percentage of its initial pool depleted by biomass harvesting. This is especially true in coastal regions, where older sandstones are particularly lacking in calcium, and where atmospheric deposition is the primary source.

Physical and Intellectual Outputs

THESIS AND DISSERTATIONS

Coons, K.L. (2014). Douglas–fir (Psuedotsuga menziesii) biomass and nutrient removal under varying harvest scenarios involving co-production of timber and feedstock for liquid biofuels. M.Sc. Thesis, Oregon State University.

TASK SM-SP-5-AIR: ENVIRONMENTAL IMPACT ANALYSIS TO SUPPORT NARA BIOFUEL DEVELOPMENT IN THE PACIFIC NORTHWEST-AIR COMPONENT

Key Personnel	Affiliation
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 quality. There is a need to investigate both positive and negative air quality impacts that biofuel harvesting may have on short- and long- term changes in air pollution within the project airsheds at scales ranging from field scale to regional scale. The specific objectives of this project are:

1. to develop supply chain emission scenarios and use these for a regional analysis of the impact of the supply chain on air quality.
2. to assess the reduction in air pollution levels associated with the reduction in prescribed burning which will occur when woody residues are harvested for biofuel production.

Activities and Results

During the past year, we have completed a series of regional air quality simulations to investigate the impact of prescribed fires on local and regional air quality. These simulations show that harvesting woody biomass for biojet fuel production will decrease the amount of slash burning that occurs in the region and result in a positive benefit for air quality. This impact is mostly confined to the fall and spring months when prescribed fire activity occurs. Figure SM-SP-5A.1 shows the benefits associated with reduction of prescribed fire activity by 70%. Also shown is PM2.5 concentration averaged for the prescribed fire season- October and November. It was also found that prescribed fire contribution to 8-hour average ozone concentration is negligible.

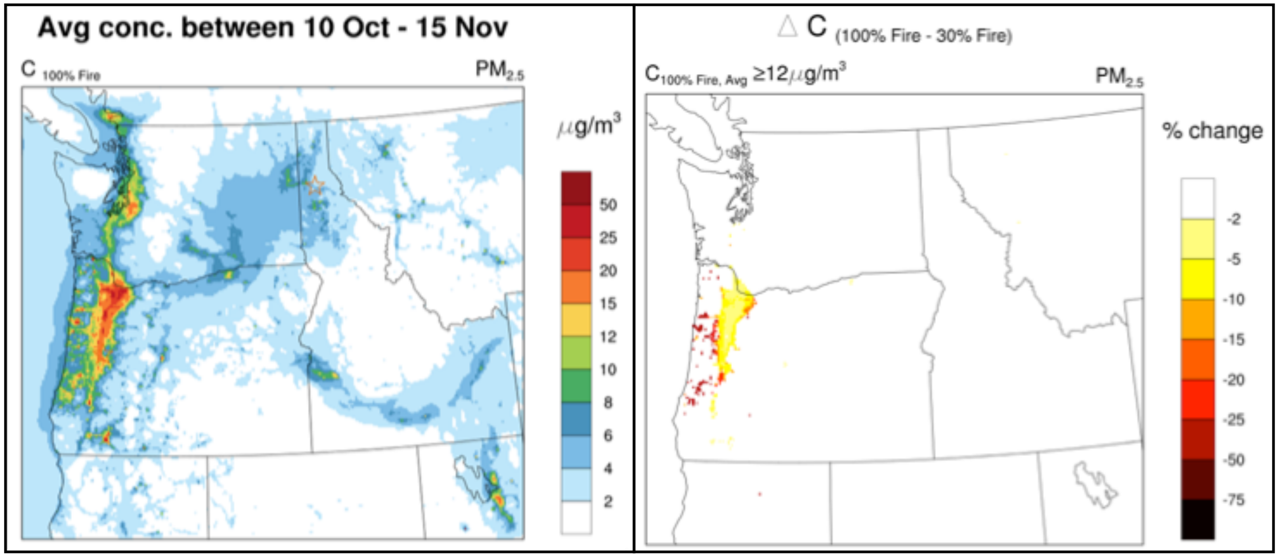


Figure SM-SP-5A.1. (left) average PM2.5 concentration for the simulation period and (right) % change in concentration observed when prescribed fire emissions were reduced by 70%

Recommendations | Conclusions

Our focus for the next year is on simulations of biorefinery and supply chain emissions. However, we are dependent upon the other design groups to provide emissions data and scenario cases. This continues to be an area of concern for our analyses.

Physical and Intellectual Outputs

Primary outputs are model simulation files and associated powerpoints and posters.

TASK SM-SP-5-WATER: ENVIRONMENTAL IMPACT ANALYSIS TO SUPPORT NARA BIOFUEL DEVELOPMENT IN THE PACIFIC NORTHWEST-WATER COMPONENT

Key Personnel	Affiliation
John Petrie	Washington State University
Michael Barber	University of Utah

Task Description

Land use and residuals management changes associated with biofuel growth, harvesting, and processing may pose unique environmental issues related to water quality. There is a need to investigate water quantity and quality impacts that biofuel harvesting may have on short- and long- term changes in sediment and nutrient loadings, hydrologic dynamics, and stream channel responses within the project watersheds at scales ranging from field scale to regional scale. The specific objectives of this project are:

(1) to 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) to collect and examine microbial communities at the test plots;
(3) to develop predictive water quantity and quality models that can be used to evaluate watershed-scale regional impacts; and
(4) evaluate the potential impacts of altered hydrologic conditions on stream channels.

The University of Utah will primarily conduct Items 1-3, although joint collaboration with field data collection is anticipated. Item 4 will be conducted by Washington State University, although joint collaboration with field data collection is anticipated.

Activities and Results

Soil samples were collected in May 2014 from Long-Term Soil Productivity (LTSP) plots to perform DNA extraction test in the laboratory. Nine samples were collected from each plot. The samples were taken at a depth of 0-20 cm using a hand shovel.

Microbial population data was collected from 28 one acre plots subject to different land treatments and statistically analyzed to evaluate a null hypothesis that changes in biomass removal do not impact subsurface environment. Four DNA extraction test for each soil sample i.e. 144 for each treatment and 16 for the control one, concluding a total of 1024 test has been performed. Two sample t-tests assuming equal variances has been performed to find out the correlation between DNA concentration and different treatments. The results of the hypothesis tests were not able to make any decision about the null hypothesis for which a biological analysis has been performed using finger printing analysis (ARISA).

Forty samples out of 1024 DNA samples, five from each treatment including the control one has been selected for the ARISA finger printing analysis, in such a way so that those can be considered as the representative sample for each treatment. Community fingerprinting is used to profile the diversity of microbial community. These techniques show how many variants of a gene are present instead of counting individual cells in a sample. The results of ARISA tests are shown in Figure SM-SP-5W.1 and Table SM-SP-5W.1.

1197 intergenic spacer sequences out of 3211 were examined and 56 genera were found; the majority of which are from taxa belonging to either the gram positive or gram-negative phyla. Table SM-SP-5W.2 shows the diversity indices results calculated by the Shanon–Weaver and Simpson’s Diversity Index method.

Task SM-SP-5.1.4. Create stream erosion model of study sites

We have performed a literature review on stream channel response to forest practices and selected models to simulate hillslope and stream channel impacts. A methodology was developed to use hillslope models to provide sediment supply data to a model of flow and sediment transport in streams. Preliminary work indicates that changes to peak flows and sediment supply are the most critical parameters for quantifying channel response. Cat Spur Creek, located in a logged watershed in northern Idaho, was selected as the field site. Data collection was conducted in July 2014 to characterize channel elevation, streambed material, and streambank vegetation. Based on the Cat Spur Creek watershed, the FS Disturbed WEPP hillslope model was used to provide sediment supply rates to Nays2DH, a two-dimensional stream model capable of predicting sediment transport and changes to bed material. Impacts from biomass removal have been conservatively estimated to increase sediment yield from the hillslope by 35 to 60% beyond the initial sediment yield due to timber harvest. This estimate is dependent upon the area disturbed by biomass removal. The increased sediment yield predicted by the FS Disturbed WEPP model was then used as input to Nays2DH. Biomass removal impacts predicted by the stream model were: 1) a decrease in average bed material diameter by up to 3 mm, and 2) increase in bedload transport by up to 5% as shown in Figure SM-SP-5W.2.

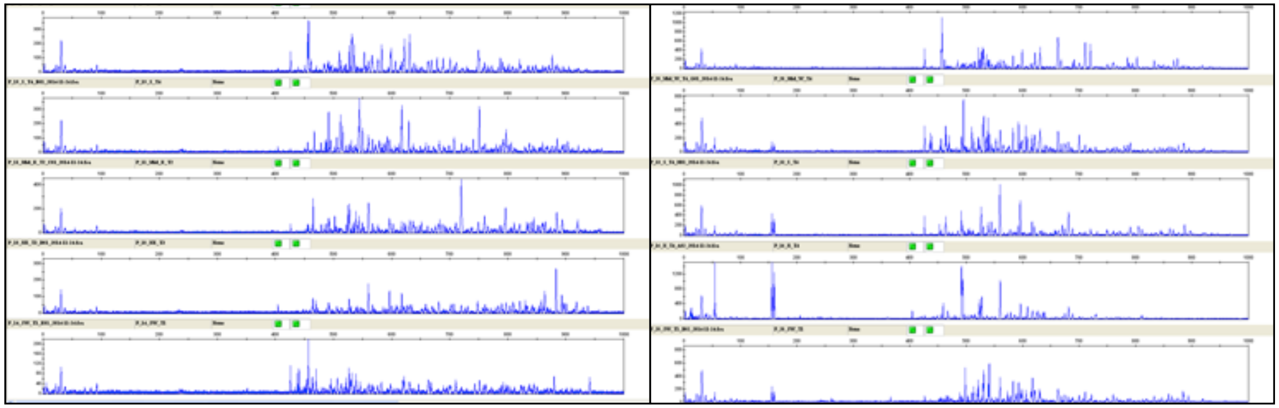


Figure SM-SP-5W.1. ARISA test run result for treatment A and B

Table SM-SP-5W.1. Range of Peak Number and sizes in the ARISA Profiles for Different Treatments

Treatments	No. of Peaks	Range of peak size (bp)	Range of spacer size (bp)
Treat A	397	208.46 – 920	86.46 – 798
Treat B	464	208.46 – 950.59	86.46 – 828.59
Treat C	404	208.48 – 917.79	86.48 – 795.79
Treat D	442	226.69 – 1002.1	104.69 – 880.1
Treat E	288	220 – 934.01	98 – 812.01
Treat F	337	208.62 – 921.7	86.63 – 799.7
Treat G	438	208.59 – 971.53	86.59 – 849.53
No Treatment	441	208.58 – 941.52	86.58 – 819.52
Total	3211		

Table SM-SP-5W.2. Diversity Index Results

Treatments	A	B	C	D	E	F	G	Unharvested
Shanon – Weaver Index (H)	2.98	3.13	3.03	3.30	3.21	3.19	3.30	3.22
Shanon’s Equtability Index (EH)	0.85	0.84	0.83	0.87	0.86	0.86	0.86	0.85
Simpson’s Index (D)	0.084	0.075	0.084	0.059	0.069	0.074	0.065	0.071

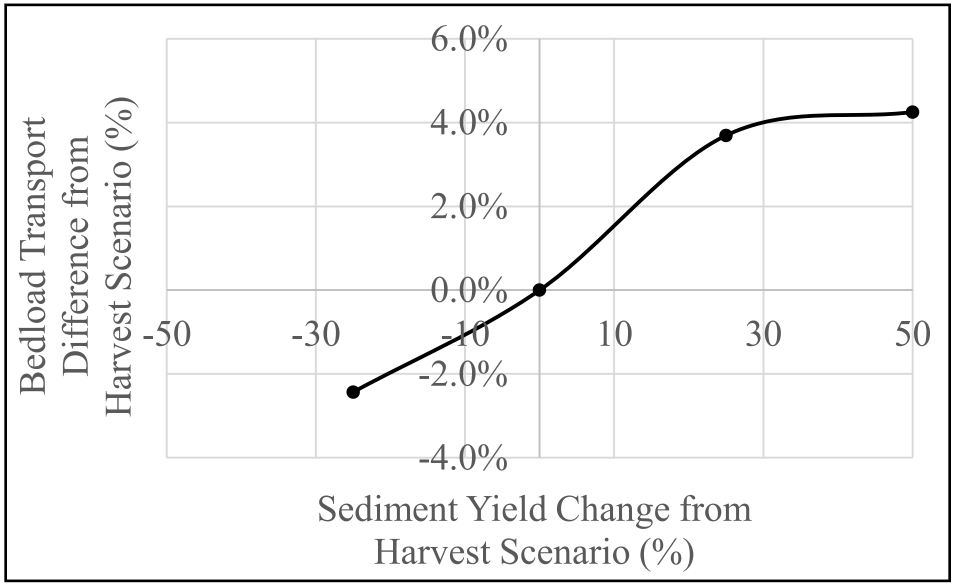


Figure SM-SP-5W.2. Correlation of sediment yield increases from hillslope to bedload transport in stream

Recommendations | Conclusions

- From all these analysis, it has been found that the biomass removal from the field does not have any detrimental impact on the long-term flux of nutrient populations and microbial ecology.
- To find out the impact on water quantity specifically on runoff, infiltration and evapotranspiration a water balance model has to be developed in near future by using Windows version of UNSAT-H model. All necessary data and literature review has already been done. Developing the water balance model will help to understand the impact of ground residual removal from hydrologic point of view.
- Future work is needed to improve hillslope sediment and runoff predictions from watersheds impacted by traditional logging and biomass removal. This work should focus on sites representative of expected field conditions. Additional data collection within the stream channel will also provide further insight into stream channel processes. A sustained monitoring and measurement campaign through cycles of watershed disturbance would be most beneficial. Such a dataset would provide important validation data for numerical models as well as quantitative metrics for stream channel impacts.

Physical and Intellectual Outputs

PHYSICAL

- Nine soil samples from each plots and four soil samples from unharvested sites were collected.
- Four DNA extraction tests from each soil sample were performed which concluded a total of 144 DNA extraction for each treatment and 1024 for the whole LTSP sites.
- Fifty-six genera were identified from the ARISA results for these LTSP sites.

CONFERENCE PROCEEDINGS AND ABSTRACTS

In progress: Hasan, M.M., Barber, M.E., Goel, R., and Mahler, R.L. (abstract and paper accepted). Understanding the consequences of land use changes on sustainable river basin management in the Pacific Northwest, USA. River Basin Management 2015, 8th International Conference on River Basin Management including all aspects of Hydrology, Ecology, Environmental Management, Flood Plains and Wetlands, A Coruna, Spain.

In progress; Wickham, R. and J. Petrie (abstract and paper accepted), Quantifying the spatial variability of stream bed grain size distributions and the influence on sediment transport modeling, ASCE EWRI Congress 2015, World Environmental & Water Resources Congress, Austin, TX, May 17-21, 2015.

RESEARCH PRESENTATIONS

Sorensen, E., R. Wickham, and J. Petrie. Spatial Distribution of Grain Sizes in Sampling Heterogeneous Stream Beds. Poster presented at the 2014 NARA Summer Undergraduate Research Experience Poster Session, Pullman, WA, August 1, 2014.

Hasan, Mohammad M., Michael E. Barber and Scott M. Holub. Microbial Population as a Function of Woody Biomass Removal Treatments. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Wickham, Ross S. and John Petrie. Response of Flow and Sediment Dynamics in Mountain Streams to Biomass Removal. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Wickham, R. and J. Petrie, Response of Flow and Sediment Dynamics in Mountain Streams to Biomass Removal, Poster Presentation at Climate, Land Use, Agriculture and Natural Resources: Activities in Interdisciplinary Research, Education and Outreach, October 7, 2014. Pullman, WA

VIDEOS AND WEBINARS

Petrie, J. Rivers Channel Changes: Impacts of Forest Management, MOSS imagine tomorrow webinar (McCall Outdoor Science School, University of Idaho), March 11, 2015

THESIS AND DISSERTATIONS

Wickham, R. The Effect of Grain Size Heterogeneity on Sediment Transport Modeling, MS Thesis, to be defended on April 20, 2015.

Hasan, M.M. Evaluating the Environmental Impact of Woody Biomass Removal for Biofuel Production, MS Thesis, to be defended on April 24, 2015.

TASK SM-SP-6: LOCAL AND REGIONAL WILDLIFE IMPACTS OF BIOMASS REMOVALS

Key Personnel	Affiliation
Matthew Betts	Oregon State University

Task Description

We will review silvicultural regimes proposed 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. Review landscape patterns resulting from regional models of biomass collection and removal. 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

Task SM-SP-6.1. Analysis of preliminary regional models completed to provide metrics for regional runs and to inform future regional model runs

The manuscript submitted by Betts and to Journal of Forestry has been conditionally accepted. In this manuscript, we describe the range of management practices used to harvest biomass, and the types of forest organisms known or expected to be impacted. We review the tradeoffs between habitat alteration and potential for global climate change mitigation. Furthermore, we place biomass harvesting in a landscape context and discuss the potential for thresholds in species responses to biomass management at stand and landscape scales. After framing the issues and current knowledge, we propose a research plan for the future.

We are continuing to conduct a meta-analysis examining the effects of intensive forest management practices on bird communities across North America. We have compiled 14,000 bird community observations from Oregon, California, Ontario, New Brunswick, British Columbia, Saskatchewan, and Alberta. Preliminary occupancy models have been run for stand-level and landscape-level impacts of intensive forest management on species richness, cavity-dwellers, and individual bird species from 8 study regions, including 2 in the Pacific Northwest. Heather Root was hired as an Assistant Professor 6 months ago, which has slowed progress on this data analysis. Jim Rivers does not have the statistical background to continue with this aspect of the project, so our intention is to hire a new postdoc to complete the analysis. The postdoc will not start until late Fall 2015, so we are requesting a no-cost extension on 2015 funds to enable that hire. With this no-cost extension, our target completion date for this task is June 2016.

As mentioned in previous updates, we have determined there are insufficient data available to develop population viability analyses for indicator species as proposed originally. As a result we are focusing our work on (1) the review above and (2) collection of field data on the impacts of biofuel removal (Task SM-SP-6.2 below).

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

Betts and Rivers (in collaboration with former postdoc Root) established a field study in western Oregon for spring/summer 2014 to examine the relationship between White-Crowned Sparrow fledglings and slash at sites with experimentally manipulated management intensity. Casual observation suggests that fledglings are using fine and coarse slash as cover between the times that they leave the nest and gain the ability to fly. This effort will dovetail with an AFRI-supported project investigating the effects of intensive forest management. During June-August 2014 we collected juvenile sparrow telemetry data to identify habitats used by fledglings and measure the association between survival and woody debris. Data are currently undergoing the QA/QC process, followed by data analysis with survival models.

In addition to our research on birds, we also initiated a field study during summer 2014 to examine the influence of biomass removal and site prep on invertebrate pollinators. Ground-nesting bees, which provide important ecosystem services in regenerating forests, are among the wildlife likely to respond to slash manipulation on small-scale plots like those established in the LTSP experiments and will be continue to be a focus of our field studies at the LTSP sites during summer 2015. Our initial field work used a combination of (1) emergence traps to quantify emergence of ground-nesting bees and (2) blue-vane traps that sample a wide array of insects to quantify presence of invertebrate pollinators in LTSP stands (Figure SM-SP-6.1). During summer 2014 we captured a large number of bees (>1900 individuals) and we are currently processing individuals so that they can be identified to species. Following lab work, we will test whether species diversity (i.e., species richness and abundance) differs relative to experimental treatments.

Figure SM-SP-6.1. Examples of a ground-nesting bee emergence trap (left) and a blue vane trap (right) used to trap invertebrate pollinators in the LTSP sites on Weyerhaeuser land during summer 2014. Emergence traps are exclosures with an open bottom that capture ground-nesting bees that overwinter in the soil and emerge as adults. In contrast, blue vane traps capture free-flying adult bees that vary widely in the type of substrates used for nesting.

Recommendations | Conclusions

Our review manuscript examines current knowledge about the utilization of dead wood by wildlife. We summarize the abundant literature on the importance of coarse woody debris for wildlife within a stand and identify knowledge gaps in the areas of fine woody debris and impacts at a landscape scale, which may be more important than local impacts. In the coming year, we will complete the meta-analysis of intensive forest management effects on bird communities, the survival analysis of White-Crowned Sparrows in relation to fine and coarse woody debris, and continue our study of the bee communities captured at the WY LTSP site.

Physical and Intellectual Outputs

PEER-REVIEWED PUBLICATIONS

Root, H. and Betts, M.G. In Revision. Biofuel and Biodiversity in Mesic Forests. Journal of Forestry

RESEARCH PRESENTATIONS

Betts, M.G. 2014. Why do species occur where they do? Land-use, Climate and Behavioral Drivers of Species distributions in a changing world. University of Georgia, April 2014.

Betts, M.G. 2014. Why do species occur where they do? Land-use, Climate and Behavioral Drivers of Species distributions in a changing world. University of York, York, United Kingdom, August 2014.

Betts, M.G. 2015. Conserving Forest Biodiversity from Moncton to Monte Verde. Université de Moncton, New Brunswick, Canada, February 2015.

Betts, M.G. 2014. Introduction to the Intensive Forest Management Experiment. Wildlife in Managed Forests: Songbirds and Early Seral Habitats of the Oregon Forests Research Institute, Albany, OR.

Rivers, J. W., and M. G. Betts. 2014. Intensive forest management practices reduce nest survival and offspring production: evidence from a landscape-scale experiment 132nd meeting of the American Ornithologists' Union, Estes Park, CO.

Rivers, J. W., J Verschuyl, A. J. Kroll, C. J. Schwarz, and M. G. Betts. 2014. Assessing herbicide impacts on songbird demography in early seral forests of the Pacific Northwest. Wildlife in Managed Forests: Songbirds and Early Seral Habitats of the Oregon Forests Research Institute, Albany, OR.

Mathis, C. L., J. W. Rivers, and M. G. Betts. 2015. Assessing the influence of organic biofuel removal on bee diversity in early seral production forests. Oregon Chapter of The Wildlife Society, Eugene, OR.

Rivers, J. W., J. Verschuyl, A. J. Kroll, and M. G. Betts. 2015. The influence of intensive forest management practices on breeding success of the white-crowed sparrow, an early seral songbird. Oregon Chapter of The Wildlife Society, Eugene, OR.

Rivers, J. W., J. Verschuyl, A. J. Kroll, and M. G. Betts. 2015. Quantifying tradeoffs between biodiversity and timber production in western Oregon: an overview of the Intensive Forest Management Study. Washington Chapter of The Wildlife Society, Grand Mound, WA.

Rivers, J. W., J. Verschuyl, A. J. Kroll, and M. G. Betts. 2015. Influence of intensive forest management on the breeding success of an early seral songbird. Washington Chapter of The Wildlife Society, Grand Mound, WA.

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 (BBER) Forest Industry Research Program will characterize the composition, quantities, spatial distribution, and other characteristics of varied sources of woody biomass across the NARA four-state area.

The specific objectives of the Feedstock Supply Chain Analysis are to identify and provide primary data necessary to assess the woody biomass inventory with particular emphasis on mill and logging residue and annual timber harvest in the 4-state region.

Activities and Results

The University of Montana's BBER Forest Industry Research Program 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.

After attending the NARA annual meeting in September 2014 and meeting with other members of the Team, we assembled information on felled tree breakage, stump height, and small end diameter for our colleagues at OSU and UW. We thank them for their interest in our research and look forward to informing other NARA investigators on how to use our logging utilization and mill residue data sets.

BBER currently has 2002 through 2012 timber harvest data (in MBF Scribner) by county and ownership available for the entire 4-state region; 2013 data for all ownerships in Washington are available; and 2013 data for several but not all owners are available for Oregon, Idaho and Montana. This timber harvest info should be useful for updating models of potentially available feedstock and measures of sustainability (e.g., growth-to-harvest ratios). These data are updated on an ongoing basis as new information is released by reporting agencies (e.g., USFS, BLM, ODF, WA-DNR, IDL, and MT-DNRC).

BBER has made a 5-state timber harvest by county and ownership database available for each year 2002 thru 2012. This has been provided to several NARA researchers, including Adams and Martinkus, and is available online: http://www.bber.umt.edu/FIR/H_Harvest.asp.

BBER researchers are now completing a refereed journal manuscript that will characterize logging residues throughout the entire 4-state NARA project area. This work will incorporate all logging utilization data collected through year 3 of the NARA project and will focus on residue prediction tools for land managers. 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 TPO data for Idaho (2011), Oregon (2008), Montana (2009), Washington (2010), with new (2013) Oregon data now posted to our BBER website. 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.

Mill residue and other production information:
Oregon- 2008 mill study available at: http://www.

Table SM-SP-7.1.Logging utilization field work progress through March 31, 2015

State	Sites	percent complete (based on 35 per state)	percent complete (based on 30 per state)
Idaho	20	57	67
Montana	22	63	73
Oregon	30	86	100
Washington	28	80	93
Total	100	71	83

bber.umt.edu/pubs/forest/fidacs/OR2008.pdf)

Montana- 2009 mill study available at: http://www.bber.umt.edu/pubs/forest/fidacs/MT2009.pdf)

Washington- 2010 mill study (provided by WA-DNR) available at: http://www.dnr.wa.gov/BusinessPermits/Topics/EconomicReports/Pages/obe_washington_state_millsurvey.aspx

Idaho- 2011 mill study available at: http://www.bber.umt.edu/pubs/forest/fidacs/ID2011.pdf)

Above four-state mill residue TPO data available on request from BBER and at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php

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 2,000 felled trees measured at 100 sites across the region (Table SM-SP-7.1).

Table SM-SP-7.1. Logging utilization field work progress through March 31, 2015

We can provide logging residue estimates for each NARA state at 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.

Logging residue information:
Idaho- 2008-2011 logging residue report available at: http://www.bber.umt.edu/pubs/forest/util/ID_logging_util_2014.pdf

Oregon (2008), Montana (2009), Washington (2010), and Idaho (2011) logging residue TPO data available on request from BBER and at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php

Research Outcomes
- Pacific Northwest land managers are gaining understanding of post-harvest logging residue volumes and distribution, and inventories of standing timber volumes throughout the 4-state project area. This enables them to more accurately forecast woody biomass feedstock availability, plan for coarse woody debris retention, and plan post timber harvest fuels treatments. In particular, BBER's TPO data is essential input to the Greg Latta/Darius Adams econometric model.
- Biomass feedstock managers are learning about the overall lack of readily available, affordable mill residues. This information has helped NARA scientists and others focus on logging residues as the primary source for biojet feedstock.
- The BBER and the US Forest Service Forest Vegetation Management staff (Ft. Collins Service Center) are jointly modifying the Forest Vegetation Simulator to more accurately predict post-harvest logging residue volumes and biomass. This work stems from the BBER's NARA-funded logging utilization research.

Recommendations | Conclusions

CONCLUSIONS

1. Mill Residues: BBER's recent TPO research (Simmons et al. 2015; McIver et al. 2012; Simmons et al. 2013) confirms preliminary observations: virtually all mill residues currently produced in the NARA 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 new home construction; and if the trend of pulp mill closures in the U.S. continues, opportunities for new or expanding uses of mill residue by the biomass sector may increase.

2. Logging Residues: BBER's recent summary of Idaho logging utilization research (Simmons et al. 2014) 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. land ownership- federal, state, private industrial, or nonindustrial private (Berg et al. 2012). Landing residue "slash" piles offer an important source of woody material for potential conversion to bio-jet and ancillary products.

3. Timber Harvest: Timber harvest volumes have generally declined over the past 20 years across all four NARA states (McIver et al. 2012; Simmons et al. 2014; Simmons et al. 2015; 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. However, substantial recovery of private lands harvest has been observed since 2010 in western Oregon and Washington as a result of increased log exports to Asia. 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 near 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. However, current legal, policy/budget, and silvicultural barriers suggest federal lands are an unreliable source of long-term biomass supply.

RECOMMENDATIONS

1. Data management: Organize NARA data so that it can be readily accessed and understood by both

NARA researchers and the public.

2. Cooperation: Focus on completing collaborative research in the last year of the NARA project. In particular, we need to wrap-up our cooperative OSU-BBER residue pile and logging utilization research. We also need to seek 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. We hope that the Adams-Latta models will make full use of our updated TPO and logging utilization work. Research products will enable land managers to accurately predict residue quantities and availability as a function of timber harvest volume and simple covariates, such as logging system employed.

3. Logging utilization studies: 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 five 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-5 logging utilization sampling efforts on Washington, Oregon, and Montana. Obtaining additional west-side samples will help ensure success of our cooperative OSU-BBER project.

BBER researchers continue to sample logging utilization, report on timber harvest, and maintain information on mill residue production and mill capacity across the 4-state NARA area. We offer several ways that our NARA colleagues can use the results of this work. Specifically:

- BBER will continue to update state-level summaries of mill and logging woody residue information. Several NARA researchers, e.g. Darius Adams and Greg Latta, Natalie Martinkus, Indroneil Ganguly, and the IDEX student groups, have used this data to estimate feedstock availability.

- Using the results of BBER's logging utilization research, U.S. Forest Service Forest Vegetation Simulator (FVS) staff and BBER investigators have developed improved FVS estimates of post-harvest residues. This work has far-reaching consequences, including improved FVS user forecasts of: woody feedstock availability, fuels loading, and fire behavior. We hope our NARA colleagues will make full use of this new capability.

- BBER researchers have developed a biomass prediction tool. This easy to use application can be web-based and will enable land managers to quickly assess the gross quantities of logging residue (i.e., slash) produced from commercial timber harvesting activities for use in biomass feedstock and wildfire fuel load analyses.

- We are developing models for the entire NARA project area that predict the ratio of logging residue volume to mill delivered volume as a function of readily available covariates, such as logging systems employed.

- NARA researchers can learn timber harvest volumes by county throughout the 4-state NARA area and California by accessing BBER's web-based cut by county tool: http://www.bber.umt.edu/FIR/H_Harvest.asp.

- State-level forest industry reports are available at: http://www.bber.umt.edu/FIR/H_States.asp. and http://www.dnr.wa.gov/BusinessPermits/SchoolFundingTrustBeneficiaries/Pages/Home.aspx

- Brief summaries of forest industry outlooks for Idaho and Montana: http://www.bber.umt.edu/FIR/H_Outlook.asp.

- Capacity studies can be accessed at: http://www.bber.umt.edu/FIR/H_Capacity.asp.

- Past logging utilization studies: http://www.bber.umt.edu/FIR/L_Util.asp.

- Forest economic data (log and hauling costs, employment, production, and wages, log prices): http://www.bber.umt.edu/FIR/ForEcon.asp.

THE FUTURE

In NARA Year 5, the BBER team will complete logging utilization field work, analyze and report logging utilization and other forest industry data, wrap-up ongoing collaborative research, 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-5 efforts will include:

- Measuring logging utilization at active logging sites in coastal Oregon and Washington;
- Processing, summarizing, and sharing 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.
- Developing predictive tools to enable land managers to gain understanding of post-timber harvest woody residue volumes and distribution.

Measurement efforts will be prioritized in western Oregon and western Washington. We anticipate being able to complete 5-6 more sites (each) in WA and OR. Neither state has had a comprehensive logging utilization study conducted in 20 years, and more up-to-date information is needed to ensure NARA modeling tools have sufficient data to accurately forecast outcomes.

We suggest that all NARA organizations, including the BBER, craft manager-friendly publications and internet-based tools in year 5. We need to ensure we leave land managers and bioenergy specialists a suite of practical, user-friendly outputs by the end of the NARA project. Dr. Vik Yadama's Outreach Team has already produced many useful science delivery products. But we cannot expect the Outreach team to solely shoulder the technology transfer burden.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Simmons, E., E. Berg, T. Morgan, C. Gale, S. Hayes. Biomass prediction tool. Manuscript in preparation.

RESEARCH PRESENTATIONS

Berg, E., E. Simmons, T. Morgan, S. Hayes, and S. Zarnoch. 2014. Improving Forest Vegetation Simulator (FVS) estimates of logging residues. Presentation to the Society of American Foresters 2014 national convention, October 6, 2014.

Berg, E., T. Morgan, E. Simmons, and S. Hayes. 2014. Logging Utilization: Decision Support Tools for Land Managers. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17.

Berg, E., T. Morgan, E. Simmons, S. Hayes, S. Zarnoch. 2014. Logging Residues: Tools for Land Managers. Poster presented at the Seattle Biomass Conference. Seattle, WA. April 28-30, 2014.

OTHER PUBLICATIONS

Simmons, E., Berg, E., Morgan, T., Zarnoch, S., Hayes, S. & Thompson, M. (2014). Logging utilization in Idaho: current and past trends. Gen. Tech. Rep. RMRS-GTR-318. Fort Collins, CO.: USDA Forest Service. Rocky Mountain Research Station. 15 p. http://www.bber.umt.edu/pubs/forest/util/ID_logging_util_2014.pdf

Simmons, E., Scudder, M., Berg, E., Morgan, T. & Hayes, S. (2015). Oregon's Forest Products Industry and Timber Harvest, 2013. Draft tables at: http://www.bber.umt.edu/pubs/forest/fidacs/OR2013.pdf

TASK SM-SP-8: EFFECTS OF VARYING FOREST FLOOR AND SLASH RETENTION ON SOIL NUTRIENT AND CARBON POOLS IN A REGENERATING DOUGLAS-FIR TREE FARM: NARA-SOILS

Key Personnel	Affiliation
Jeff Hatten	Oregon State University

Task Description

This scope of work describes the work that Dr. Jeff Hatten (OSU) will do in collaboration with Dr. Scott Holub (Weyerhaeuser). The overall goal is to examine the effects of organic matter (forest floor and slash) removal and soil compaction on soil carbon and nutrient cycles and site productivity. The responsibilities of the OSU Forest Soils Lab (Hatten) include 1) monitor and report on soil moisture and temperature data, 2) analyze whole soils and density fractions pre-, post-, 1 yr post- and 2 yr post for elemental contents stable isotopic ratios, 3) examine whole soils pre-, post-, 1 yr post- and 2 yr post for exchangeable nutrient pools, 4) examine inputs of carbon and nutrients into mineral soils using pan lysimeters, 5) foliar response to soil changes, and 6) examine soil carbon cycling through soil respiration. Hatten will be ultimately responsible for all work completed under this scope of work and he will oversee one MSc level student that will be conducting most of the work on the project with the assistance of undergraduate workers.

1) Soil moisture and temperature.

We will monitor 32 soil locations in all treatment plots (7 treatments (A, B, C, D, E, F, and G)* 4 replicates) and additional stations installed in the uncut forest (4 replicates). These soil monitoring stations will include Decagon data loggers with 1 relative humidity/air temp @ 15cm sensor and soil moisture/temperature probes installed at 10, 20, 30, and 100cm soil depth. This data will be compiled and treatments differences written up into reports, theses, and submitted for publication. The compiled data will be made available to all collaborators on the project prior to publication of the data.

2) C, N, 13C, and 15N of whole soils and density fractions.

Will examine composited soils from the <2.0mm size fraction collected pre-, post-, 1 yr post- and 2 yr post-harvest from 5 treatments (A, B, C, D, and E) + the uncut forest. (6 treatments * 4 replicates = 24 plots). Pre- and post-harvest soils have been collected to 100cm and will be analyzed to that depth. We will collect soils from 25 locations in plot from the 0-15cm horizon and forest floor for the 1 yr post- and 2 yr post-harvest assessment. We analyze the carbon (C) and nitrogen (N) content and stable isotopic composition of whole soils, three density fractions, and roots (from pre-harvest sample collection only).

3) Exchangeable nutrient pools.

We will examine the available nutrient pools of the surface soil and O-horizons for pre-, post-, 1 yr post- and 2 yr post-harvest assessments in 5 treatments (A, B, C, D, and E) and the uncut forest. We will examine exchangeable nitrate and ammonium using KCl extractions and Bray extractable P. These extracts will be analyzed by our team in the IWW collaboratory. Exchangeable cations will be extracted using ammonium acetate and analyzed using an ICP in the central analytical lab.

4) Pan lysimeters.

We will develop, construct, and install two pan lysimeters into each replicated of 5 treatments (A, B, C, D, and E) and the uncut forest. We will also collect atmospheric deposition and throughfall deposition from this apparatus and a limited number of locations. Soil solutions from these lysimeters will be collected and analyzed once per month (when present). We will examine these solutions for nitrate, ammonium, total N (DON by difference), TOC, ortho-phosphate in the IWW collaboratory. Cations will be analyzed using an ICP in the central analytical lab.

5) Foliar response.

During year 2 will assess tree heights and foliar concentrations of nutrients in 5 treatments (A, B, C, D, and E). These assessments will be made on trees in 0.1ha plots near the pan and tension lysimeters (UW). Will collect and composite 1 year old foliage from 5 trees. Foliage will be analyzed for Total C, N, P, Ca, Mg, K, and Al. We will also send foliage to be analyzed for 13C and 15N.

6) Soil respiration.

We will take soil respiration measurements once per month in 5 treatments (A, B, C, D, and E) and the uncut forest from 4 locations per plot. These measurements will be made for at least 2 growing seasons. Soil respiration measurements will be made with a LiCor 8100 and 10cm soil respiration chamber. At each location will install two kinds of soil collars: 6cm inserted 1 cm into mineral soil with no O horizon and 35 cm inserted 30cm into mineral soil to exclude roots. From each location will collect three kinds of soil respiration: 1) total soil respiration + O horizon respiration – soil respiration chamber set directly on soil surface, 2) total soil respiration – soil respiration chamber set on 6cm soil collar, and 3) heterotrophic soil respiration + O horizon respiration – soil respiration chamber set on 35cm soil collar.

Activities and Results

We approached the study of soils and long-term site productivity with a set of questions that had not been directly approached in the scientific literature: Do higher soil temperature and moisture after harvesting and organic matter removal result in higher heterotrophic activity? Does this higher activity result in higher than expected nutrient (i.e. N) availability that subsidizes early tree nutrition? To this end we have installed soil moisture and temperature probes, pan lysimeters, and soil respiration collars. These data have been collected since about December 2012 and continue to be collected. We have also performed density fractions that will be analyzed for 13C and 15N to examine relative rates of soil C and N cycling. Preliminary results support our hypothesis that these OM removal experiments result in warmer soil temperatures (Figure SM-SP-8.1). Interestingly, we have found that the effects of organic matter removal have propagated to 100cm depth, a phenomena that has not been reported in the literature. However, the effect of soil temperature has not caused a subsequent increase in periodic measures of heterogenic activity (i.e. soil respiration), but we still need to examine trends in an accumulated signal of heterotrophic activity (e.g. 13C and 15N of soils). We will continue this research by performing density fractionations on soils collected during the early part of this summer (2015). These density fractions will be examined for stable isotopes which will elucidate whether or not C and N are being cycled differently in the soil. Additionally, we have acquired funding to examine the hypothesis that roots from the previous stand subsidize regrowing stand and soil carbon. We will examine the whole soils and density fractions for biomarkers of lignin, cutin, and suberin in order to determine if these roots are contributing a significant amount of carbon to soil carbon pools in the first 2-years after harvest.

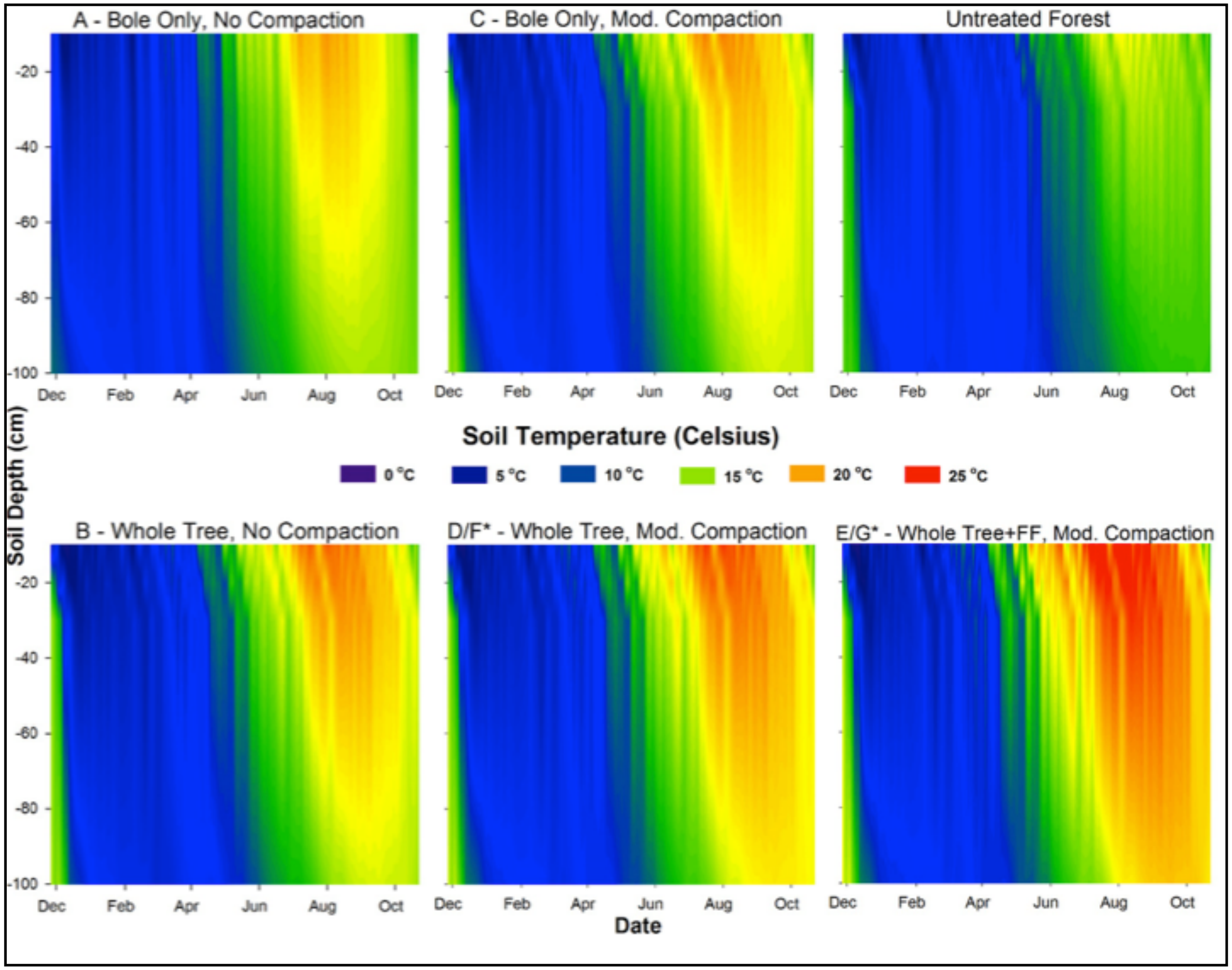


Figure SM-SP-8.1. Soil temperature heat maps across the first year after treatment (months 6-17).

Recommendations | Conclusions

We have found a significant change in soil temperature in the whole soil profile, including deeper portions of the soil. We are currently focusing on trying to determine if this change in soil temperature has resulted in any effect on heterotrophic activity. We will be examining periodic measurements of soil respiration. We will also examine the stable isotopic signature of soils to determine if N is cycling at a faster rate, which would suggest that these high soil temperatures drive higher mineralization rates that may prop up tree productivity.

Physical and Intellectual Outputs

RESEARCH PRESENTATIONS

Gallo, A., J.A. Hatten. 2014. Long-term soil productivity on managed forests: Mechanisms of apparent resilience after intensive biomass removal. Northwest Forest Soils Council. Ellensburg, Washington. February 21, 2014. (Poster)

Gallo, A., J.A. Hatten. 2014. Long-term soil productivity on managed forests: Mechanisms of apparent resilience after intensive biomass removal. Oregon Society of Soil Scientists. Bend, Oregon. February 27, 2014. (Poster)

Gallo, A., J.A. Hatten. 2014. Long-term soil productivity on managed forests: Mechanisms of apparent resilience after intensive biomass removal. Western Forestry Graduate Research Symposium. Corvallis, Oregon. April 21-22. (Poster)

Holub, S., R. Harrison, and J. Hatten. 2014. How do removals affect long-term productivity?: Long-term Soil Productivity (LTSP) studies. Seatac, Washington. September 16-18. (Oral)

Holub, S. N. Meehan, R. Meade, G. Johnson, R. Harrison, M. Menegale, J. Hatten, and A. Gallo. 2014. NARA Long-term Soil Productivity (LTSP) Project – 2014 Update. Northwest Advanced Renewables Annual Meeting. Seatac, Washington. September 16-18. (Poster)

Gallo, A., J.A. Hatten. 2014. Long-term soil productivity on managed forests: Mechanisms of apparent resilience after intensive biomass removal. Northwest Advanced Renewables Annual Meeting. Seatac, Washington. September 16-18. (Poster)

Gallo, A., J.A. Hatten. 2014. Immediate response mechanisms to account for sustained tree growth following intensive biomass removal on Long-Term Soil Productivity (LTSP) sites. Soil Science Society of America Annual Meeting. Long Beach, California. November 3-6. (Poster)

Gallo, A., J.A. Hatten. 2015. Immediate response mechanisms to account for sustained tree growth following intensive biomass removal on LTSP sites. Oregon Society of Soil Scientists. Hood River, Oregon. February 26, 2015. (Poster)

Gallo, A., J.A. Hatten. 2015. Immediate response mechanisms to account for sustained tree growth following intensive biomass removal on LTSP sites. Northwest Forest Soils Council. Hood River, Oregon. March 14, 2015. (Oral)

Gallo, A., J.A. Hatten. 2015. Biophysical responses in soil following intensive biomass removals. Western Forestry Graduate Research Symposium. Corvallis, Oregon. April 28, 2015. (Oral)

SYSTEMS METRICS

TECHNO-ECONOMICS TEAM

TASK SM-TEA-1: TECHNO-ECONOMICS ANALYSIS

Key Personnel	Affiliation
Gevan Marrs	Weyerhauser
Tom Spink	TSI

Task Description

Gevan Marrs and TSI will collaborate to construct a complete techno-economic (TEA) 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 capital expenditure (Capex) vs. scale, optimization against feedstock costs at scale, selection of base case facility scale.
- Other financial incentives (renewable identification numbers (RINS) for renewable fuel standard 2 (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.

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.

In year four the TEA team will refine and update the TEA for the one selected pretreatment process. The updated TEA will include details specific to a site identified in the NARA IDX process, and have refined process specifications from the one selected pretreatment process. It will incorporate improvements identified through on-going work in other teams, including feedstock logistics and pre-treatment, fermentation and alcohol-to-jet conversion steps, and lignin co-products development and market assessment. Additionally, the product take-away details will be incorporated such that the site-specific bio-jet arrives at specific PNW airport(s), and marketing details of other lignin residue co-products are improved.

An additional task assigned to the TEA team is to partner with Cosmo Specialty Fibers (CSF) in the development of scenarios that convert existing sulfite pulp mills into bio refineries. The result of this work for NARA is an educational opportunity for personnel in CSF and the publication of a generic paper by NARA personnel describing the retrofit possibilities to bio refineries for sulfite pulp mills.

These tasks are summarized and incorporated into the previous tasks as follows:

Task SM-TEA-1.7. Solicit process improvements in key areas and update economics on Mild Bisulfite (MBS) process

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

Task SM-TEA-1.11. Evaluate retrofits of existing sulfite mills to the NARA MBS process

Activities and Results

Figure SM-TEA-1.1 describes the selected NARA Mild Bisulfite (MSB) process as defined by joint work between the ASPEN team and the TEA team. There are eight distinct departments; Feedstock Preparation, Pretreatment, Enzymatic Hydrolysis, Gevo (fermentation to jet), Distribution, Boiler, Co-Products, and Utilities. Six departments are within ASPEN design (Gevo is ASPEN) and two (Utilities and Distribution) are not within ASPEN design.

A rough draft of an integrated bio refinery report (IBRR) is being completed that has the following chapters; Index, Executive Summary, Model Method, Integrated Model, Feedstock Preparation, Pretreatment, Enzymatic Hydrolysis, Gevo, Distribution, Co-Products, Boilers, Utilities, Environmental, Financial, and Appendix. Each chapter includes a process description and ASPEN diagram, Input/output data, Capex, Opex, and Environmental notes. A rough draft IBRR is posted to NARA Google Drive and is intended to be interactive to suggestions, corrections, and general educational purposes. The IBRR is intended as a foundation document for the TEA where ASPEN, and other economic details, are archived.

Figure SM-TEA-1.2 depicts a first draft economic sensitivity analysis of the NARA biorefinery. The four largest drivers in the sensitivity analysis are: Market value of bio-jet, Activated Carbon Market Price, Capex change from base case, and the impact of RINS.

One identified improvement opportunity remains to be quantified – repurposing of an existing asset. The benefit of this is of course dependent upon assumptions about avoided Capex due to re-using assets. Preliminary work has shown it to be very difficult to precisely determine the value, which can be placed on an existing asset, as both buyer and seller want to maximize return. It seems very likely that we will be forced to accept a convention of evenly splitting the difference between zero value and maximum potential value for any assets identified as useful in repurpose. This will dramatically reduce repurpose value compared to common assumptions in the literature, where assets are obtained at no cost.

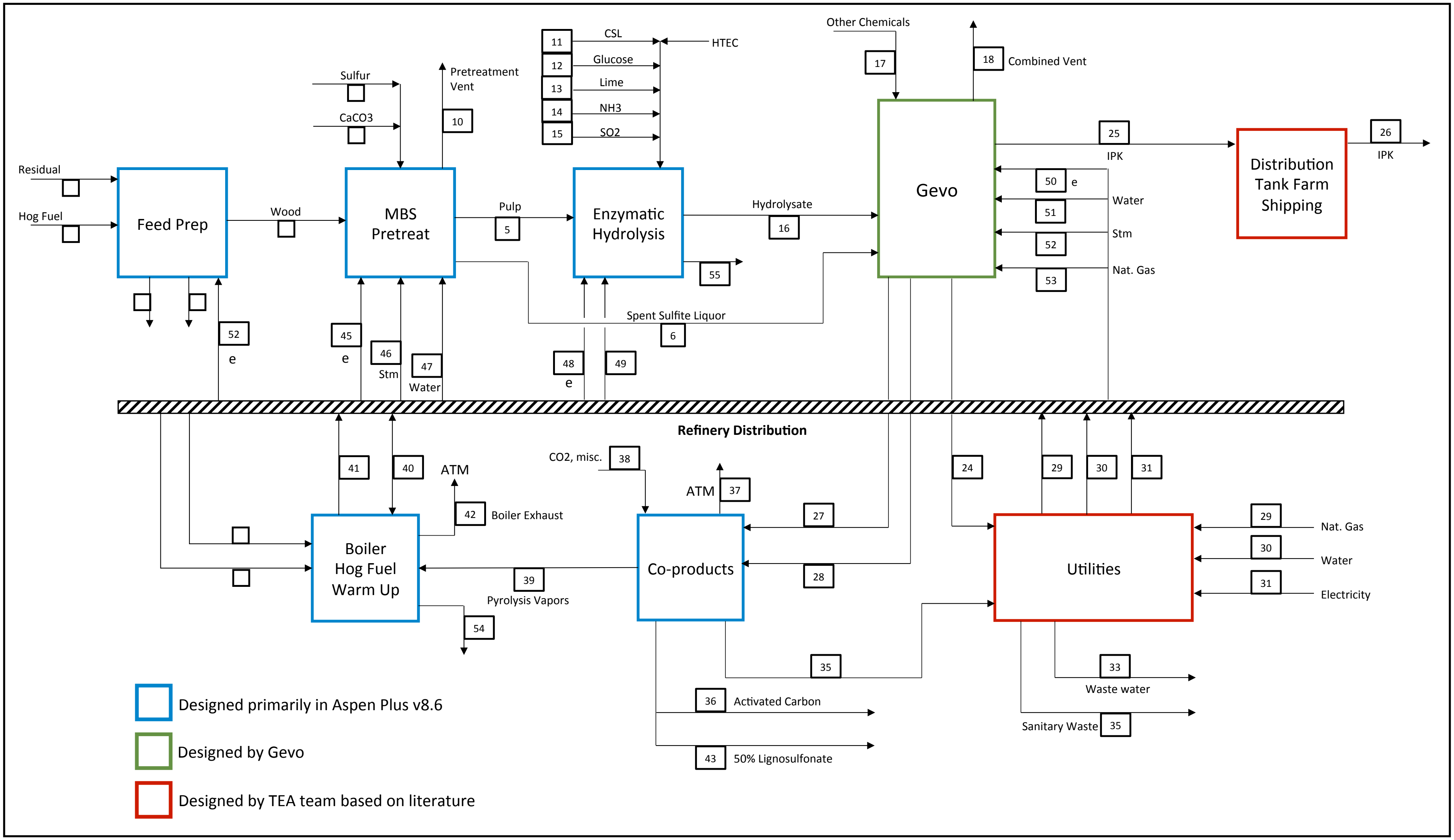


Figure SM-TEA-1.1. Integrated NARA Mild Bisulfite (MBS) Biorefinery Process

Figure SM-TEA-1.3 depicts the first draft for mass and economic value of revenue streams. From this portrayal, it can be seen how significant a large yield drop in activated carbon, and / or loss of RINs, will be to overall project economic return.

Updates to process during this fourth year, and not yet incorporated into Figure SM-TEA-1.3, are;

1) optimization by Gevo to eliminate the production of octane and produce the equivalent amount of iso-paraffinic kerosene (IPK). This increases the overall yield of IPK on wood to 52.4 gallons of IPK

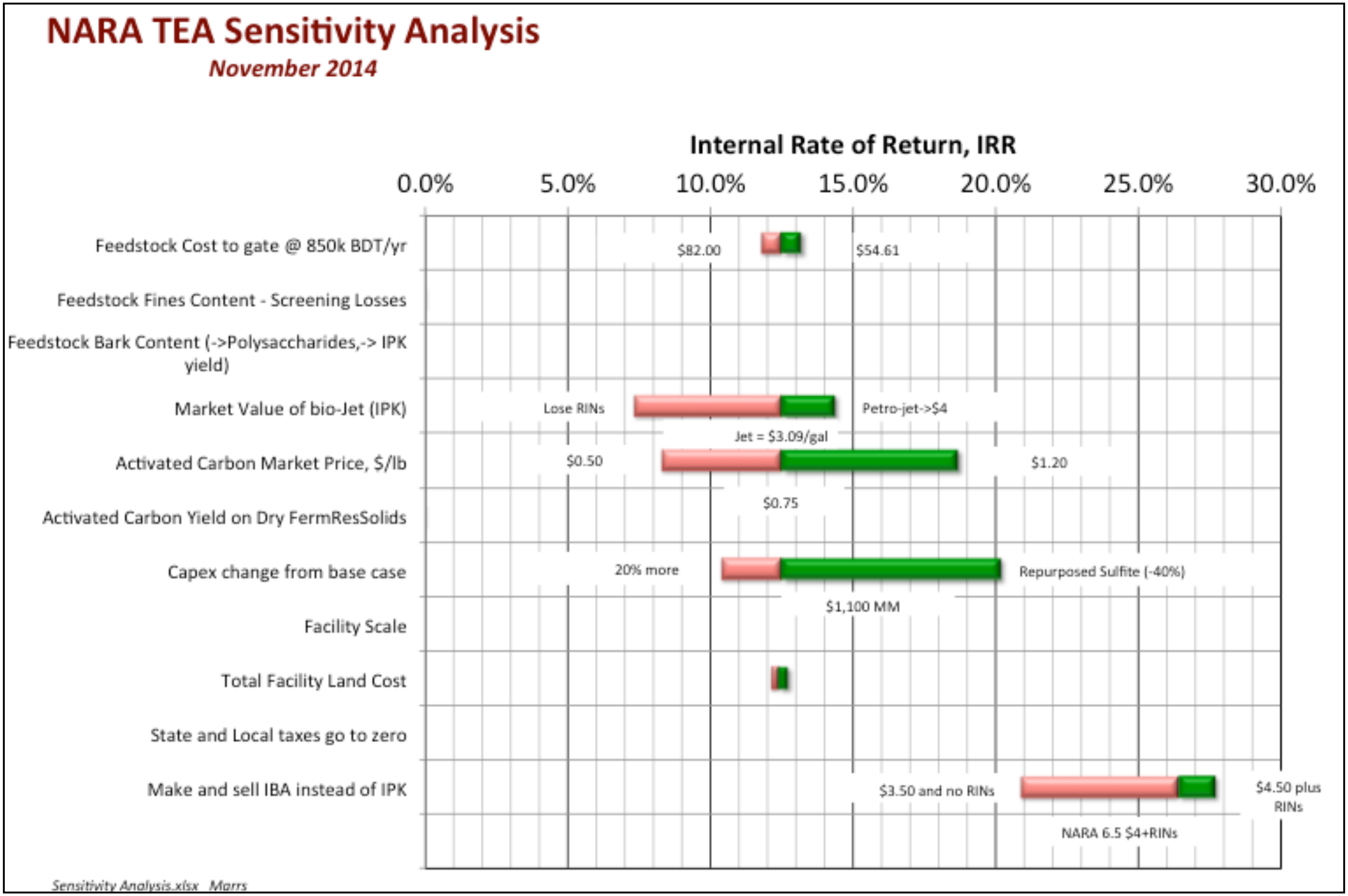
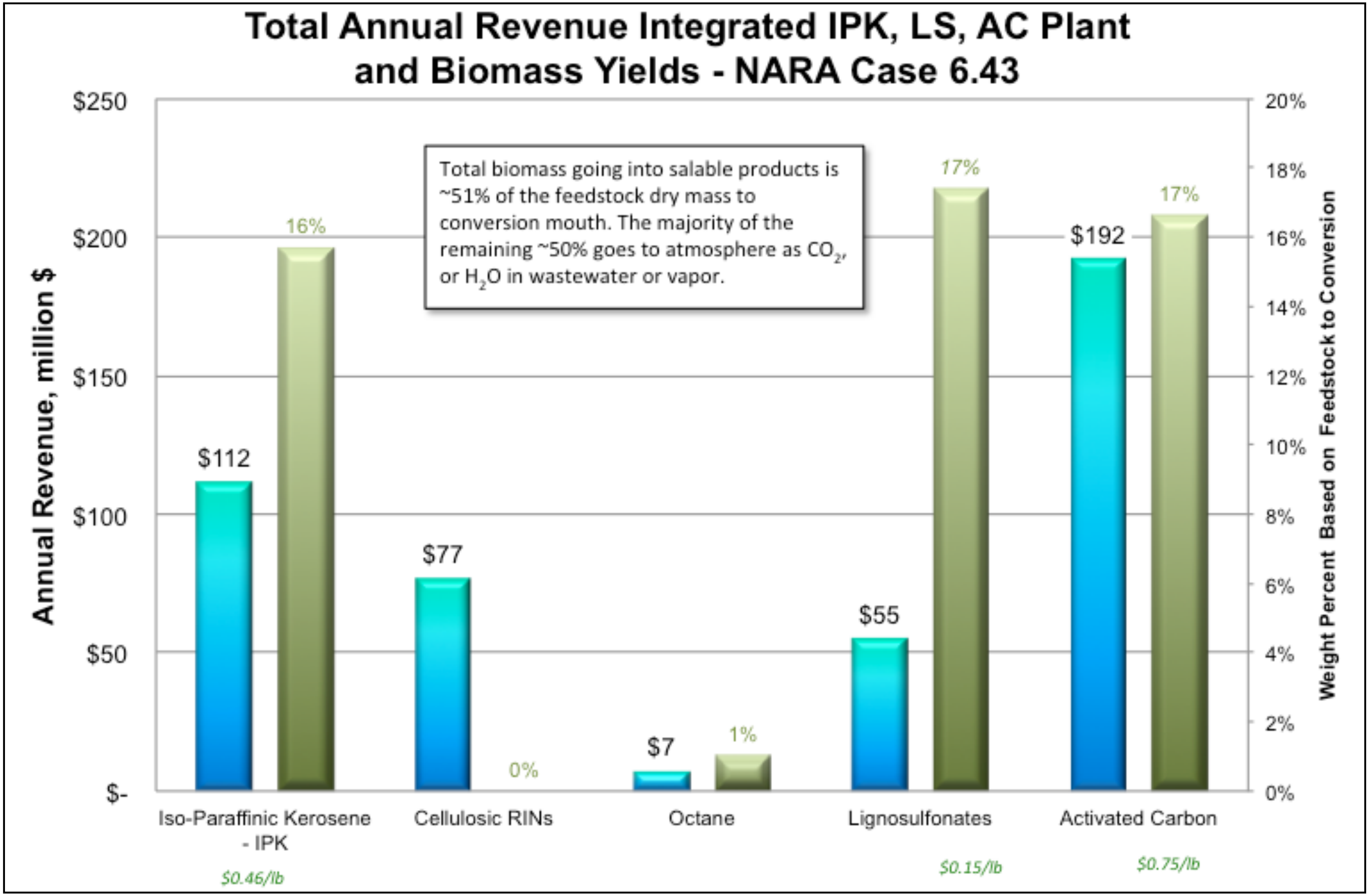


Figure SM-TEA-1.2. Sensitivity Analysis results for some key uncertainty factors showing impact on overall project Internal Rate of Return (IRR).

per bone-dried ton (bdt) feedstock. However, since the added IPK revenue is offset by octane not being sold, the net economic impact is quite small: and 2) further research on activated carbon (AC) has determined that the likely yield is 22.5%, rather then the initially assumed 40%. Because of the significance of AC revenue in the base case shown in Figure SM-TEA-1.3, such a yield reduction reduces annual revenue by about $84 MM, dropping the project initial rate of return (IRR) to about 6.6%. This is obviously a very significant reduction in project attractiveness.



Total biomass going into salable products is ~51% of the feedstock dry mass to conversion mouth. The majority of the remaining ~50% goes to atmosphere as CO_2, or H_2O in wastewater or vapor.

Figure SM-TEA-1.3. Revenue and product yield on feedstock for the major products in TEA Case 6.43.

Recommendations | Conclusions

1. Using the latest "base case" TEA, the expected return on investment is about 12%. For such a large capital investment (>$1 billion), and for a risky facility (having never been built before), this level of return is unlikely to induce investors to commit funds. An IRR somewhere greater than 20 to 25% is realistically required attract interest. Thus, very substantial cost reductions, and / or revenue increases to increase the IRR by such a large amount are required. At this time, no such substantial improvements are being considered by the TEA staff.

2. When the TEA is updated to reflect the now-likely activated carbon yield of 22.5% instead of 40%, the IRR will be substantially lower (about 6.5%). Clearly this makes it even a much greater improvement needed to get to 20-25% IRR.

3. The ASPEN model and Integrated Biorefinery Report (IBRR) is nearing completion of the rough draft. This draft has proven to be much more complex than expected. The draft is to be posted to NARA Google drive in the view only mode to encourage comments, corrections and possible modifications. There is guidance required on future use of the model as to intellectual property (IP) issues, access, and who operates the model. It is recommended that senior leadership be presented issues and options.

SYSTEMS METRICS

ASPEN MODELING TEAM

TASK SM-AM-1: ASPEN MODELING OF THE NARA CONVERSION PROCESS

Key Personnel	Affiliation
Shulin Chin	Washington State University

Task Description

The WSU-BSYSE team will work in collaboration with Weyerhaeuser and TSI to evaluate and improve upon currently developed techno-economic analysis (TEA) models for the softwood-to-bio-jet production project. Existing knowledge and models will be incorporated for this task and the improved models built by the team will be used to evaluate the tradeoffs in capital expenditures versus operating cost based on the choice of different design and operational parameters. Analysis of logistics will also include economic benefits using a system of distributed sugar depot, which could reduce transportation costs. A sensitivity analysis of differing fuel prices at varied plant capacities will be used to allow determination of delivered feedstock and output products in relation to plant capacities. The main scope of work includes:

- Development of an integrated ASPEN model with key modules with consideration of various alternatives for conversion and pre-processing as identified by the project team
- Conduct TEA of the system for the major operations specified
- Conduct sensitivity analysis to identify high return improvements for the unit operations to guide the R&D and process integration efforts
- Optimize the system based on the improvements made on the processes during the project and various major constraints that the operation may have, and
- Interact with the LCA team to provide needed inputs to their work.

Discounted cash flow rate of return analyses will be conducted to incorporate capital and operating costs into a single framework along with business decisions and cash flow assumptions. The result is an estimated minimum fuel selling price, Internal Rate of Return, or net present value, depending on the desired metric. The key outputs will be:

1. Evaluation of alternative pretreatment technologies: the developed model will help to compare the performance of different pretreatment technologies under investigation in terms of efficiency and overall cost reduction.
2. Co-product valuation: Assess value of co-products such as lignin, and other small molecules and its effect on profitability of plant.
3. Use of distributed sugar depots vs. a traditional biomass processing, evaluating an alternative plant design that could reduce the final cost of the biojet fuel.

All the analyses performed in this task will be performed in consultation with other teams in the overall project and iterative refinement will be performed to help guide future developments.

Activities and Results

The ASPEN team in the past three months has been working on completing a draft of the Integrated Biorefinery Report (IBRR). This document is intended to demonstrate the mass and energy flows in the NARA biorefinery as well as the capital and operating costs of each department. The biorefinery overview is seen below in Figure SM-AM-1.1. It is anticipated that this document can be shared with various members of NARA to assist in their work.

In addition, work has continued on the integrated ASPEN model, which is nearly complete. The integrated ASPEN model will contain a majority of the technical information gathered throughout the project, and is intended for use in optimization of the project.

Currently, work is being focused on updating and checking the capital costs of each of the departments and checking the values against known industry sources or publications. In particular, the utilities and enzymatic hydrolysis departments require more work.

Recommendations | Conclusions

The departmental models as is are nearing completion, and we have accurate information for the majority of departments. The co-products economics remains a great uncertainty. It appears that the volume of coproducts that we are producing would significantly saturate the current market (both for lignosulfonate and for activated carbon). As a result, these findings should be taken into consideration for the overall techno economic analysis (TEA) of the refinery.

Physical and Intellectual Outputs

RESEARCH PRESENTATIONS

Gao, Allan, Tom Spink and Shulin Chen. 2014. Aspen Plus Process Modeling of NARA Biorefinery Departments. 2014 NARA Annual Meeting, Seattle, WA, September 15-17 (poster).

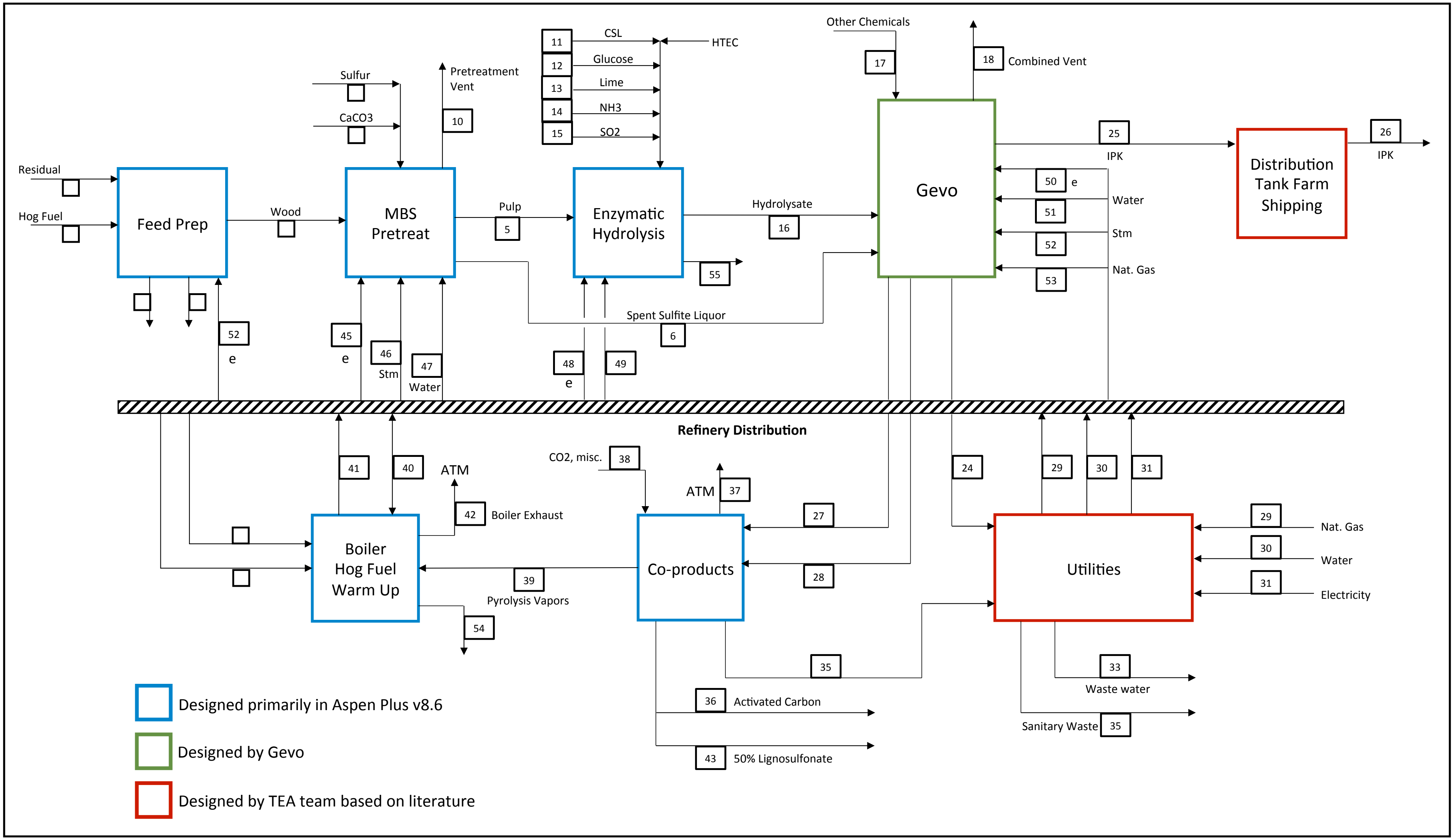
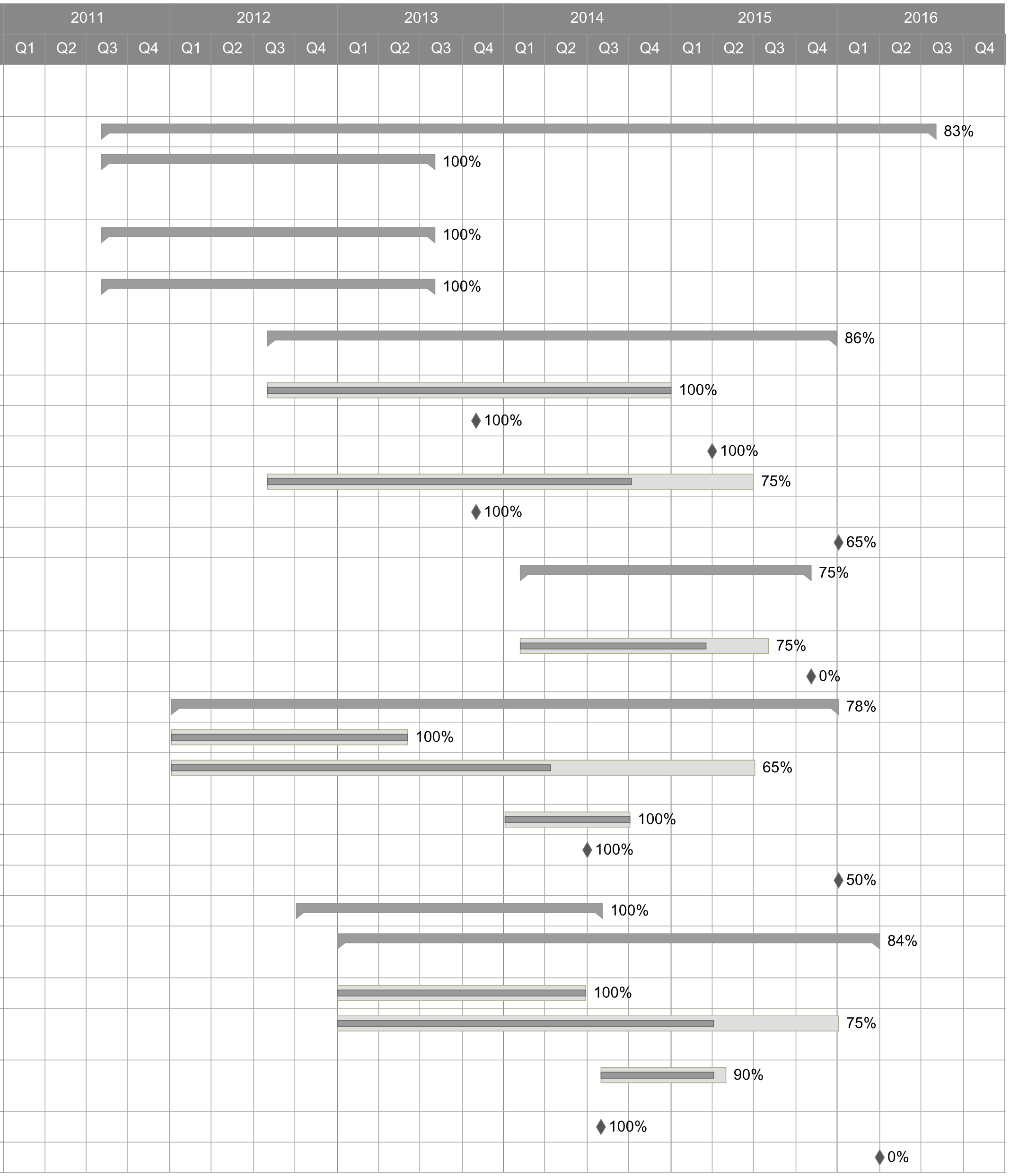


Figure SM-AM-1.1. Refinery overview with process streams

SystemsMetrics_EPP

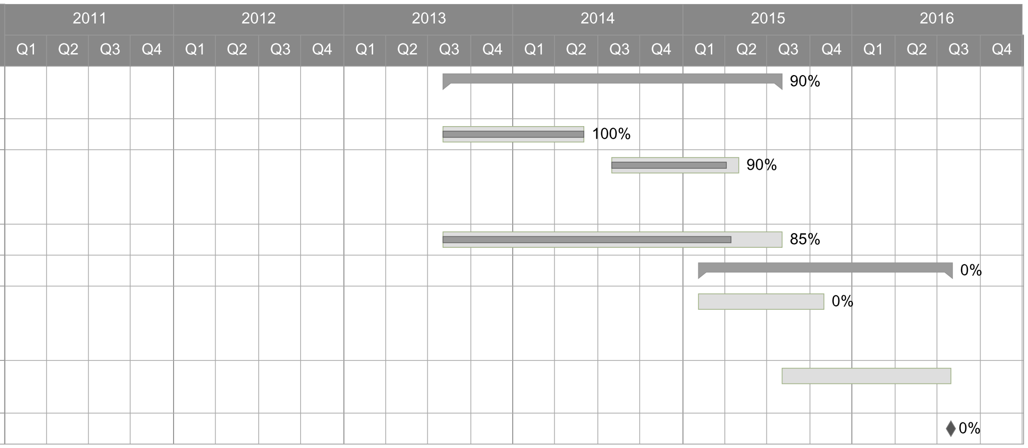
	Task Name	
1	SYSTEMS METRICS - ENVIRONMENTALLY PREFERRED PRODUCTS TEAM	
2	⊟ SM-EPP-1. Environmentally Preferred Products	83%
3	⊞ Task SM-EPP-1.1. “Public” stakeholders (SHs): demographic, psychographic, and market-specific assets through dataset analysis (Leigh Stowell, Rupasingha, and Roper-Putnam)	100%
8	⊞ Task SM-EPP-1.2. Review Sustainability Approaches: ecolabels, stds., product claims, LCA/EIO data sources & models	100%
13	⊞ Task SM-EPP-1.3. Review Regional Bioenergy Stakeholder Perceptions: issues, influencial groups, etc.; NARA site personal/focus group interviews and analysis	100%
26	⊟ Task SM-EPP-1.4. “Informed” stakeholder interaction/operationalization (pop’s., sampling, constructs, protocols)	86%
27	Western Montana Corridor (WMC)	100%
28	Preliminary Report	◆ 100%
29	Final Report	◆ 100%
30	West Side (WS)	75%
31	Preliminary Report	◆ 100%
32	Final Report	◆ 65%
33	⊟ Task SM-EPP-1.5. Refine Operationalization – pop’s., sampling, constructs, protocols – select additional NARA community sites and provide Social Hotspot Analysis	75%
34	Nara community SH interviews	75%
35	Report	◆ 0%
36	⊟ Task SM-EPP-1.6. Techno-Market Assessment: Jet Fuels	78%
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	100%
40	Jet fuel products - data collection preliminary report	◆ 100%
41	Jet fuel products - data analysis report	◆ 50%
42	⊞ Task SM-EPP-1.7. Economic, Environmental & Social Assessment: Jet Fuels	100%
46	⊟ Task SM-EPP-1.8. Techno-Market Assessment: BioProduct Polymers (1-2 product categories)	84%
47	Examine & define market opportunities for select co-products	100%
48	Collect co-products data from U.S. biorefineries via secondary and primary data collection	75%
49	Identify key channel, buyers & specifiers for select bio-based polymer co-products in PNW	90%
50	Bio-based polymer co-products - data collection preliminary report	◆ 100%
51	Bio-based polymer co-products - data analysis report	◆ 0%



Exported on April 23, 2015 9:59:51 AM PDT

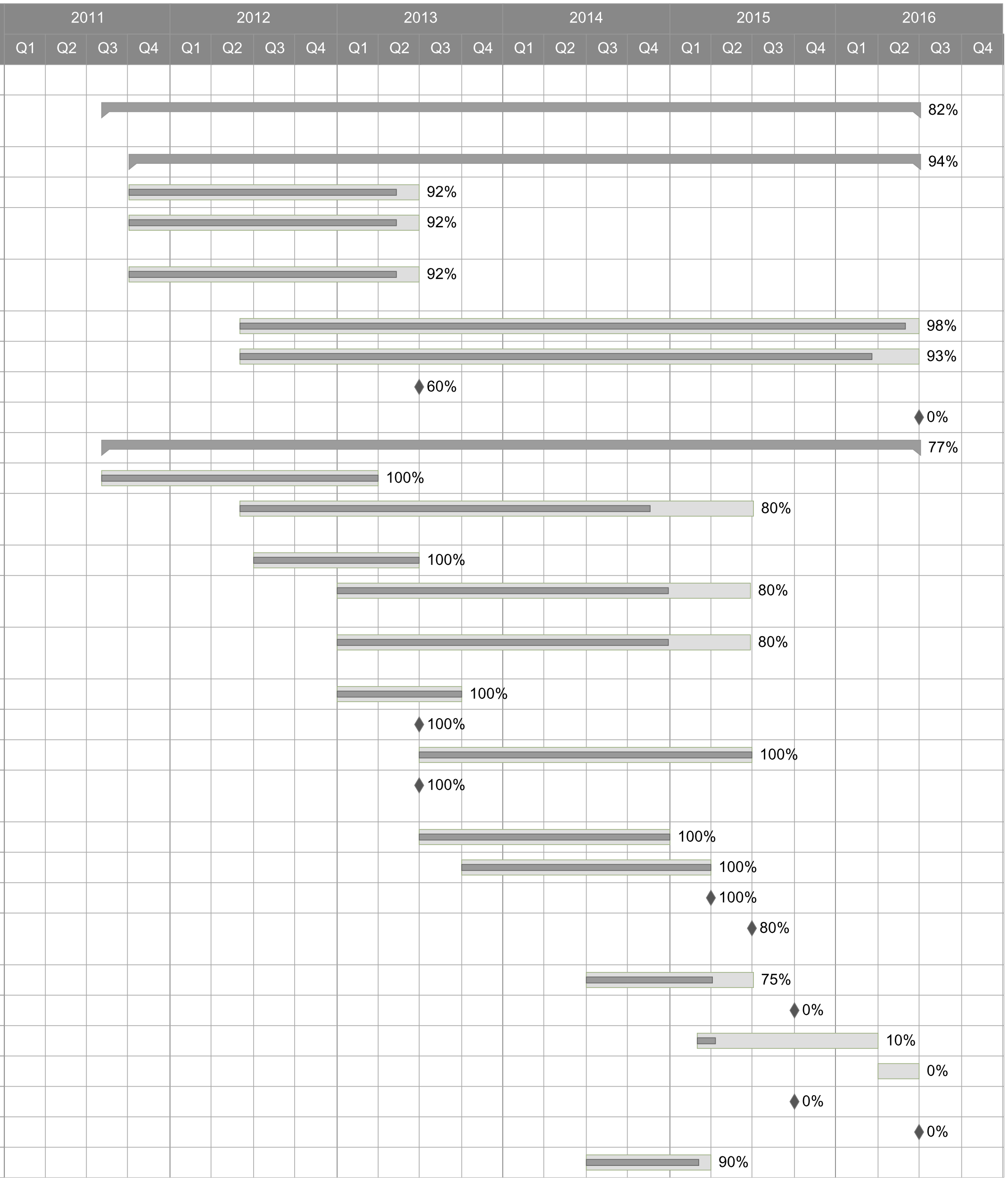
Page 1 of 2

	Task Name
52	⊟ Task SM-EPP-1.9. Economic, Environmental & Social Assessment: BioProduct Polymers
53	Collaborate w/ LCA & SH NARA teams to develop env & social hotspot analyses
54	Define select "ideal" bio-based polymer co-products & substitutes in terms of properties, prices, & other attributes; Evaluate env/social criteria; Dev value props
55	Incorporation of co-product modules into parameterized biojet model
56	⊟ Task SM-EPP-1.10. Prototype Integrated EPP Protocol
57	Develop a prototype integrated protocol for expanding methodologies developed in Tasks 6 & 8 across product categories by designing a process consistent with EPP best practices
58	Develop an EPP marketing and procurement decision support tool to integrate economic, environmental and social impacts of NARA biojet and co-products
59	Final EPP Report



SystemsMetrics_LCA

	Task Name	
1	SYSTEMS METRICS - LCA & COMMUNITY IMPACT TEAM	
2	SM-LCA-1. LCA Assessment of Using Forest Biomass as a Feedstock for Biofuels	82%
3	Task SM-LCA-1.1. Soil Carbon Analysis	94%
4	Review literature on carbon impacts of forest thinning and residual collection	92%
5	Review literature of carbon implications of alternate systems for harvest, collection and transport of forest thinnings and residuals	92%
6	Review literature of impacts of collecting forest thinnings and residuals on soil carbon and stand productivity including the soil impact of avoided wildfires	92%
7	Review impact of forest residual removal on soil carbon and stand productivity	98%
8	Collect soil carbon data	93%
9	Preliminary report	60%
10	Final report	0%
11	Task SM-LCA-1.2. LCA Analysis	77%
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)	80%
14	Develop framework LCA analysis for forest residuals (Inland Empire)	100%
15	Conduct framework LCA analysis for pretreatment (in conjunction with Gevo and Catchlight)	80%
16	Integrate framework forest residual and pretreatment LCA with biofuel LCA (with Gevo)	80%
17	Collect LCA data for Inland Empire	100%
18	Preliminary LCA report for feedstock (Inland Empire)	100%
19	Integrate LCA data into framework LCA (Inland Empire)	100%
20	Preliminary LCA framework with report for complete process (Inland Empire) (in conjunction with Gevo and Catchlight)	100%
21	Develop framework LCA analysis for forest residuals (NARA Community #2)	100%
22	Collect LCA data for NARA Community #2	100%
23	Preliminary LCA report for feedstock (NARA Community #2)	100%
24	Preliminary LCA framework with report for complete process (NARA community #2) in conjunction with Gevo and Catchlight	80%
25	Integrate LCA data into framework LCA (NARA Community #2)	75%
26	Complete LCA analyses for both locations	0%
27	Conduct peer review of LCA data and revise	10%
28	Upload LCI data to national databases	0%
29	Preliminary LCA report	0%
30	Final LCA Report	0%
31	Identify potential alternative pathways for biomass to alcohol/biofuel	90%



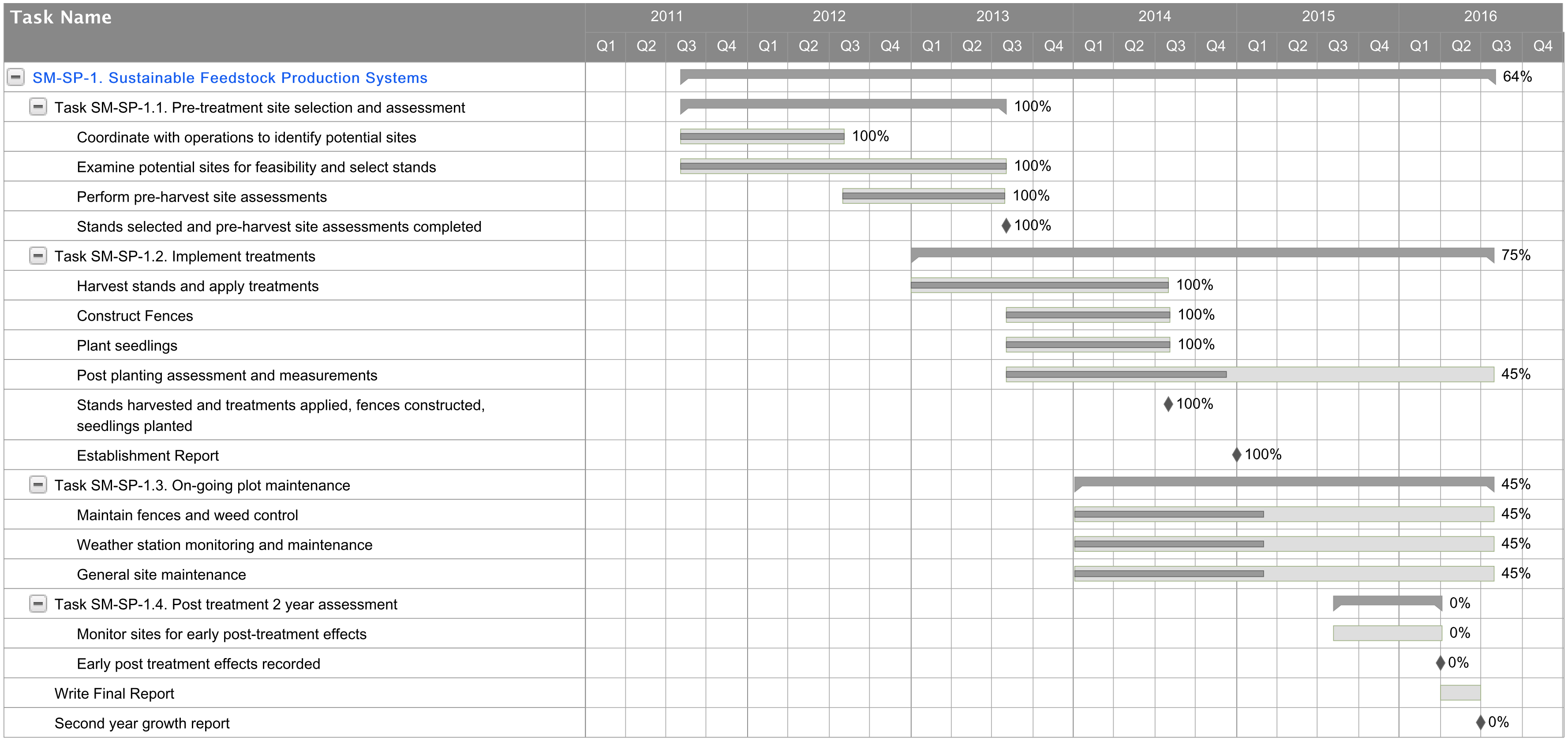
Exported on April 13, 2015 11:54:06 AM PDT

Page 1 of 2

Exported on April 13, 2015 11:54:07 AM PDT

SustainableProduction_Holub

NARA

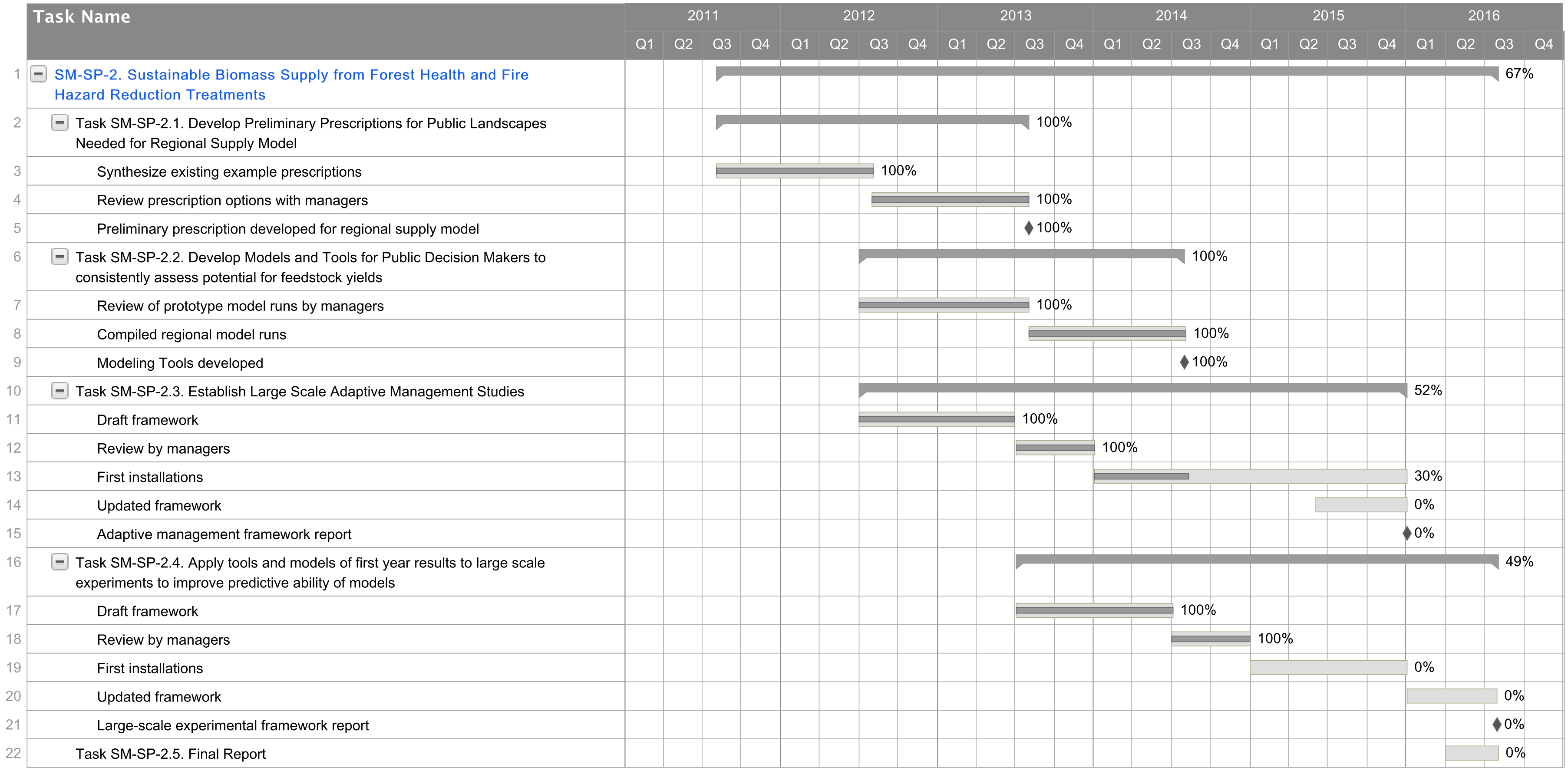


	Task Name
1	SM-SP-1. Sustainable Feedstock Production Systems
2	Task SM-SP-1.1. Pre-treatment site selection and assessment
3	Coordinate with operations to identify potential sites
4	Examine potential sites for feasibility and select stands
5	Perform pre-harvest site assessments
6	Stands selected and pre-harvest site assessments completed
7	Task SM-SP-1.2. Implement treatments
8	Harvest stands and apply treatments
9	Construct Fences
10	Plant seedlings
11	Post planting assessment and measurements
12	Stands harvested and treatments applied, fences constructed, seedlings planted
13	Establishment Report
14	Task SM-SP-1.3. On-going plot maintenance
15	Maintain fences and weed control
16	Weather station monitoring and maintenance
17	General site maintenance
18	Task SM-SP-1.4. Post treatment 2 year assessment
19	Monitor sites for early post-treatment effects
20	Early post treatment effects recorded
21	Write Final Report
22	Second year growth report

Exported on April 22, 2015 3:08:51 PM PDT

Page 1 of 1

SustainableProduction_Bailey



	Task Name	
1	SM-SP-2. Sustainable Biomass Supply from Forest Health and Fire Hazard Reduction Treatments	67%
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 model	100%
6	Task SM-SP-2.2. Develop Models and Tools for Public Decision Makers to consistently assess potential for feedstock yields	100%
7	Review of prototype model runs by managers	100%
8	Compiled regional model runs	100%
9	Modeling Tools developed	100%
10	Task SM-SP-2.3. Establish Large Scale Adaptive Management Studies	52%
11	Draft framework	100%
12	Review by managers	100%
13	First installations	30%
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	49%
17	Draft framework	100%
18	Review by managers	100%
19	First installations	0%
20	Updated framework	0%
21	Large-scale experimental framework report	0%
22	Task SM-SP-2.5. Final Report	0%

Exported on April 22, 2015 2:23:24 PM PDT

Page 1 of 1

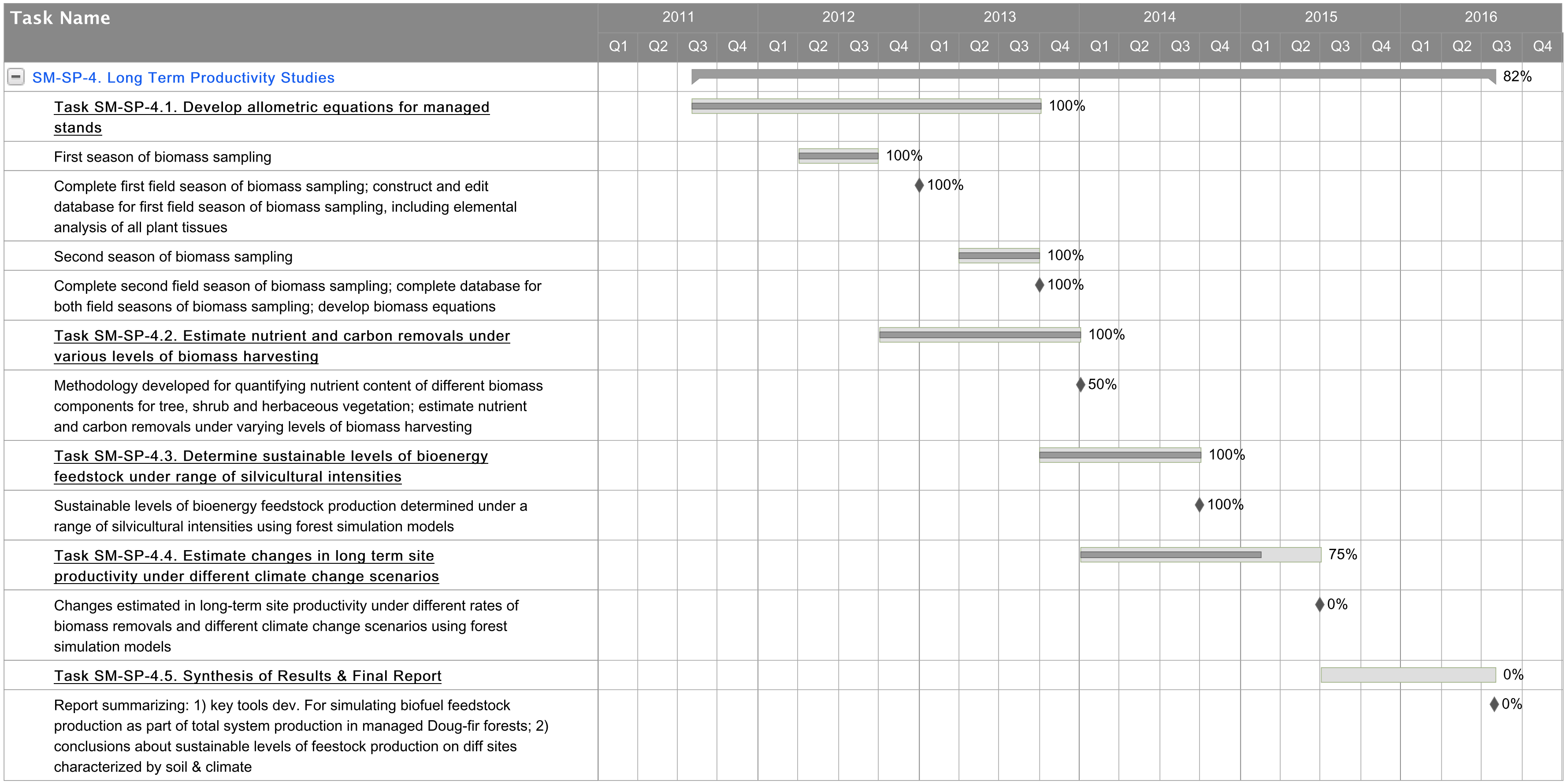
SustainableProduction_Adams_Latta

	Task Name
1	SM-SP-3. Biomass Modeling and Assessment
2	Task SM-SP-3.1. Develop Preliminary Biomass Model and Supply Curves for OR, WA, ID, MT
3	Extend existing models to include biomass
4	Develop transportation model
5	Develop harvest projections
6	Coordinate with silviculture, soil productivity and logistics groups on model inputs
7	Task SM-SP-3.2. Second iteration regional biomass supply curves as improved estimates of biomass availability and costs become available.
8	Revise and iterate the Task 1 models in response to information from other groups (including logistics and silviculture groups)
9	Task SM-SP-3.3. Model alternative plant locations and capacities
10	Generate projections of resource supplies and costs under alternative assumptions of biomass processing locations and biomass supply
11	Task SM-SP-3.4. Final Report
12	Summary of harvest projections, transportation model, alternative plant location/capacities, and biomass/supply curve model

Exported on April 21, 2015 3:36:16 PM PDT

Page 1 of 1

SustainableProduction_Maguire



	Task Name	
1	SM-SP-4. Long Term Productivity Studies	82%
2	Task SM-SP-4.1. Develop allometric equations for managed stands	100%
3	First season of biomass sampling	100%
4	Complete first field season of biomass sampling; construct and edit database for first field season of biomass sampling, including elemental analysis of all plant tissues	100%
5	Second season of biomass sampling	100%
6	Complete second field season of biomass sampling; complete database for both field seasons of biomass sampling; develop biomass equations	100%
7	Task SM-SP-4.2. Estimate nutrient and carbon removals under various levels of biomass harvesting	100%
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	50%
9	Task SM-SP-4.3. Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities	100%
10	Sustainable levels of bioenergy feedstock production determined under a range of silvicultural intensities using forest simulation models	100%
11	Task SM-SP-4.4. Estimate changes in long term site productivity under different climate change scenarios	75%
12	Changes estimated in long-term site productivity under different rates of biomass removals and different climate change scenarios using forest simulation models	0%
13	Task SM-SP-4.5. Synthesis of Results & Final Report	0%
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 feestock production on diff sites characterized by soil & climate	0%

Exported on April 22, 2015 3:19:55 PM PDT

Page 1 of 1

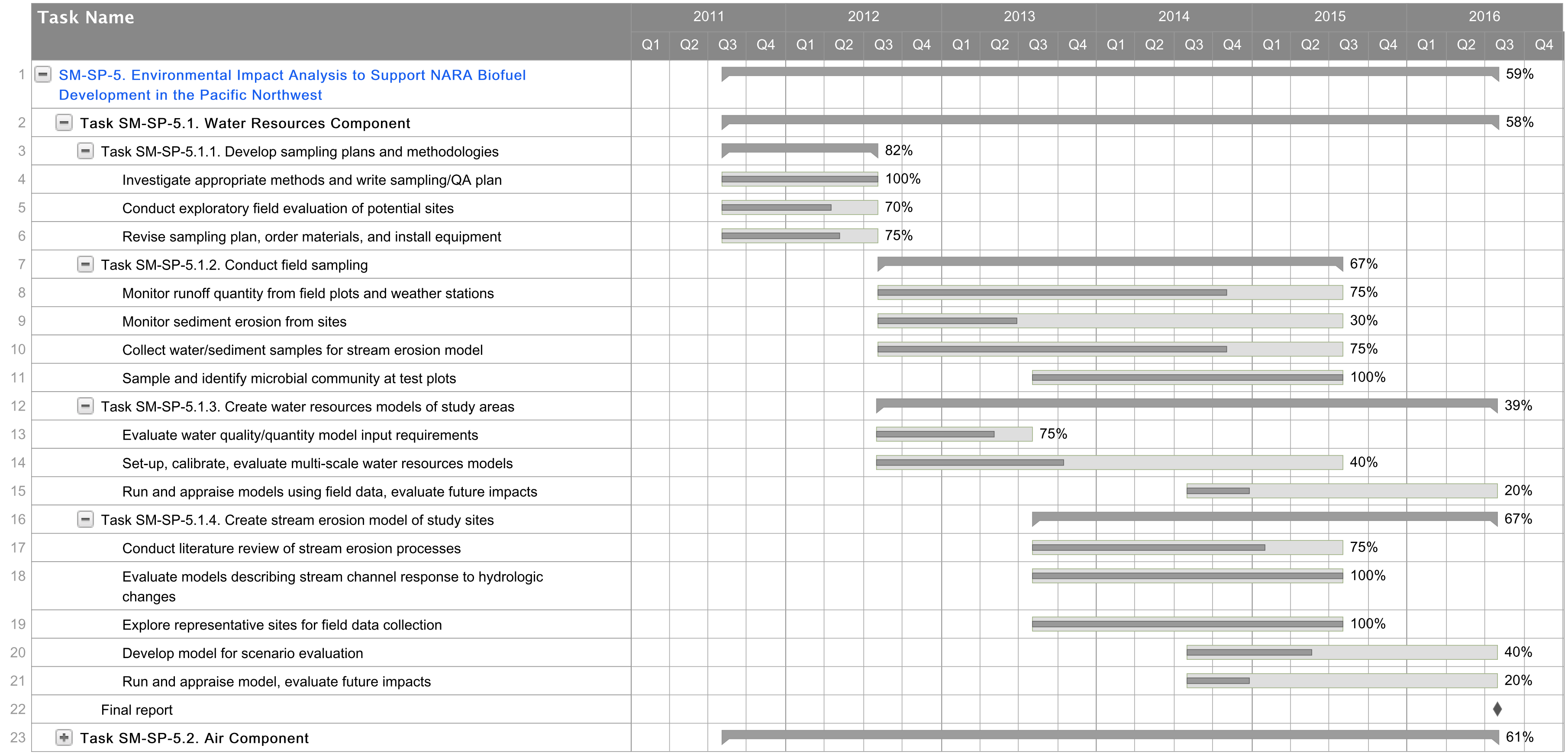
SustainableProduction_Petrie_Lamb

	Task Name	
1	SM-SP-5. Environmental Impact Analysis to Support NARA Biofuel Development in the Pacific Northwest	61%
2	Task SM-SP-5.1. Water Resources Component	58%
23	Task SM-SP-5.2. Air Component	63%
24	Task SM-SP-5.2.1. Regional analysis of supply chain scenarios for air quality	49%
25	Develop scenarios for evaluation of air quality	25%
26	Set-up, evaluate multi-scale air models	80%
27	Run and appraise model, evaluate future impacts	50%
28	Task SM-SP-5.2.2 Assessment of the positive impact of reduced prescribed fires	100%
29	Analysis of prescribed fire impacts on air quality	100%
30	Base case (no fire emissions)	100%
31	Prescribed fire case (with all prescribed fire emission data from NFEI 2011)	100%
32	Sensitivity analysis case	100%
33	Final report	◆20%

Exported on May 4, 2015 8:42:04 AM PDT

Page 1 of 1

SustainableProduction_Petrie_Lamb



	Task Name	
1	SM-SP-5. Environmental Impact Analysis to Support NARA Biofuel Development in the Pacific Northwest	59%
2	Task SM-SP-5.1. Water Resources Component	58%
3	Task SM-SP-5.1.1. Develop sampling plans and methodologies	82%
4	Investigate appropriate methods and write sampling/QA plan	100%
5	Conduct exploratory field evaluation of potential sites	70%
6	Revise sampling plan, order materials, and install equipment	75%
7	Task SM-SP-5.1.2. Conduct field sampling	67%
8	Monitor runoff quantity from field plots and weather stations	75%
9	Monitor sediment erosion from sites	30%
10	Collect water/sediment samples for stream erosion model	75%
11	Sample and identify microbial community at test plots	100%
12	Task SM-SP-5.1.3. Create water resources models of study areas	39%
13	Evaluate water quality/quantity model input requirements	75%
14	Set-up, calibrate, evaluate multi-scale water resources models	40%
15	Run and appraise models using field data, evaluate future impacts	20%
16	Task SM-SP-5.1.4. Create stream erosion model of study sites	67%
17	Conduct literature review of stream erosion processes	75%
18	Evaluate models describing stream channel response to hydrologic changes	100%
19	Explore representative sites for field data collection	100%
20	Develop model for scenario evaluation	40%
21	Run and appraise model, evaluate future impacts	20%
22	Final report	♦
23	Task SM-SP-5.2. Air Component	61%

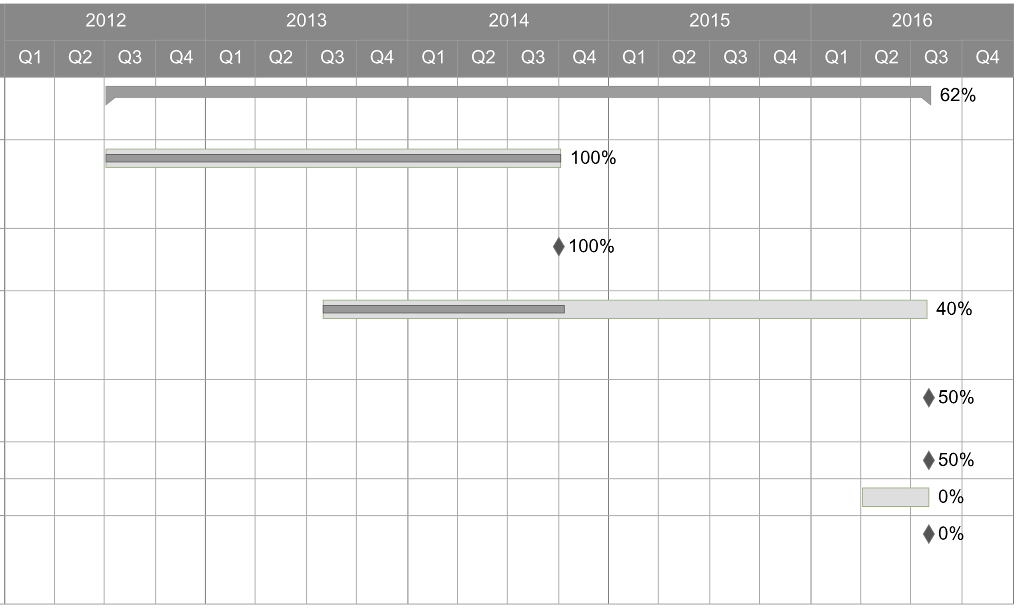
Exported on April 22, 2015 3:46:51 PM PDT

Page 1 of 1

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	Literature review summarizing impacts of biofuel extraction on biodiversity and identifying empirical research needs
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 demographic effect of biofuel extraction on songbirds (from empirical study)
6	Report summarizing pollinator impacts from WY LTSP field work
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

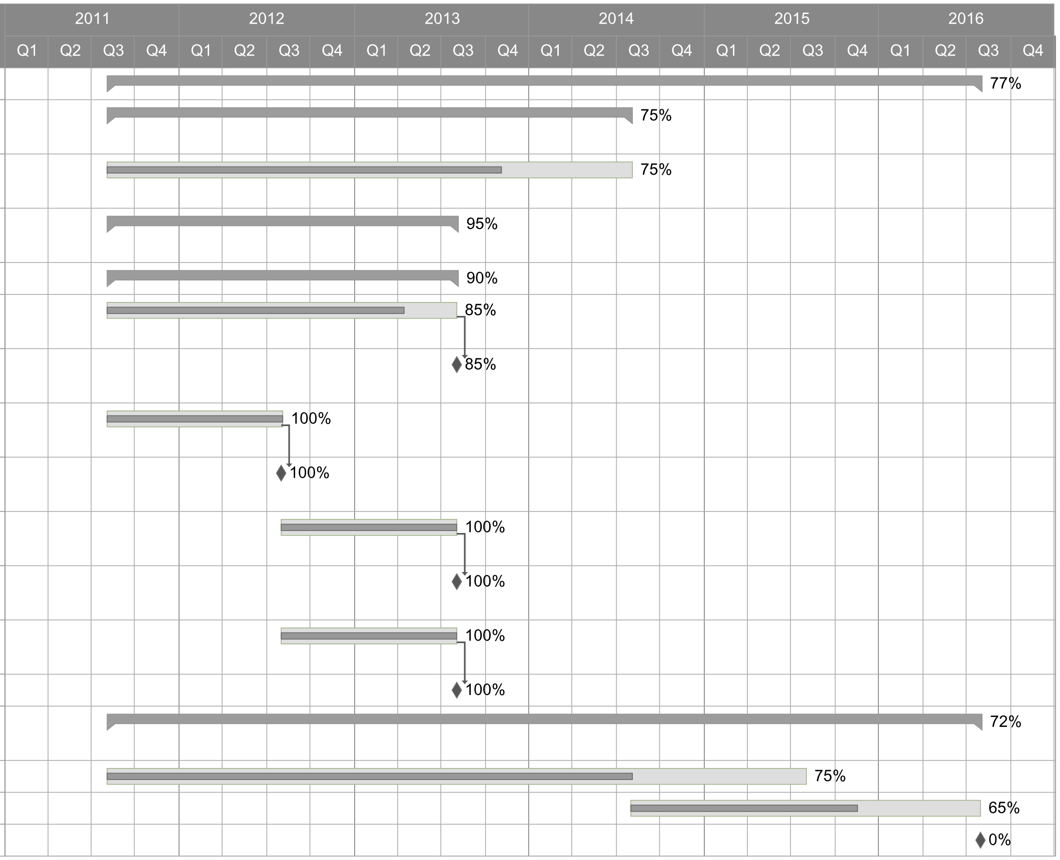


Exported on April 23, 2015 10:46:44 AM PDT

Page 1 of 1

SustainableProduction_Morgan

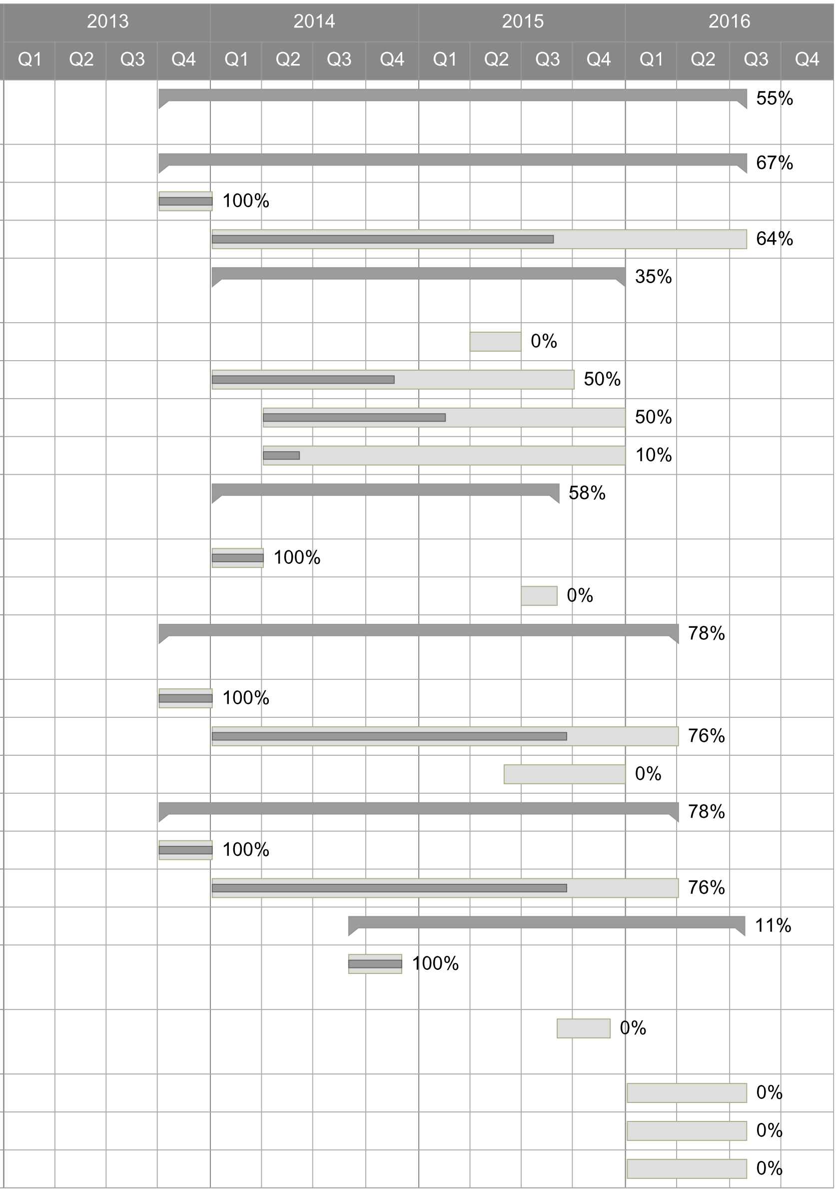
	Task Name
1	SM-SP-7. Supply Chain Analysis
2	Task SM-SP-7.1. Coordinate new and existing Idaho & Montana ("east-side") forest inventory and other data for use in "west-side" models
3	Coordinate with "west-side" modeling team on data needs and standards for Idaho & Montana
4	Task SM-SP-7.2. Enhance and update primary mill residue and capacity information for 4-state region
5	Task SM-SP-7.2.1. Survey of primary mill facilities in Washington and Oregon
6	Cooperate with Washington DNR on mill surveys to collect mill residue and capacity information
7	Washington primary mill (residue, wood use, capacity, etc.) data available for modeling
8	Provide updated estimates of Oregon mill residue and capacity information from mill censuses
9	Oregon primary mill (residue, wood use, capacity, etc.) data available for modeling
10	Provide updated estimates of Montana mill residue and capacity information from mill censuses
11	Montana primary mill (residue, wood use, capacity, etc.) data available for modeling
12	Provide updated estimates of Idaho mill residue and capacity information from mill censuses
13	Idaho primary mill (residue, wood use, capacity, etc.) data available for modeling
14	Task SM-SP-7.3. Enhance and update logging and other forest residue for 4-state region
15	Conduct logging utilization studies in Idaho, Montana, Oregon and Washington
16	Incorporate updated logging residue data into woody supply analysis
17	Final report on forest/logging residue and primary and secondary mill residue



Exported on April 14, 2015 10:41:50 AM PDT

Page 1 of 1

SustainableProduction_Hatten

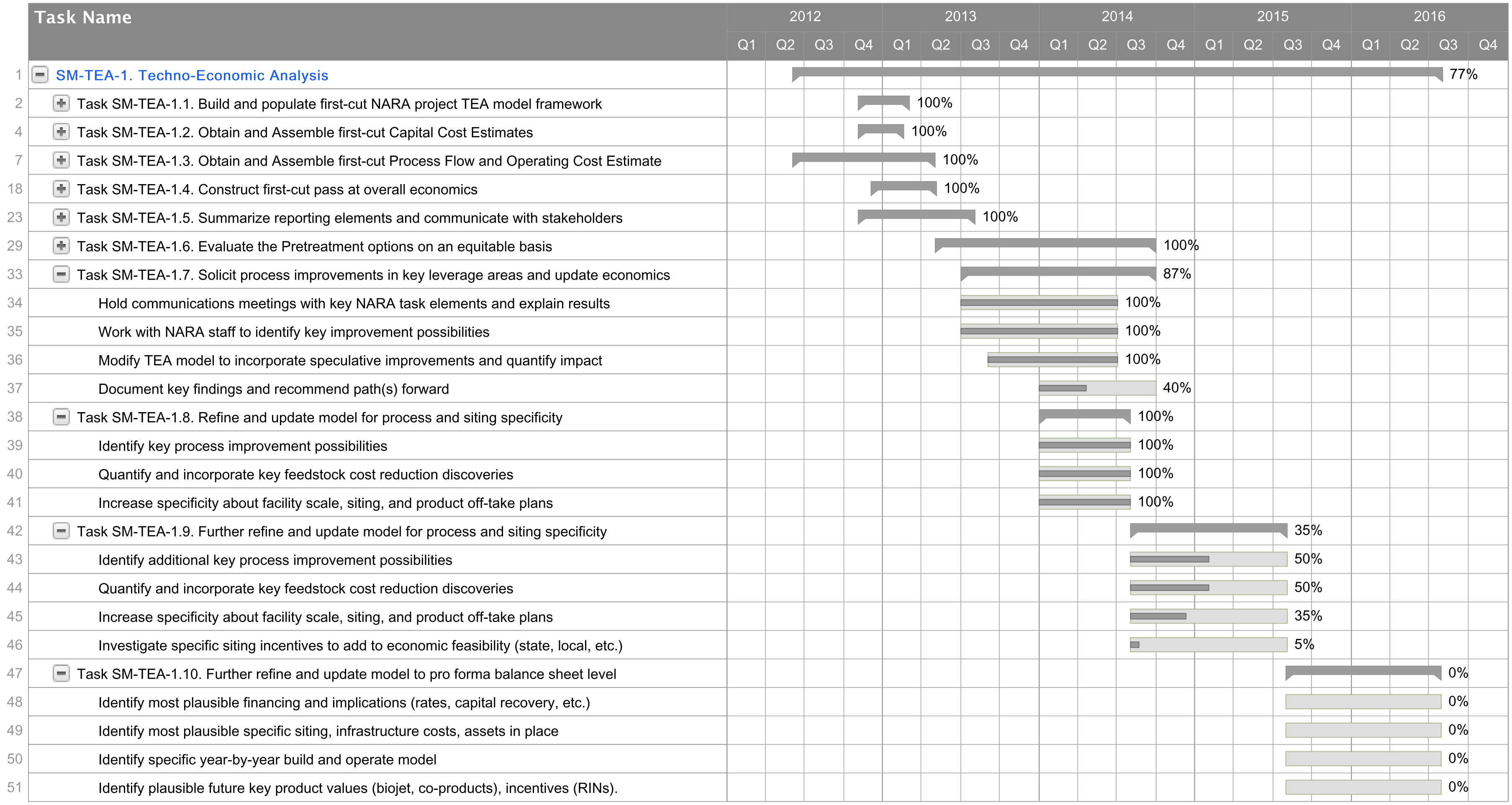


	Task Name	
1	SM-SP-8. Effects of Varying Forest Floor and Slash Retention on Soil Nutrient and Carbon Pools in a Regenerating Douglas-fir Tree Farm: NARA-Soils	55%
2	Task SM-SP-8.1. Monitor and report on soil moisture and temperature data	67%
3	Soil Moisture Installation	100%
4	Soil Moisture and Temperature Measurements	64%
5	Task SM-SP-8.2. Analyze whole soils and density fractions pre-, post-, 1 yr post- and 2 yr post for elemental contents stable isotopic ratios	35%
6	Soil Collection - Year 2 after treatment	0%
7	Density Fractionations	50%
8	Elemental Determinations	50%
9	Stable Isotope Determinations	10%
10	Task SM-SP-8.3. Examine whole soils pre-, post-, 1 yr post- and 2 yr post for exchangeable nutrient pools	58%
11	Available Nutrients pre- and post-treatment	100%
12	Available Nutrients 2 yr post-treatment	0%
13	Task SM-SP-8.4. Examine inputs of carbon and nutrients into mineral soils using pan lysimeters	78%
14	Pan Lysimeter Installation	100%
15	Pan Lysimeter Solution Collection	76%
16	Task SM-SP-8.5. Foliar response to soil changes	0%
17	Task SM-SP-8.6. Examine soil carbon cycling through soil respiration	78%
18	Respiration Collar Installation	100%
19	Soil Respiration Measurements	76%
20	Task SM-SP-8.7. Manuscript, Report Preparation, Data Archive	11%
21	Milestone/Deliverable 1: Conference presentation on effect of compaction on distribution of soil carbon and nutrients	100%
22	Milestone/Deliverable 2: Conference presentation on the effect of organic matter removal on soil carbon and nutrients	0%
23	Milestone/Deliverable 3: Manuscript preparation on soil carbon	0%
24	Milestone/Deliverable 4: Manuscript preparation on soil nutrients and site productivity	0%
25	Milestone/Deliverable 5: Final Report preparation	0%

Exported on April 22, 2015 3:32:43 PM PDT

Page 1 of 1

SystemsMetrics_TEA

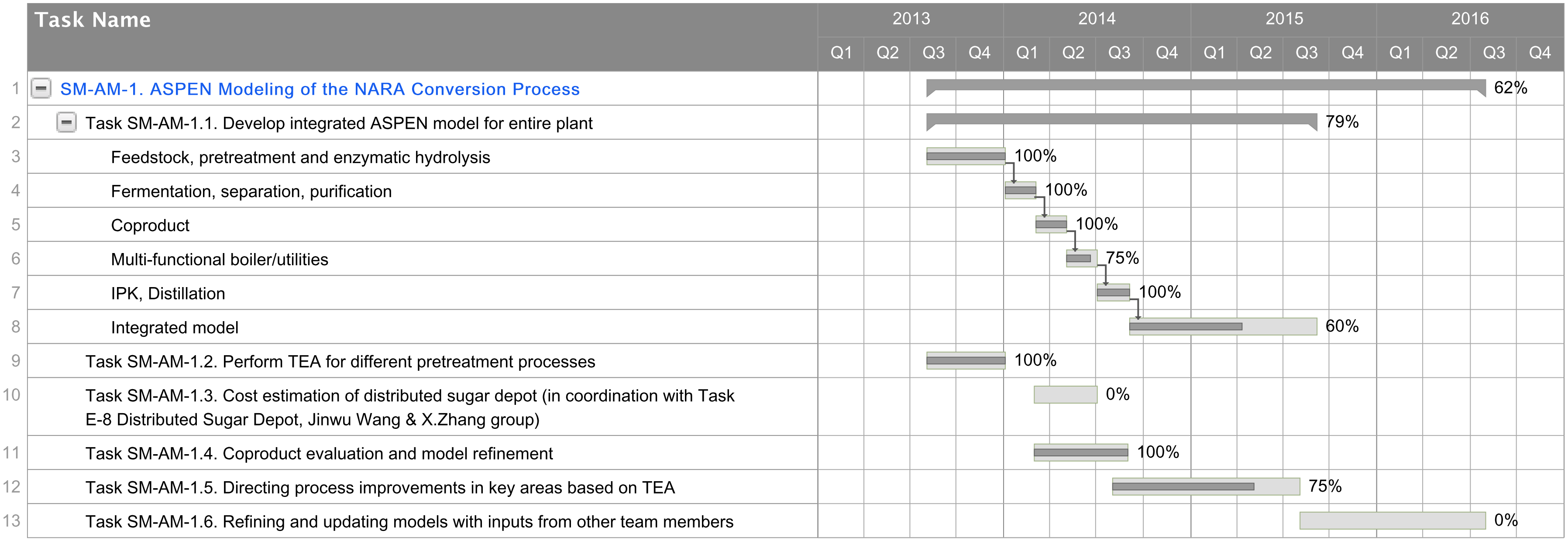


	Task Name	
1	⊟ SM-TEA-1. Techno-Economic Analysis	77%
2	⊞ Task SM-TEA-1.1. Build and populate first-cut NARA project TEA model framework	100%
4	⊞ Task SM-TEA-1.2. Obtain and Assemble first-cut Capital Cost Estimates	100%
7	⊞ Task SM-TEA-1.3. Obtain and Assemble first-cut Process Flow and Operating Cost Estimate	100%
18	⊞ Task SM-TEA-1.4. Construct first-cut pass at overall economics	100%
23	⊞ Task SM-TEA-1.5. Summarize reporting elements and communicate with stakeholders	100%
29	⊞ Task SM-TEA-1.6. Evaluate the Pretreatment options on an equitable basis	100%
33	⊟ Task SM-TEA-1.7. Solicit process improvements in key leverage areas and update economics	87%
34	Hold communications meetings with key NARA task elements and explain results	100%
35	Work with NARA staff to identify key improvement possibilities	100%
36	Modify TEA model to incorporate speculative improvements and quantify impact	100%
37	Document key findings and recommend path(s) forward	40%
38	⊟ Task SM-TEA-1.8. Refine and update model for process and siting specificity	100%
39	Identify key process improvement possibilities	100%
40	Quantify and incorporate key feedstock cost reduction discoveries	100%
41	Increase specificity about facility scale, siting, and product off-take plans	100%
42	⊟ Task SM-TEA-1.9. Further refine and update model for process and siting specificity	35%
43	Identify additional key process improvement possibilities	50%
44	Quantify and incorporate key feedstock cost reduction discoveries	50%
45	Increase specificity about facility scale, siting, and product off-take plans	35%
46	Investigate specific siting incentives to add to economic feasibility (state, local, etc.)	5%
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 model	0%
51	Identify plausible future key product values (biojet, co-products), incentives (RINs).	0%

Exported on April 22, 2015 4:11:19 PM PDT

Page 1 of 1

SystemsMetrics_AM



	Task Name	
1	SM-AM-1. ASPEN Modeling of the NARA Conversion Process	62%
2	Task SM-AM-1.1. Develop integrated ASPEN model for entire plant	79%
3	Feedstock, pretreatment and enzymatic hydrolysis	100%
4	Fermentation, separation, purification	100%
5	Coproduct	100%
6	Multi-functional boiler/utilities	75%
7	IPK, Distillation	100%
8	Integrated model	60%
9	Task SM-AM-1.2. Perform TEA for different pretreatment processes	100%
10	Task SM-AM-1.3. Cost estimation of distributed sugar depot (in coordination with Task E-8 Distributed Sugar Depot, Jinwu Wang & X.Zhang group)	0%
11	Task SM-AM-1.4. Coproduct evaluation and model refinement	100%
12	Task SM-AM-1.5. Directing process improvements in key areas based on TEA	75%
13	Task SM-AM-1.6. Refining and updating models with inputs from other team members	0%

Exported on April 21, 2015 3:02:50 PM PDT

Page 1 of 1

NARA Goal Four

3RD Cumulative Report April 2014 - March 2015

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 engage regional stakeholders and foster working collaborations to develop a wood-based biofuel and co-product industry, the NARA Outreach Team hosted and completed a NW Wood-based Biofuels + Co-Products Conference (April 28-30, 2014) in Seattle. This first-time conference provided a mix of industry and academic representatives followed by a large student and government presence. This mix fit well with NARA's mission to provide multiple stakeholder groups with analyses and data that facilitate a wood to biofuels and co-product industry. In addition, the sizable student presence complemented NARA's goal to enhance bioenergy literacy for a sustainable work force. Another opportunity to involve stakeholders with NARA research occurred in conjunction with NARA's annual meeting in Seattle (Sept. 15-17). Here, regional stakeholders attended a one-day series of presentations and panel discussions devoted to NARA's work on the economic, social and environmental sustainability of using wood residuals to make biojet fuel and other bio-related co-products. The invited guests provided critical recommendations and perspectives to NARA's work. The NARA Outreach team represented NARA at the WA Biomass Coordination Group and MT Forest Products Industry Roundtable and described the ongoing progress with NARA regional supply chain studies at seven regional stakeholder meetings. For this reporting period, NARA researchers presented over 150 times at 69 separate venues throughout the world.


Supply chain presentations in Montana. NARA Photo

Laurel James meets with forestry professionals . NARA Photo

STUDENT/STAKEHOLDER INTERACTION

To envision regional supply chain assets and provide recommendations and strategies on their utility, the Education Team assists the outreach efforts by forming collaborations between students, NARA mentors and stakeholders to provide regional supply chain analyses. NARA researchers and university students participate in a year long integrated design course called Integrated Design Experience (IDX), offered through the Institute for Sustainable Design at Washington State University. In this collaborative course, multidisciplinary student teams analyze biofuel supply chain scenarios in partnership with regional stakeholders. For this reporting period, this group focused their supply chain analysis on the entire NARA region of Idaho, Montana, Oregon, and Washington, as opposed to sub-regional analyses in previous years. They identified and ranked facility sites that could accommodate varied segments of the supply chain and refined the forest residual volume calculations for the various facility sites considered. These sites are categorized as either solids depots, liquid depots, conversion plants or integrated biorefinery. The IDX group communicated their findings to regional stakeholders via webinars on 10/20/14 and 11/19/14. The Wauna Pulp and Paper Mill was highlighted as a high ranking site for a liquid depot and integrated biorefinery and will be the subject of a site inventory and design project completed in May, 2015 (Task E-3).

A similar collaboration of students, NARA mentors, and stakeholders was employed with the NARA Tribal Partnership Program (TPP). The TPP group provided the Confederated Salish and Kootenai Tribes (CSKT) a 10-year biomass supply projection study in NARA Year-3. In this reporting period, they will investigate the Tribe's forestry residue potential from existing tribal stewardship sites in adjacent federal lands, as well as the overall residue potential of a ten-mile buffer around the reservation, which is nominally available to the Tribe through the Tribal Forest Protection Act. The TPP will also investigate the availability of Renewable Identification Numbers (RINs) credits associated with lands under the Tribal Forest Protection Act and project emissions from a potential sulfite-based sugar-processing depot on the reservation. The TPP group arranged for Douglas-fir forest residuals to be acquired from CSKT and Muckleshoot tribal forests to be used by NARA to generate 1000 gallons of biojet fuel (Task E-1).

SUGAR DEPOT ANALYSIS

To utilize forest residuals from remote areas where direct woody feedstock transport to a biorefinery is cost prohibited, a distributed production scenario is being explored where forest residuals are converted into "sugar syrup" that can be transported for further product development. Achieving this goal could potentially decrease biomass transport and labor costs while extending utilization of existing facilities. Distributed production can also provide a diversified biomass source to mitigate supply risks and reduce the supply radius. To investigate this potential, experiments were conducted to explore transforming wood residuals inexpensively into a transportable pellets, panels or sugars. Douglas-fir residuals were milled to 30 μm particles, hydrolyzed, and fermented using Gevo's GIFT™ technology (Task C-AF-1; E-8). The yeast biocatalysts were able to grow and produce isobutanol in 100% wood-milled hydrolysate, which contrasts to a limitation of 40% hydrolysate for yeast biocatalyst fermentation using sulfite-based hydrolysate. The energy consumption and sugar yields for wood milling have been determined, and a preliminary techno-economic analysis (TEA) indicates that sugar production through this milling process is economically competitive with processes used to generate sugar from other cellulosic materials. A more complete TEA for all unit operations anticipated in a sugar depot refinery model, using milled wood pretreatment, is underway (Task subE-8). Structural and chemical characterizations were determined for the milled particles; further analysis revealed that that no chemical inhibitors to the fermentation process were in the sugar stream and that the lignin was highly reactive. These results indicate that the milling process can produce pretreated material from Douglas-fir residuals that is as good if not superior to thermal-chemical pretreated material and is a promising technology for depot sized facilities (Task E-8).

MUNICIPAL SOLID WASTE

Forest residues constitute a majority of the wood biomass supply considered for producing biojet. Another source of wood residue feedstock is construction and demolition debris (C&D) portion of municipal solid waste (MSW). NARA researchers characterized the waste wood residues from select material recovery facilities (MRF) and determined that carbohydrate content is similar between MRF wood supplies and forest residuals. MRF wood supplies do, however, contain higher levels of ash, metals and alkanes. The MRF wood materials were pretreated using a sulfite-based method (SPORL), and the hydrolysate was enzymatically hydrolyzed. A mass balance from the pretreatment and hydrolysis experimentation will be available in Summer 2015 (Task E.7).

SIGNIFICANT OUTPUTS REPORTED THIS PERIOD FOR NARA TEAMS SUPPORTING SUPPLY CHAIN COALITIONS

- NARA Outreach Team hosted and completed a NW Wood-based Biofuels + Co-Products Conference (April 28-30, 2014) in Seattle: Proceedings (Task O-1)
- An Analysis report was completed ranking sites in the western Oregon and Washington (MC2P) for solids depots, liquid depots, conversion plants or integrated biorefinery (Task E-3).
- A webinar was provided to educate and receive stakeholder comments regarding facility site ranking results (Task E-3).
- A Preliminary Scoping report was created to outline the analysis work being done by IDX for the Pacific Northwest region (Task E-3).
- Supplemental information regarding mitigation plans for natural disasters in the MC2P region were developed and posted (Task E-3).
- Douglas-fir forest residuals were acquired from CSKT and Muckleshoot tribal forests to be used by NARA to generate 1000 gallons of biojet fuel (Task E-1).

SIGNIFICANT OUTCOMES

To participate in first production of bio-jet fuel from forest residuals and the resulting demonstration flight, the Confederated Salish and Kootenai Tribes (CSKT) and the Muckleshoot Tribe provided forest residuals from their tribal forests (Task E-1; Task O-1).

TRAINING

Name	Affiliation	Role	Contribution
Mond Guo	WSU-TC	Graduate Student (PhD)	
Sanne' Rijkhoff	Ruckelshaus Center/DGSS	DGSS RA	
James Casey	University of Idaho	Graduate Student	Data collection on slash pile volumes
Jon Potter	WSU	Graduate Student (MS)	IDX fellow. Tasked with assisting with external communications for the class, including templates for presentations, printing posters, etc. Jon has also been the primary lead on the supply chain analysis for the MC2P region and is in the process of writing a paper to compare the WMC with the MC2P region
Vincent McIntyre	WSU	Graduate Student (MS), started June 2014	IDX fellow. Tasked with analyzing the markets in the PNW region. Vince has also been assisting with creating a new IDX GIS repository for all data pertinent to the PNW region.
Peter Gray	WSU, Economic Sciences	Graduate Student (PhD)	Lead Supply Chain specialist for the IDX team. His responsibilities include an economic analysis of the supply chain for distributed and localized models of biomass collection.
Natalie Martinkus	WSU, Civil Engr.	Graduate Student (PhD)	Lead GIS specialist for the IDX team. Her responsibilities include collection, documentation, and analysis of all GIS assets in the PNW region.
McKenzie Payne	University of Idaho	Graduate Student (MS)	Writing articles on the following: developing opportunities for an emerging biofuels industry in the Pacific Northwest, examining environmental impacts, and stakeholder support for wood-based biofuels.
Scott Millman	University of Idaho	Graduate Student (MS)	Writing articles focused on developing opportunities for an emerging biofuels industry in the Pacific Northwest. Writing literature review for paper on biofuels site selection, and searching for newspaper articles chronicling support or opposition to biofuels facilities.
Joshua Hightree	University of Idaho	Graduate Student (MS)	Worked on facility and sizing needs for IBR at Cosmo Specialty Fibers and Kapstone Pulp and Paper
Jorge Jordan	University of Idaho	Graduate Student (MS)	Developing traffic impact models for IBR and liquid depot sites in the PNW.
Ryan Jacobson	University of Idaho	Graduate Student (MS)	Working on biomass estimates for solids, liquids and IBR facilities in the Pacific Northwest. Developing an online biomass and cost estimator.
Alexandria Marienau	University of Idaho	Graduate Student (MS)	Examining economic develop organizations & their support for wood-based biofuels and bioenergy
Courtney Mattoon	University of Idaho	Graduate Student (MS)	Examining economic develop organizations & their support for wood-based biofuels and bioenergy
Rui Zhu	WSU, Civil Engr.	Graduate Student (MS)	Outreach responsibilities: maintain stakeholder master list, NARA's official Twitter account; compile database of assets; and assist with other outreach activities. Research responsibilities: study the effects of hot water extraction (HWE) on Douglas-fir biomass and understand the influence of processing factors; investigate the impact of HWE on the downstream sulfite pretreatment of Douglas-fir biomass and corresponding sugar yields; exploring the reinforcing potentials of cellulose nanofibrils (CNFs) using electrospinning technology.

Sarah Dossey	CMEC, WSU	Technical Assistant	Developing Knowledge Base; assisting with conferences; compiling database of stakeholders
Janna Loeppky	Oregon State Univ	Graduate Student	Reporting on NARA OSU research
Raul Pelaez Samaniego	WSU	Post-Doc	Raul is performing all the testing and data analysis for this study.
Lanxing Du	CMEC	Visiting PhD Student	Characterization of lignin residues
Jinxue Jiang	WSU, Materials Science & Engr.	Graduate Student (PhD)	Fundamental understanding of milling effect on recalcitrance of biomass
Yalan Liu	WSU, Materials Science & Engr.	Graduate Student (PhD)	Size Reduction and Sulfite Pretreatment of Softwood for Efficient Hydrolysis and High Value Products Yield
Huinan Liu	WSU, Engr.	Graduate Student (MS)	Enhancing the Milled Wood Enzymatic Hydrolysis Through Post-Milling Kneading by a Torque Rheometer
Rodney Seals	University of Arkansas	SURE student	Testing the milled wood lignin residues as an binder for wood pellets
Eileen Wu	University of California at Berkeley	SURE student	Characterization and comparison of hydrolysates from the mechanical pretreatment and other thermochemical pretreatments

RESOURCE LEVERAGING

Resource Type	Resource Citation	Amount	Relationship or Importance to NARA
Grant	FAA ASCENT Project 1. Alternative Jet Fuel Supply Chain Analysis		A proposal has been accepted by the FAA to support collection of data on perceptions of biofuel, market dynamics and logistical challenges associated with widespread adoption of aviation biofuel. This proposal includes the NARA region for initial implementation, but will extend into other regions as well. The CAAM model will be augmented with additional data from this effort.
	China Scholarship Council (CSC)		Support for Yalan Liu and Jinxue Jiang
RA Funding	WSU, Provost Office		Support for Mond Guo
RA Funding	WSU, Provost Office		Support for Natalie Martinkus
RA Funding (submitted 1/2016)	U.S. Department of Energy	$100,000	Extend NARA/IDX research in Clearwater basin to examine small-scale biofuels production
Scholarship	China Scholarship Council (CSC)		Support for Yalan Liu and Jinxue Jiang
RA Funding	WSU, Provost Office		Support for Huinan Liu
Grant funding	The Joint Center for Aerospace Technology Innovation (JCATI)	$98,000	Title: Mechanical Pretreatment to Produce Cellulosic Sugars at a Pilot Scale

SUPPLY CHAIN

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 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:

I. 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.
1) Implement targeted outreach activities for engaging stakeholders and advancing bioenergy literacy to professionals.
2) Catalog activity outcomes and benchmark reports and studies.

II. 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 two major tasks.
1) Engaging stakeholders to assist in compiling supply chain assets, analyzing potential supply chain structure, and forming regional alliances.
2) Assist in establishing NARA pilot supply chain (PSC) study region and coordinating activities with NARA's IDX and other research teams for conducting supply chain analysis in the region.

Activities and Results

Bioenergy Literacy

TASK 1:

NARA's Outreach Team hosted and completed the NW Wood-based Biofuels + Co-Products Conference (April 28-30, 2014) in Seattle. Proceedings of the conference are archived and available to the public. A report summarizing the event statistics is attached in Appendix A.

To describe NARA's progress, outputs and activities to NARA members, stakeholders and the general public, 37 newsletter stories were distributed to 976 email subscribers with an average viewing percentage at 27.3 %. Additional information regarding NARA related activities were disseminated through 77 NARA blog posts. 151 NARA presentations were made throughout the world at 69 separate events.

One hundred and four posts on NARA Facebook were generated linking USDA blogs, NARA updates and newsletters, NARA YouTube videos, meetings/events in biofuel/cellulosic bioenergy fields, and other AFRI-CAP information. Post about the NARA ELP

Matrix had the largest reach. Of the people accessing NARA's Facebook, 71% are men and 29% women.

The NARA website reached 11,893 individual users throughout the world of which 57.6% were new users during this annual reporting period.

Seventeen videos were posted on the NARA YouTube channel. These videos present NARA researchers describing their work to determine the sustainability of a wood residual to biojet fuel and co-products industry.

An infographic was developed to articulate the broad impacts provided by NARA Education and Outreach activities, and three fact sheets were developed to highlight the NARA's Tribal Partnership Program, NARA education programs and the supply chain flow and products derived from the production of biojet fuel from forest residuals.

TASK 2:

A repository of unbiased scientific knowledge on wood-based biased biofuels and co-products (Knowledge Base) was converted to a dynamic stakeholder resource. Over 950 users throughout the world (at least one user from 84 countries; majority of users are from the U.S. and Brazil) have accessed the site since it has been established in 2014.

The Outreach and the Education teams are capitalizing on NARA's effort in Year 5 to produce 1000 gallons of biojet fuel by documenting and producing professional-quality media to promote bioenergy literacy. In order to secure a U.S Northwest representative Douglas-fir feedstock supply to produce 1000 gallons of biojet fuel made from forest residuals and used for a demonstration flight, forest residuals from Washington, Oregon and Montana were collected (Figure O.1.1). The Outreach Team video recorded the collection of these feedstocks and conducted interviews with the landowners and foresters. The video recordings will be used to document the production of biojet fuel from forest residuals and construct educational videos.

Figure O.1.1. Forest residuals used for NARA 1000 gallons biofuel production. A) Weyerhaeuser site in southwest Oregon, B) Confederated Salish and Kootenai Tribe forest in northwest Montana, C) Muckleshoot Tribe forest in northwest Washington.

Build Supply Chain Coalitions

TASK 1:

The NARA Outreach team represented NARA at the WA Biomass Coordination Group and MT Forest Products Industry Roundtable (serve as stakeholder leadership teams providing guidance with regional supply chain analyses) and described the ongoing progress with NARA regional supply chain studies at seven regional stakeholder meetings.

Recognizing the need to actively engage ENGOs, the Outreach team compiled a list of individuals and environmental organizations for a personal visit for their perceptions and opinions.

The involvement of the Outreach Team at the varied feedstock sites (Tribal lands and Weyerhaeuser property) during media production reinforced the engagement between NARA and stakeholders and enhanced stakeholder knowledge regarding NARA activities.

TASK 2:

The NARA Outreach team assisted the Education Team's IDX group with planning and writing a Profile document for NARA's Year 4 Supply Chain Study, which summarizes available assets; connected the IDX team with key industry stakeholders (GP, Weyerhaeuser, Port Townsend Paper Company, and ZeaChem); and organized fieldtrips to familiarize students with production/conversion facilities relevant to the NARA project. The Outreach Team also assisted the Education Team in reviewing and compiling the MC2P supply chain study report.

Recommendations | Conclusions

Based on our interactions with the stakeholders and team members, following are the three tasks we would like to concentrate on in the final year of the NARA project:

1) Engage ENGOs. Environmental communities haven't been well represented at stakeholder meetings, conferences, and/or surveys. To capture their concerns and opinions regarding utilization of forest residuals for biofuels, we will need to engage through personal visits and communications.
2) Develop media to capture biojet fuel production within the context of NARA's biofuel process.
3) Dissemination of NARA research findings through an International Conference in Spring 2016.

Physical and Intellectual Outputs

RECOMMENDATIONS/CONCLUSIONS

Zhu, R. and V. Yadama. 2014. "Effects of hot water extraction (HWE) pretreatment on compositional and physicochemical changes of Douglas-fir," Biomass and Bioenergy (Submitted)

Zhu, R. and V. Yadama. "Isolation and characterization of cellulose nanofibrils (CNFs) from hot water extraction (HWE) treated Douglas-fir." In preparation for submission to a refereed journal.

CONFERENCE PROCEEDINGS AND ABSTRACTS FROM PROFESSIONAL MEETINGS

Proceedings of the NW Wood-Based Biofuels + Co-Products Conference, Seattle, WA, April 28-30, 2014.

Yadama, V. 2015. "Siting of Processing Facilities for Wood-To-Biojet Conversion in Oregon," 77th Oregon Logging Conference, Eugene, OR, February 19-21, 2015

Yadama, V. 2015. "Web-based portals for dissemination of research-based findings to stakeholders on wood-to-biofuel conversion," Poster Presentation, National Extension Energy Summit: Climbing Toward Energy Sustainability, Seattle, WA, April 7-10.

RESEARCH PRESENTATIONS

Gray, Peter. 2014. "Wood-based Aviation Biofuels Supply Chain," the Western Region Forest Resources Association 2014 Spring Meeting, Pasco, WA, April 23.

Rawlings, Craig. 2014. "Tribal Forest Enterprises: 30,000 Feet View with an Economic Development Perspective," at the Forest Economics & Managing Resources in a Rising Market Workshop, The Intertribal Timber Council Meeting, Worley, Idaho, June 26.

Zhu, R. and V. Yadama. 2014. "Effects of hot water extraction (HWE) pretreatment on compositional and physicochemical changes of softwood Douglas-fir," 68th Forest Products Society International Convention, Quebec City, Quebec, Canada, August 10-14.

Englund, Karl. 2014. "Overview of NARA," the Western Development Committee Forestry Meeting, Richland, WA, August 20.

Englund, Karl. 2014. "Education and Outreach for educating the future employees of the "green" industry workforce," WA Clean Tech Alliance Meeting, Seattle, WA, October 8.

OTHER PUBLICATIONS

Burke, C., S. Leavengood, and V. Yadama. 2015. "Using slash piles to make chemical products: an update on the Northwest Advanced Renewables Alliance (NARA) activities," The Western Forester, Jan/Feb, pp 7-9. (http://www.forestry.org/northwest/westernforester/2015/)

NEWSLETTERS

NARA Newsletters: (http://www.nararenewables.org/news/newsletter)

ONE-PAGERS WERE DEVELOPED AND POSTED TO THE NARA WEBSITE

https://nararenewables.org/docs/one-pager/SupplyChainProducts.pdf

https://nararenewables.org/docs/one-pager/BioenergyEducation.pdf

VIDEOS AND WEBINARS

Preliminary Site Selection for NARA Supply Chain

Site Selection Webinar

17 other videos produced by NARA's Outreach Team

TRAININGS, EDUCATION AND OUTREACH MATERIALS

NARA's Outreach Team hosted and completed the NW Wood-based Biofuels + Co-Products Conference (April 28-30, 2014) in Seattle. Proceedings of the conference are archived and available to the public.

Knowledge Base: A repository of unbiased scientific knowledge on conversion of woody biomass into bio-jet fuel and co-products.

NEWS STORIES AND PRESS RELEASES

4/24/14	AgInfoNet	Wood Based Biofuels Conference
4/24/14	The Eco Report	Towards a wood based aviation biofuel
4/29/14	KPLU Seattle	Progress turning woody debris into biofuels
5/6/14	the Eco Report	Will utilizing Forest Residuals Deplete Soil Nutrients
5/13/14	the Eco Report	Dr Kevin Boston on the Availability of Biomass
8/29/14	WSU TV Advertisement	Go-Coogs Ad
11/12/14	WSU News	WSU honored for strengths in clean technology
11/19/14	WSU News	Nov.19: Students present potential biorefinery sites

Appendix A

REPORT ON NORTHWEST WOOD-BASED BIOFUELS + CO-PRODUCTS CONFERENCE SEATTLE, WA, APRIL 28-30, 2014

The goal of this conference was to bring together the community of researchers, business leaders, government agencies, and economic development personnel to share and exchange research findings, ideas, and strategies for the common goal of sustainable development of wood-based bio-refineries for production of biofuels and co-products in the Pacific Northwest. (Agenda)

Conference outputs (presentations) are archived in the form of Proceedings. In addition, six conference presentations were posted at the NARA YouTube page (https://www.youtube.com/user/nararenewables).

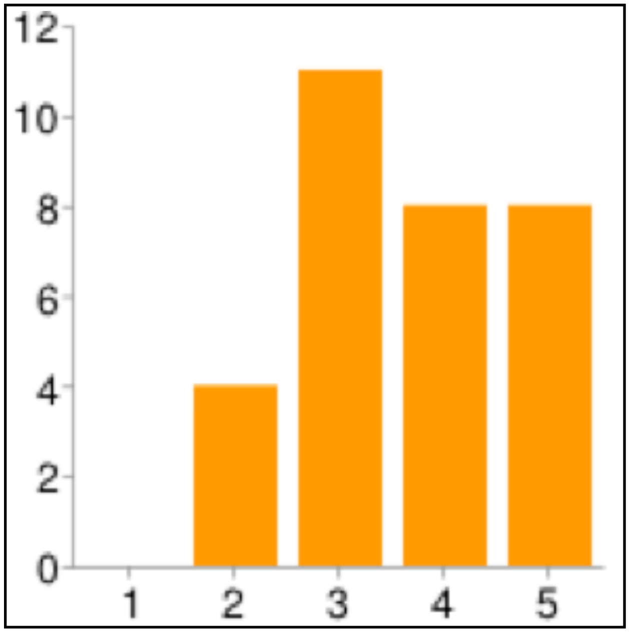
Registrations by State	
California	5
Colorado	3
District of Columbia	2
Idaho	13
Illinois	1
Louisiana	1
Michigan	2
Minnesota	1
Mississippi	1
Montana	10
Nevada	1
North Dakota	1
Oregon	24
Tennessee	1
Virginia	1
Washington	127
Wisconsin	3

Following are the summary statistics of the conference:
Total Registrations: 211
Speakers: 50
Student registrations: 41
Posters in Poster Session: 33 submitted

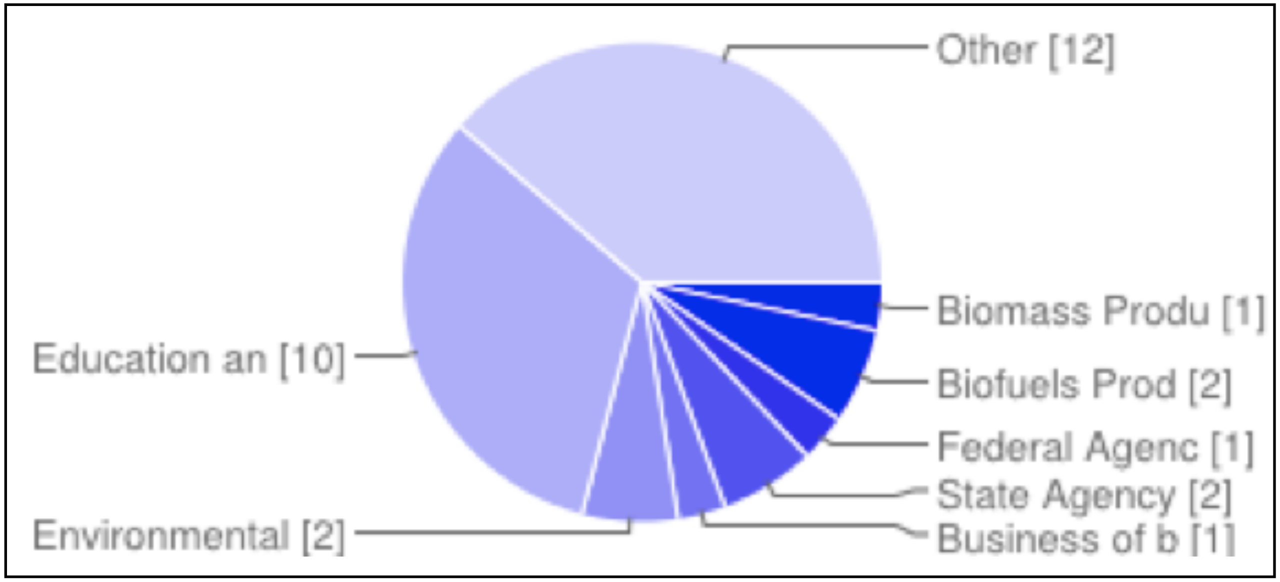
Demographic Data: Data breaking down attendee composition is shown in the tables below. More demographic information can be also found in May 2014 NARA Newsletter.

Registrations by Country	
Canada	9
Germany	1
Greece	1
Sweden	1
United States	199

My knowledge about converting woody biomass to biofuels and co-products has increased as a result of attending the conference (scale of 1 to 5, with 5 signifying a significant change).



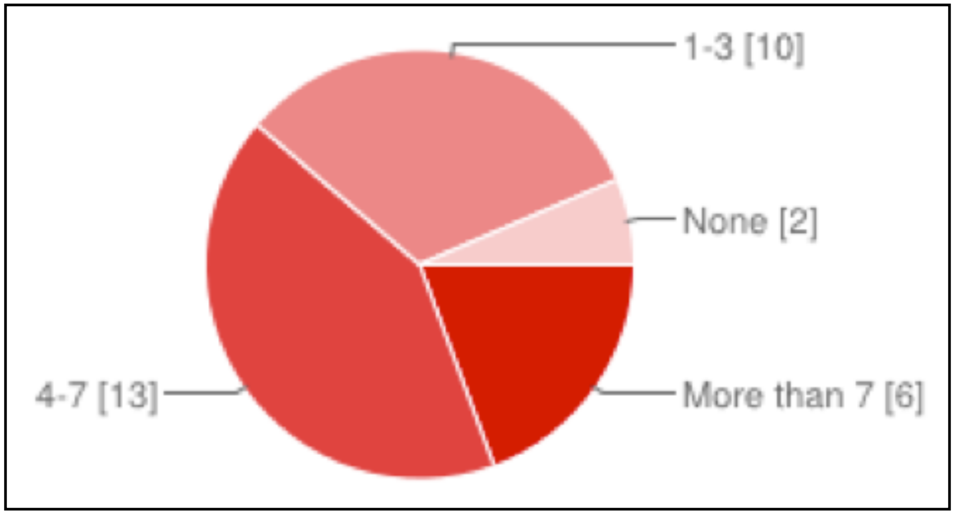
Summary of Post-Conference Survey (Based on 31 responses; 15% response rate)
Description of conference attendees:



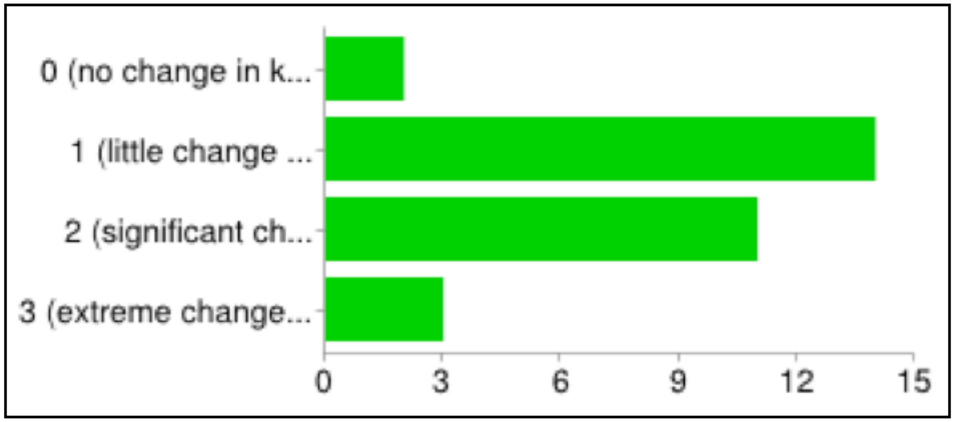
<table>
<tr><td colspan="2">Total Companies/Universities/State Agencies Represented: 89</td></tr>
<tr><td colspan="2">State Agencies Represented: 11</td></tr>
<tr><td colspan="2">Universities Represented: 17</td></tr>
<tr><td colspan="2">All others (NGOs, private companies): 61</td></tr>
<tr><td>Alaska Airlines</td><td>Montana State University Extension Forestry</td></tr>
<tr><td>American Science and Technology Corporation</td><td>Mt. Adams Resource Stewards</td></tr>
<tr><td>Avista Utilities</td><td>NARA Tribal Partnership Projects</td></tr>
<tr><td>BacGen Technologies</td><td>OFIC</td></tr>
<tr><td>BASF SE</td><td>Oregon State Department of Energy</td></tr>
<tr><td>BC Bioenergy Network</td><td>Oregon State University</td></tr>
<tr><td>Bio[Fuels & Mass] Consulting</td><td>Pacific Northwest National Laboratory</td></tr>
<tr><td>Biomass Magazine</td><td>PCS Biofuels</td></tr>
<tr><td>Boeing Commercial Airplanes</td><td>Port Blakely Tree Farms L.P.</td></tr>
<tr><td>Borregaard LignoTech USA</td><td>Rayonier</td></tr>
<tr><td>BRUKS Rockwood</td><td>Rehrmann & Associates</td></tr>
<tr><td>Catchlight Energy</td><td>Roseburg Forest Products</td></tr>
<tr><td>Chimas Hellas S.A.</td><td>Seneca Sustainable Energy</td></tr>
<tr><td>Clearwater Forestry Services</td><td>Sundrop Fuels</td></tr>
<tr><td>Climate Solutions</td><td>TerraPower, LLC</td></tr>
<tr><td>College of Forestry and Conservation at the University of Montana</td><td>The Watershed Center</td></tr>
<tr><td>Colorado State University</td><td>The William D. Ruckelshaus Center</td></tr>
<tr><td>Confederated Tribes of Warm Springs</td><td>Thomas Spink International</td></tr>
<tr><td>Conifex Timber Inc.</td><td>University of British Columbia</td></tr>
<tr><td>Cosmo Specialty Fibers</td><td>University of California, Davis</td></tr>
<tr><td>Desert Research Institute</td><td>University of Idaho</td></tr>
<tr><td>DR Systems Inc</td><td>University of Idaho McCall Outdoor Science School</td></tr>
<tr><td>Ena Energi AB</td><td>University of Minnesota, Twin Cities</td></tr>
</table>

Ensyn Corporation	University of Montana
Eureka Rural Development Partners	University of Tennessee
EWTA	University of Washington
F.H. Stoltze Land and Lumber Co.	University of Wisconsin
Facing the Future	USDA Forest Service
Forest Business Network	USDA, Rural Development
Forest Concepts, LLC	USDA-FS Rocky Mountain Research Station
Forestry Equipment Company	WA Department of Commerce
Forterra	Washington Forest Protection Association
Gevo, Inc.	Washington State Department of Agriculture
Gifford Pinchot Task Force	Washington State Department of Natural Resources
Global Verde Media LLC	Washington State Department of Ecology
GreenWood Resources Inc.	Washington State University
Hermann Brothers Logging	Washington State University Extension
Humboldt State University	Waterfall Group
Idaho National Laboratory	Weyerhaeuser Co
International Climate Energy Program and National Wildlife Federation	Whatcom Conservation District
John Jump Trucking	Whole Energy
Kittitas County Chamber of Commerce	William D. Ruckelshaus Center
Lorenzen Engineering, Inc.	Wind River Biomass Utility LLC
Mercer International	WoodLife Environmental Consultants LLC
Mercurius Biorefining	
Michigan Technological University	

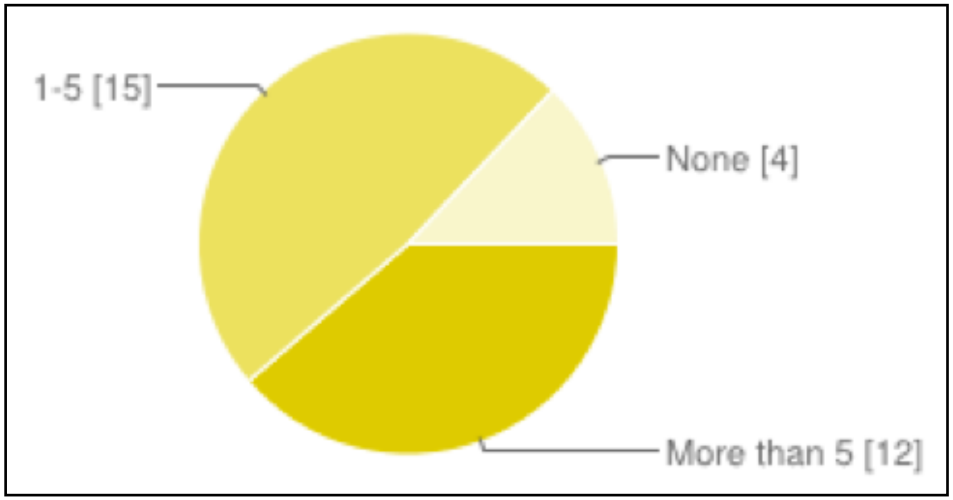
Number of new ideas and connections between ideas from which you gained a better understanding? (through talks and networking)



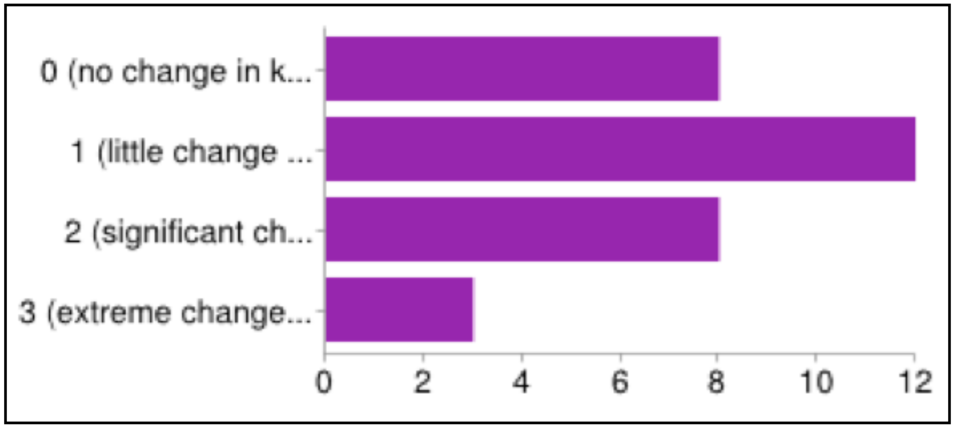
Stakeholder perceptions about use of woody biomass for biofuels [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



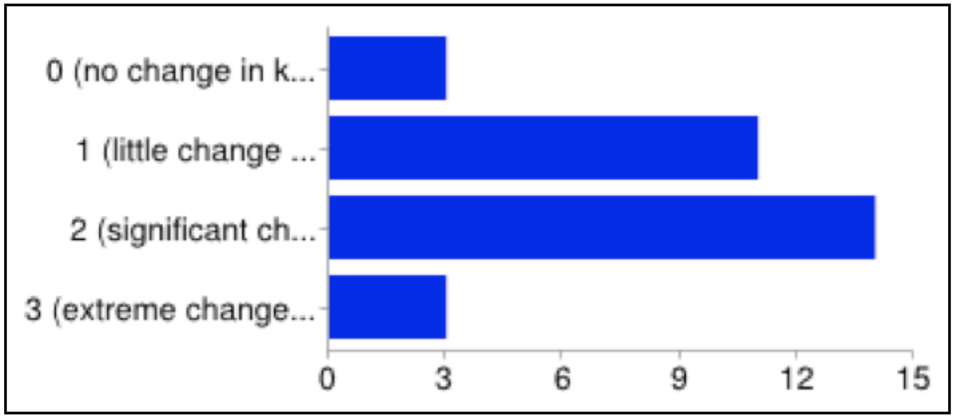
How many important contacts did you make at this Symposium?



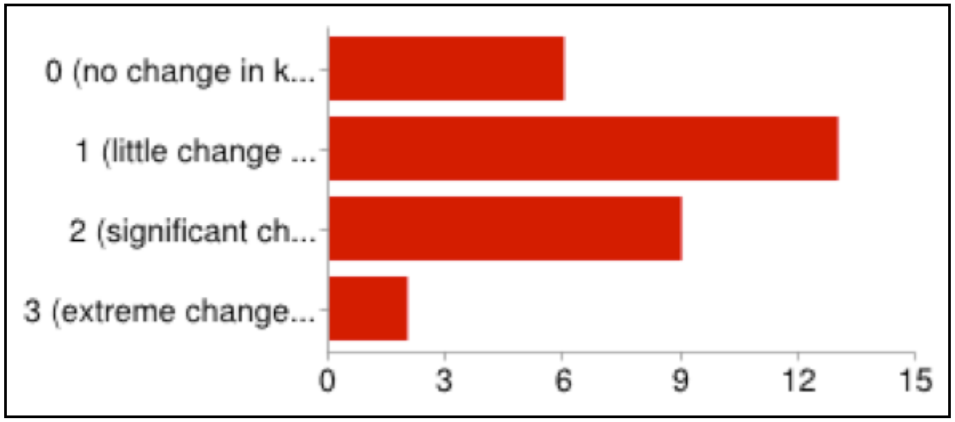
Why woody biomass can be used for biofuels [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



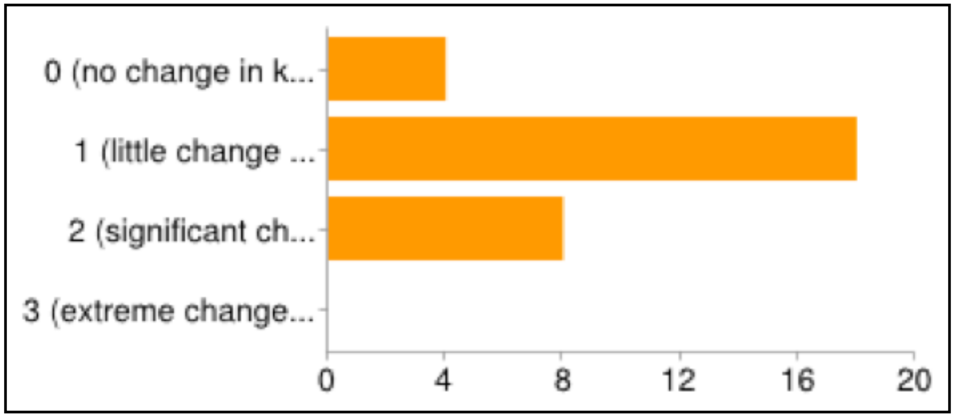
Potential for chemical co-products from woody biomass [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



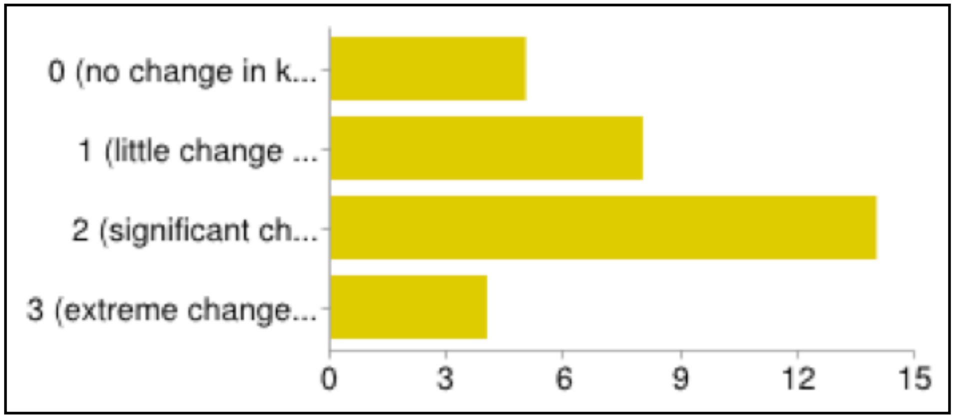
Biomass pre-conversion options [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



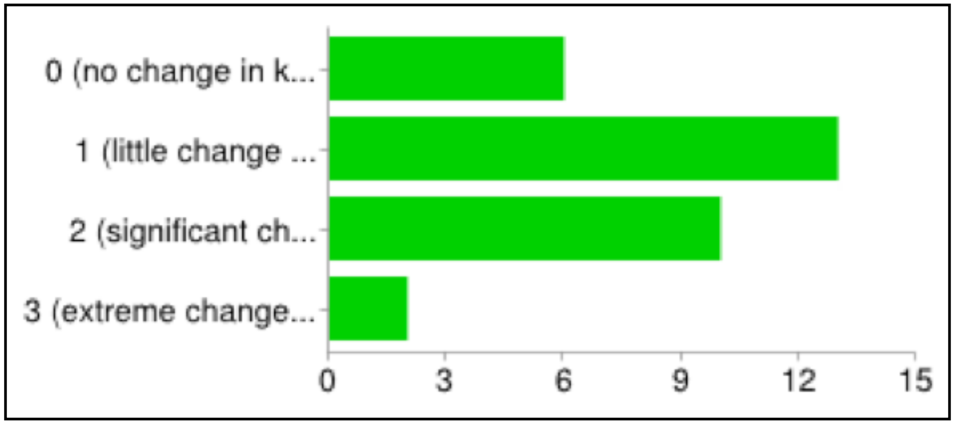
Biomass collection technologies [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



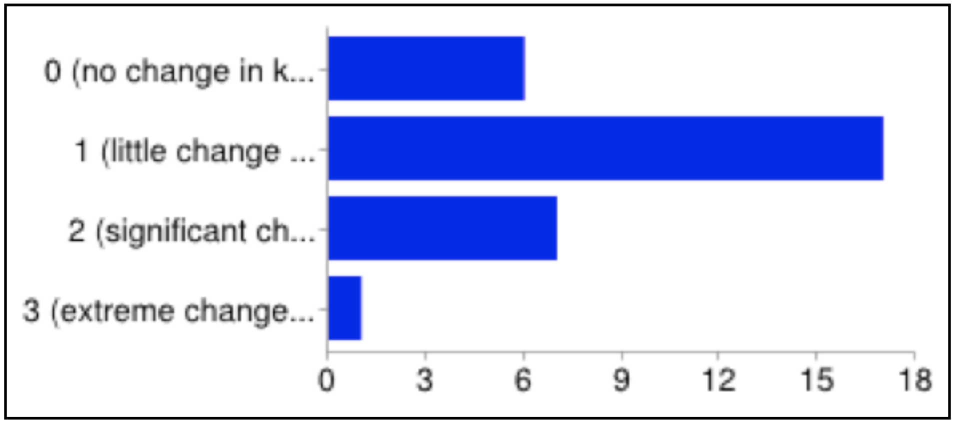
Chemical conversion of biomass into biofuels [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



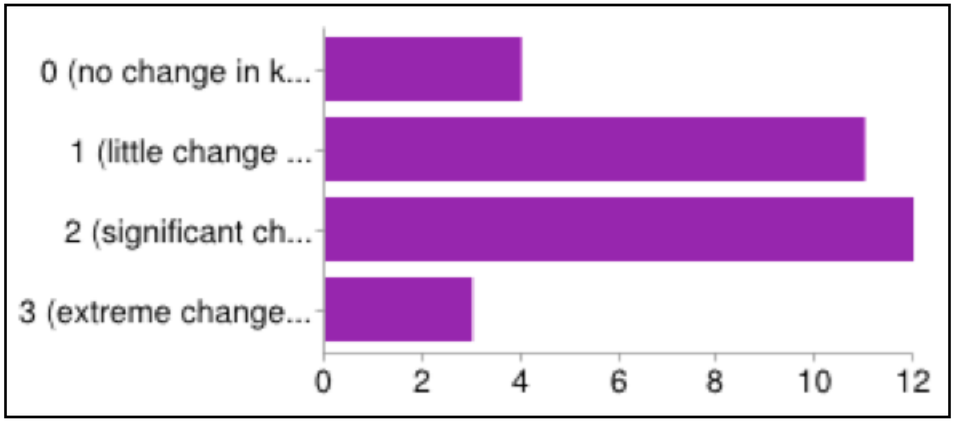
Enzymatic conversion of biomass into biofuels [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



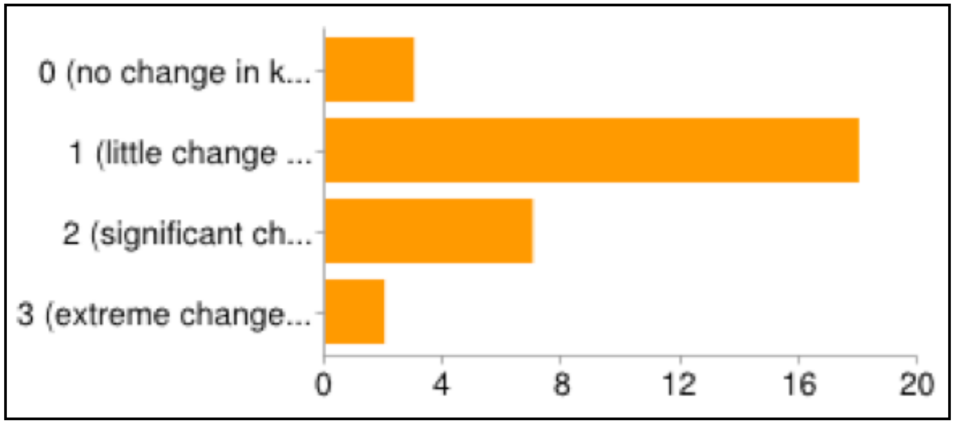
Environmental impacts of producing biofuels from woody biomass [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



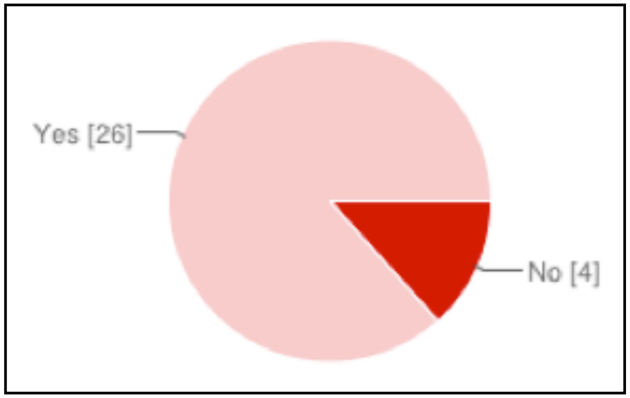
Challenges of converting woody biomass into biofuels and co-products [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



Supply chain for converting wood to biofuels and co-products [Please indicate, with a check mark, any increase in the level of your knowledge in the areas described by the statements below.]



Would you consider attending a follow-up conference in 2016?



PLEASE SUGGEST TOPICS YOU WOULD LIKE TO SEE ADDRESSED IN 2016 CONFERENCE.

- Rotary shear production of biofuel feedstock
- Densification of biomass for transport
- Results of current pilot programs; (if data available) more on actual yields as opposed to projected models; more case studies on outreach efforts
- A lot more on biochar as another product in the chain from biomass--pluses, minuses, etc. How does biochar work with (or against) anaerobic digestion as an overall energy scheme, for example.
- Valuable chemical production from lignocellulosic sugar, besides biofuel; Techno-economics analysis of both chemical production and biofuel production from woody biomass.
- World wide impacts of Bio fuel on the economy, the environment and social justice.
- Thanks WSU for providing this conference. It had important resource and technical content and was done very well. Please offer the conference again -- if not every year, at least every other year. Maintain a good technical content re conversion. PS: I attended the first day and second morning (conversion track), and found most of those presentations quite helpful, especially in the conversion track. A full day on conversion technology would be helpful for me. You might also wish to consider adding a few presentations on utilization -- pros and cons of biofuels in application in engines and power generation.
- Plans for integration of policies necessary to ensure industry viability.
- The marketing of products derived from woody biomass.
- The fundamentals of moving treated/untreated biomass to a processing facility from the woods needs to be addressed either as a future topic or additional research. The cost of doing so needs to come down significantly to make this work.
- I really enjoyed the format of speakers on Tuesday morning. 20 minutes for each presenter with time at the end of all speakers within the 1.5 hour time frame worked very well.
- Environmental organizations' concerns along with our industry's responses. Biochar applications updates.
- mobile /modular pre conversion technologies renewable chemical / biobased co product opportunities

TASK O-2: MONTANA STATE UNIVERSITY NARA EXTENSION INITIATIVES

Key Personnel	Affiliation
Peter Kolb	Montana State University

Task Description

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 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 3 articles on NARA project for statewide media outlets. Contribute towards NARA website.

Milestones Year 3:
Write woody biomass harvesting retention guidelines for Montana BMP booklet. Conduct one workshop for Montana landowners and Logging Association on woody biomass harvesting guides for ecological sustainability in the context of climate change. Provide woody biomass harvesting guides and instruction to two annual SFI logger and producer workshops. Continue to contribute towards test bed site selections in Montana. Distribute NARA test bed site information and biomass harvesting guidelines to various stakeholder groups across Montana.

Milestones Year 4:
Finalize and publish Woody Biomass Harvesting Guidelines for Montana. Provide feedstock specification information to major stakeholder and landowner groups across Montana for feedback. Provide updates to SFI training workshops. Develop biomass informational component for incorporation into Montana Forest Stewardship training program and Stewardship/Treefarm management plan template. Write 2 popular articles on NARA program progress for popular media outlets. Provide updates for NARA website.

Milestones Year 5:
Update and finalize feedstock brochure for potential Montana suppliers. Provide 2 woody biomass fieldtrips for test bed community. Write 3 popular articles for media outlets across Montana, and two articles for forest landowner publications and websites. Offer updates to annual logger and mill SFI training and landowner workshops. Assist with NARA web page and conference.

Activities and Results

MSU Extension Forestry presented posters with NARA research results to-date for our Montana Landowner minicollege (83 participants) as well as reported NARA progress and status as both the Montana Statewide Wood Energy Team conference and Montana Wood Products Roundtable. In addition final edits to the new Montana Forestry Best Management Practices Guide that include wood retention recommendations for forest harvesting activities were conducted and this guide was published. Editing continued on the 5-part YouTube video series entitled “Understanding how forests of the Northern Rockies function and the implications of management and climate change” and an expected release is June 2015. Planning for a biomass harvesting workshop for the Montana Logging Association was initiated with an expected workshop delivery of April 28.

Recommendations | Conclusions

The NARA project has concluded that, for the time being, western Montana is unsuitable for initial biomass harvesting to the specification required by existing technologies. We continue to monitor NARA progress with the hope that a viable market for forest harvesting residuals will eventually develop. We are also working with another research project (BANR) and use references and information gained through the NARA project to enhance and guide this projects research development.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

- Final edit and release of Montana Forestry Best Management Practices 3rd edition with new specific references throughout text to address preferred biomass retention following harvest (pg 59).

RESEARCH PRESENTATIONS

- Display at 2015 Forestry MiniCollege, Missoula; (Audience: Non-industrial private forest landowners, forestry professionals)
- Provided NARA update to the Montana Statewide Wood Energy Team (USDA award of $250,000 to stimulate development of wood energy projects in the state.) http://goo.gl/tuhc2x
- Provided NARA updates to the Montana Wood Products Roundtable forum

OTHER PUBLICATIONS

- Biomass to energy, woody debris retention and carbon accounting—future markets or conflicts? http://www.forestseedlingnetwork.com/media/53540/mtforest_landowner_conf_e-broch_2014.pdf
- http://e3a4u.info/wp-content/uploads/Wood-Heat-Entire-Document.pdf - published
- http://www.msuextension.org/forestry/Resources/pdf/FF_CaseStudyFridelyFire_PK.pdf - published
- Developed new online tool for wood energy education: How much Energy is in a Slab of Wood? http://www.msuextension.org/forestry/WB2E/slabenergycalc.htm
- Wrote one popular article with the intent of increasing public understanding of forest harvesting of beetle killed lodgepole pine forests – was printed in most Montana newspapers.
- Submitted/published three articles on eXtension Wood Energy CoP:
  o Estimating Space Heating Demand and Effective Costs;
  o A Simple Comparison of Heating Fuels;
  o How much Energy is in a Slab of Wood?

VIDEOS AND WEBINARS

- Edited and worked on three videos on the role of forest management in the future for wood supply, biomass energy and climate change across the northern Rockies for projected release on YouTube in June 2015.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

- http://www.msuextension.org/forestry/NARA.html
- Online Resource Library for Wood Pellets http://www.msuextension.org/forestry/WB2E/pellets.htm
- Review and Adaptation of the NARA pilot Assessment Tool for Bioenergy Literacy (http://goo.gl/KO3TDr) to audience response system.
- Online adaptation and implementation of NARA surveys:
  o Energy Literacy Assessment (https://montana.qualtrics.com/SE/?SID=SV_1Yo4uDkriL8qlpj)
  o NARA Stakeholder Survey (https://montana.qualtrics.com/SE/?SID=SV_5ziVmIKOa8BeX89)
- Online adaptation and implementation of Annual Montana Wood Biomass Energy Facilities Survey
  o Survey, http://goo.gl/t7jYGe
  o Data compilation and analysis
  o Facilities online reports/time series, http://goo.gl/sxma4E

TASK O-3: UNIVERSITY OF MONTANA NARA EXTENSION INITIATIVES

Key Personnel	Affiliation
Todd Morgan	University of Montana

In NARA project Year-3, the University of Montana Extension effort was canceled to focus on logging residue assessments (Task SM-SP-7). Montana outreach interests will be maintained through Montana State Extension faculty in Task O-2.

TASK O-4: OREGON STATE UNIVERSITY NARA EXTENSION INITIATIVES

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

My primary role with respect to this project has been to serve as the key outreach liaison for Oregon. In that regard, I have focused my 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 in the project. 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 giving lectures for graduate students and faculty at OSU.

My 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.

Janna Loeppky, a graduate research assistant at OSU, interviewed NARA researchers at OSU to produce a series of short NARA 'Research Briefs' that describe the research and its practical implications, with a particular focus on the private woodland owner audience. This target audience was selected in that I have asked my colleagues in Forestry & Natural Resources Extension at OSU to help disseminate these briefs to their stakeholders (e.g., through their newsletters) – which are primarily private woodland owners. Prior to graduation, Janna developed five research briefs.

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 organized conference calls and meetings about the NARA project independently of my efforts or of the efforts of other NARA team members; and Sue Safford with Oregon BEST has asked for information about technology commercialization opportunities from the project that might come about for Oregon. I believe 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 my 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 me for more of the details about the research efforts connected with this project, i.e., tasks related to task 1 - Bioenergy Literacy. Therefore, I will focus future efforts 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 conferences is one approach I've used to achieve this goal as is working with other outreach team members to develop educational materials such as articles for Western Forester, newsletter articles for OSU Extension Forestry faculty, and maintaining a NARA page on the Oregon Wood Innovation Center website.

Physical and Intellectual Outputs

RESEARCH PRESENTATIONS

Leavengood, S. 2014. Northwest Advanced Renewables (NARA) Project Update – Fall 2014. October 22. Corvallis, OR. Seminar for WSE 507.

OTHER PUBLICATIONS

Burke, C., Leavengood, S, & Yadama, V. (2015, Jan./Feb.). Using slash piles to make chemical products. Western Forester, 60(1), 7-9. Retrieved from http://www.forestry.org/media/docs/western-forester/2015/WFJanFeb2015.pdf

Loeppky, J., J. Sessions. 2014. Transportation of Residues: Would you bundle?

Loeppky, J., K. Boston. 2014. Estimating Biomass Availability

Loeppky, J., D. Maguire. 2014. Estimating Nutrient Removals under Varying Intensities of Harvesting Residue Utilization.

Loeppky, J., 2014. NARA Graduate Student Research: The 2014 Western Forestry Graduate Research Symposium.

TASK O-5: UNIVERSITY OF IDAHO NARA EXTENSION INITIATIVES

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.
   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

Efforts in the past quarter were coupled with existing Extension field based programs and activities where the NARA project was introduced and basic concepts of the project were discussed. As per request of other NARA researchers, I developed a spreadsheet of names and addresses of all wood processing facilities in Idaho. Graduate student is collecting data on forest residuals volumes in Idaho.

A survey of logging contractors was recently conducted to assess attitudes and beliefs towards utilizing woody biomass as a biofuel. Results have not been summarized, but briefly, many logging contractors would rather utilize other methods to dispose of slash besides burning it. Figure O-5.1 shows how slash is current disposed of in Idaho.

When asked if there was a cost effective alternative to burning forest residuals for disposal, would you consider using it, almost 75% of the logging contractors surveyed were likely to consider it (Figure O-5.2).

When asked how communities would benefit if an alternative to burning was available, the majority thought added jobs would be the biggest benefit (Figure O-5.3).

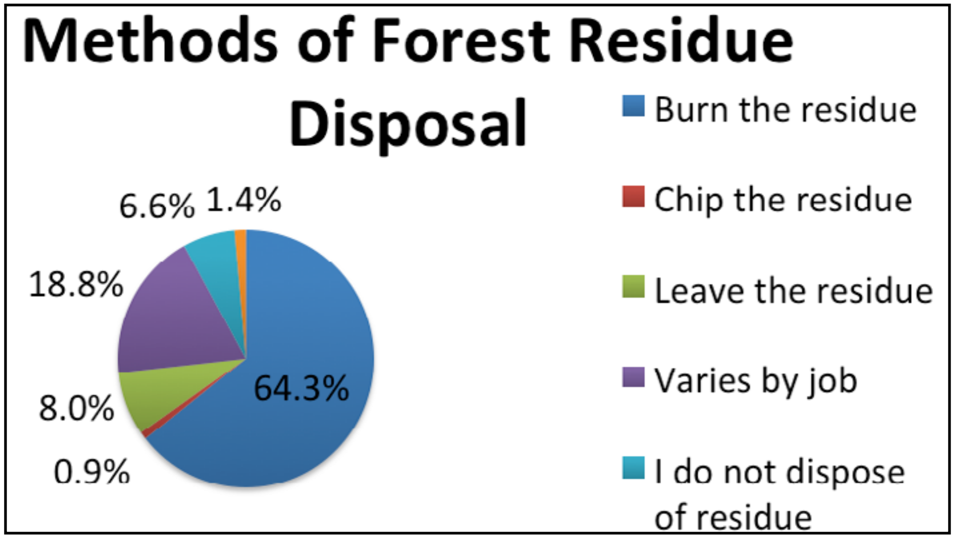


Figure O-5.1. Methods of forest residual disposal in Idaho

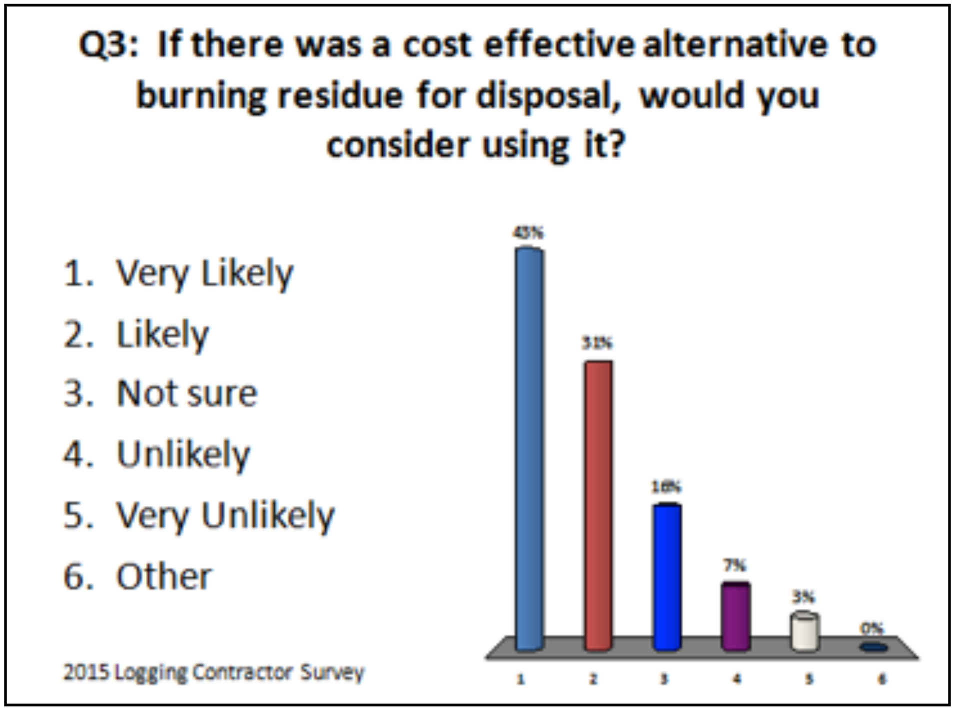


Figure O-5.2. Consideration to using cost effective alternative to burning forest residuals

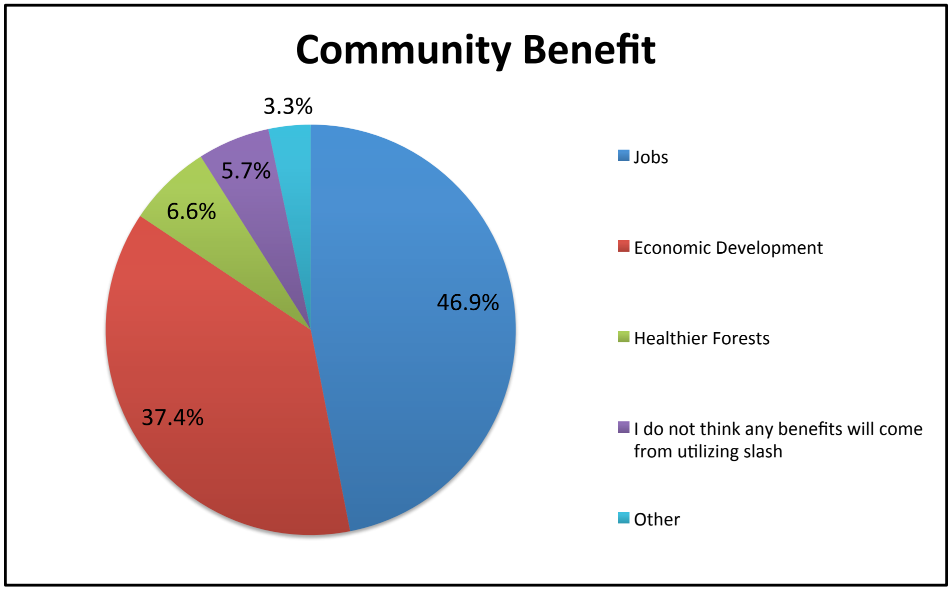


Figure O-5.3. Likely benefit if forest residuals were used for commercial use.

Recommendations | Conclusions

Logging contractors, who are the first step and critical link in the supply chain, are open to viable alternatives for slash utilization. Once technology is available, it would be rapidly adopted by the workforce.

Physical and Intellectual Outputs

PHYSICAL

- Stakeholder survey was created using turning point technologies and collected at 7 logging contractor workshops across Idaho

REFEREED PUBLICATIONS

Brooks, R. and J. Moroney. Forestry Tour Educates Youth in North Central Idaho. 2014. Journal of Extension. Vol. 52, No. 4. August, 2014. Available at: http://www.joe.org/joe/2014august/iw4.php

RESEARCH PRESENTATIONS

Cochran, A., and R. Brooks. 2015. Biofuels from forest residuals. Poster presented at National Extension Energy Summit. Seattle, WA. 9 April 2015

Brooks, R. 2015. Forest Resources Program at Idaho. Presentation given at American Forest Resource Council Annual Meeting. Portland, OR. 8 April, 2015.

Brooks, R., and A. Cochran. 2015. Biofuels from forest residuals. Presentation given at National Extension Energy Summit. Seattle, WA. 9 April 2015

Brooks, R. 2015. Biofuels from forest residuals. Presentation given at Small log conference. Spokane, WA. 25 March 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Hayden, ID. 4 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Sandpoint, ID. 11 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Orofino, ID. 17 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. McCall, ID. 20 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. St. Maries, ID. 24 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Kamiah, ID. 27 Mar. 2015

Cochran, A. and R. Brooks. 2015. Biofuel options from forest residuals. Presentation given at Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Moscow, ID. 31 Mar. 2015

TRAININGS, EDUCATION AND OUTREACH MATERIALS

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Hayden, ID. 4 Mar. 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Sandpoint, ID. 11 Mar. 2015

Brooks, R. 2015. UI Extension Forestry Tree Planting Workshop. Moscow, ID. 13 March 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Orofino, ID. 17 Mar. 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. McCall, ID. 20 Mar. 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. St. Maries, ID. 24 Mar. 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Kamiah, ID. 27 Mar. 2015

Brooks, R. 2015. Idaho Loggers Education to Advance Professionalism workshop. UI Extension Workshop Series. Moscow, ID. 31 Mar. 2015

Brooks, R. and M. Vachon. 2015. IDEX students field trip to ZeaChem. 23 March, 2015.

Brooks, R. How biomass and biofuels fits in with a thinning regime. UI Extension Forestry Thinning & Pruning Field Day, McCall, ID.5/15/14

THESIS AND DISSERTATIONS

Casey, J., and R. Brooks. Examining Alternative Methods of Measuring Logging Residues: A Comparison of Traditional and Laser-Based Slash Pile Estimators. Dec. 8, 2014. Thesis proposal. Moscow, ID.

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 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.

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

BIOENERGY LITERACY

With other Outreach Team members, one-page fact sheets and infographics providing information on research progress being made by other NARA teams continue to be developed. These are posted on the website (http://www.nararenewables.org/about/info-graphics-fact-sheets) and available to NARA members for printing and distribution.

They include:
- Bioenergy in Education
- Supply Chain Products
- Environmental Impact Assessments

Providing feedback on various NARA communications team outputs is an ongoing task. An updated Congressional Briefing Paper was prepared for the PNW Research Station Director to take to Washington, DC (April 2015) for meetings with Congressional members and staff and other stakeholders.

Participation in meetings and conferences in a variety of capacities has occurred. I served as a member of the Steering Committee, moderator and attendee of first NARA conference Northwest Wood-based

Biofuels and Co-Products held in Seattle, WA Seattle (April 28-30, 2014). There were close to 200 attendees. A poster presentation titled "Wood-to-Biofuels Infrastructure: Supply Chain Analysis" was given at the Forest Products Society 68th International Convention (August 10-13, 2014). Quebec City, Canada. I attended the NARA annual meeting in Seattle, WA to hear the progress of other teams and discuss how best to use this information in reaching stakeholders. Following the meeting, the outreach team discussed the Advisory Board's report and prepared a written response to address their comments.

The Outreach Team met in February 2015 to discuss final Outreach materials. Videos of various length and targeted audiences and an eBook to document the entire project were discussed. Following this, I have worked with a videographer to capture footage and interview material on NARA feedstock production.

BUILDING SUPPLY CHAIN COALITIONS

In conversations and at meetings relative to biomass and its utilization (such as the Small Log conference March 2015), I offer information on NARA and its goals and encourage stakeholders to visit the website and register or provide them with specific contacts in their area of interest. IDX efforts in evaluating specific sites as a solid, liquid, or IBR node now offer additional opportunities to connect with decision-making personnel that would further NARA's goals.

Recommendations | Conclusions

The Outreach process is continual and adaptive. Efforts to identify and engage stakeholders continue, especially in the environmental community. I am connecting with Collaborative Forest Landscape Restoration Project (CFLRP) management teams and other partnerships where the US Forest Service has a presence to ensure active participation by the agency. Opportunities to leverage outreach efforts through professional channels continues. The depot concept developed by IDEX provides opportunities for rural communities to participate in this project and is of particular interest to rural communities, especially those with National Forest land in close proximity. Members of the outreach team will coordinate with IDX students to identify and meet with key personnel at the specific sites they have put forth as being likely candidates for NARA depots.

Physical and Intellectual Outputs

PHYSICAL

Video footage of in-woods chipping and interviews of key personnel to the process were conducted on the Weyerhaeuser site in Cottage Grove, OR.

RESEARCH PRESENTATIONS

A poster presentation titled "Wood-to-Biofuels Infrastructure: Supply Chain Analysis" was given by Lowell at the Forest Products Society 68th International Convention. Quebec City, CAN (8/10-13/2014).

TASK O-7: WILLIAM D. RUCKELSHAUS CENTER

Key Personnel	Affiliation
Michael Kern	Ruckelshaus Center
Michael Gaffney	Ruckelshaus Center

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," and 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. 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. Over time, DGSS has also participated in stakeholder (SH) Assessment and engagement efforts as a part of the Outreach team, and has been engaged in active participation with the EPP team on physical-social asset assessment efforts, supporting the Community Asset Assessment Model development effort. 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, and new primary data collected by other NARA participants in the EPP team, 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.
5. Finalization of the Community Asset Assessment Model for application across the NARA region and, in conjunction with other projects such as FAA ASCENT, nationally.

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 with the exception of ongoing statistical analysis and development of the CAAM. 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 continued to be 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 again assisted in the development, planning, and facilitation of the September 2014 NARA annual meetings in Seattle, Washington. The Center also facilitated the NARA Advisory Board meeting discussion during the 2014 annual meeting.

The Center, with the NARA leadership committee, communications team and outreach team, continued to work 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. Three more briefings were sent out April 2014, July 2014, and December 2014.

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 to develop the CAAM model. 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, as informed by new primary data collected by other EPP team members in the region.

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 model development and testing.

- Continue participation on the Outreach Team regarding stakeholder engagement

Physical and Intellectual Outputs

- The Center, in collaboration with the NARA executive team, developed, planned, and facilitated the September 2014 NARA annual meetings in Seattle, WA.

- The Center, with the NARA leadership committee, communications team and outreach team, continued to worked closely with the Advanced Hardwood Biofuels Northwest (AHB) 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.

- The EPP team has developed three conference posters, two conference presentations, and has had one publication accepted for publications, in addition to participating in at least one university academic showcase (WSU) with respect to the CAAM and community characteristic assessment projects.

RESEARCH PRESENTATIONS

Rijkhoff, Sanne, Season Hoard, Michael Gaffney, Paul Smith, Natalie Martinkus, Nicholas Lovrich, John Pierce and Michael Wolcott. Refining Community Asset and Attribute Modeling: Applying Social Data to Inform Bio-Fuel Project Site Selection in the NARA Region. Poster, 2014 NARA Annual Meeting, Seattle, WA, September 15-17.

Smith, Paul, Season Hoard, Michael Gaffney, Tammi Laninga and Jillian Moroney, 2014. The NARA Community Assessment Model. Poster, WSU 2014 Academic Showcase.

Gaffney, Michael, Season Hoard, Paul Smith, Sanne Rijkhoff, 2014. Paper presentation The NARA Community Assessment Model at the annual IBBC conference, Seattle, WA.

TASK O-8: STRATEGIC FEEDSTOCK PRODUCTION ANALYSIS FOR THE WESTERN MONTANA CORRIDOR

Key Personnel	Affiliation
Brian Stanton	GreenWood Resources

Task O-8 was completed in NARA project Year-2.

SUPPLY CHAIN

EDUCATION TEAM

TASK E-3: BIOREGIONAL INTEGRATED DESIGN EXPERIENCE (IDX)

Key Personnel	Affiliation
Tamara Laninga	University of Idaho
Michael Wolcott	Washington State University
Karl Olson	Washington State University

Task Description

IDX is an integrated design studio experience for students in engineering, design (architecture and landscape architecture), natural resources, and 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 (UI) and Washington State University (WSU). The course is a trans-disciplinary planning and design studio that addresses planning and infrastructure needs of communities exploring their role in 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. PhD students from NARA with special expertise in required areas act as consultants to the IDX teams, improving the level of analysis.

Five different pilot supply chain regions will be served, one 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 IDX studio are:

- Every student exits with strong collaborative research, questioning, and design methods to utilize in their academic and professional work within their discipline.
- Provide technical assistance to communities interested in participating in the emerging biofuel economy. We will assist these communities begin the process of transformation necessary for them to be engaged in the biofuels supply chain.

Activities and Results

In year 4, IDX completed the Pacific Northwest (PNW) Supply Chain Analysis, examining the four-state NARA region. The goal was to characterize, describe and understand the linkages and evaluate the supply chain performance in various market regions in the PNW. A framework and site selection database was developed that enabled a greater understanding of the linkages among producers, processors, suppliers, distributors, and markets. Supply chain networks and product volumes vary from region to region based on available natural (e.g., feedstock availability) and physical (e.g., roads, rail, pipelines, mills) assets, as well as market demand.

The NARA Year-4 PNW analysis, while building on the first three studies conducted in years 1-3, refined the site selection methodology and biomass supply curves. IDX examined the region as a whole, and also performed sub-regional analyses based on market demand across the PNW to set feedstock requirements for integrated biorefinery (IBR) facilities. Embedded into this analysis, was the identification and ranking of viable processing sites (e.g. solids and liquids depots, conversion and IBR facilities) in each market region for converting forest residuals to isobutanol and/or biojet fuel. The facility types identified and examined by IDX are described below and shown in Figure E-3.1.

1. DEPOT FACILITY: A pretreatment facility that prepares the biomass for processing in a conversion facility. Two depot options are investigated and are detailed as follows:
Solids Depot: a pre-conversion facility that receives post-harvest forest residuals, forest thinnings, and/or C&D waste biomass. Mechanically processed materials could be shipped by rail or highway truck to a receiving liquids depot, conversion plant, IBR or other potential end user (e.g., fuel pellet manufacturer).
Liquids Depot: a pre-treatment facility that receives raw and mechanically processed woody residuals directly from nearby forests, or chips from a solids depot. A liquids depot produces a concentrated sugar-rich syrup that would be transported for conversion to isobutanol at an IBR for further refining into biojet fuel or other chemical conversion facilities.

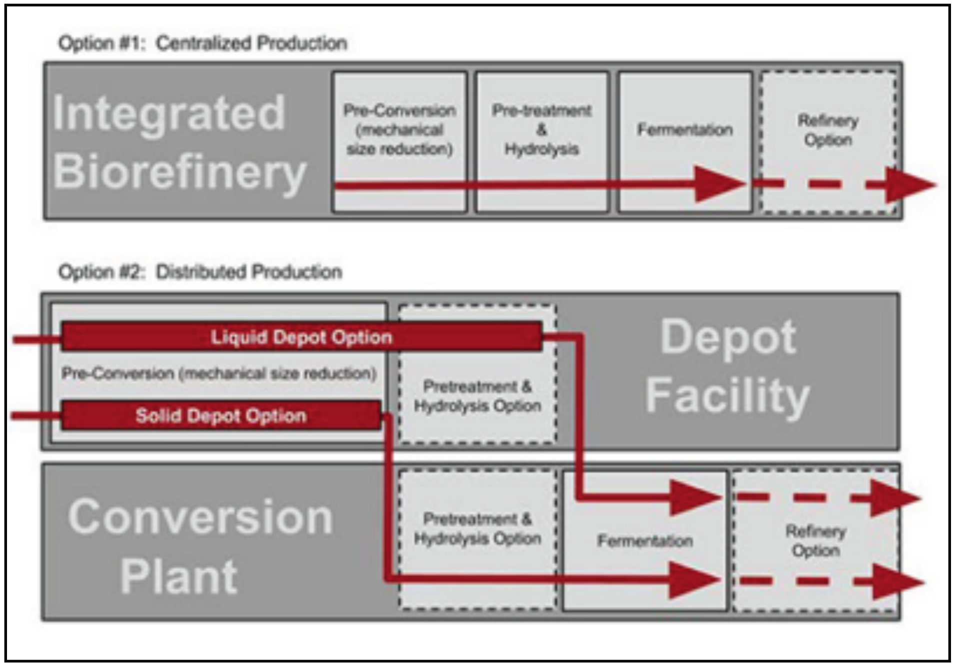


Figure E-3.1. IDX Facility Types

2. CONVERSION PLANT: A high-capacity plant that takes in chips from a solids depot or liquid sugars from a liquids depot and produces isobutanol.

3. INTEGRATED BIOREFINERY (IBR): A high-capacity plant that converts biomass from raw slash or other woody residuals all the way to biojet fuel.

The presentations for the PNW Site Selection Analysis, as well as the sub-regional analyses for the Olympic Peninsula, Northern Oregon, Southern Oregon, and the Western Montana Corridor and the are available at this link.

In addition to the PNW analysis, IDX selected the Wauna Pulp and Paper Mill for co-locating a liquids depot with the current operations. The Wauna Mill was the top facility in our site selection database for a liquids depot and IBR. Washington State University engineering students and University of Idaho planning and landscape architecture students completed a site inventory and analysis. Through this work, IDX selected two locations on the Wauna site for locating a liquids depot. The two site designs will be completed in April and presented in a webinar in early May.

Recommendations | Conclusions

Year 4 IDX incorporated detailed site characteristics and geographic data from years 1-3 into an improved site selection excel database, available for viewing here. The database was shared with NARA Research Teams for further refinement of site selection criteria to optimize the locations of solids and liquids depots, and IBRs. The improved database and decision matrix also incorporated new information from NARA feedstock logistics and pre-treatment technologies to further refine the PNW analysis. Specifically, NARA techno-economic analysis biomass volumes needed to be adjusted for the various types of models under analysis. To have a successful depot or an IBR, the biomass volumes needed to be scaled properly for proposed site operations. IDX worked with the as-

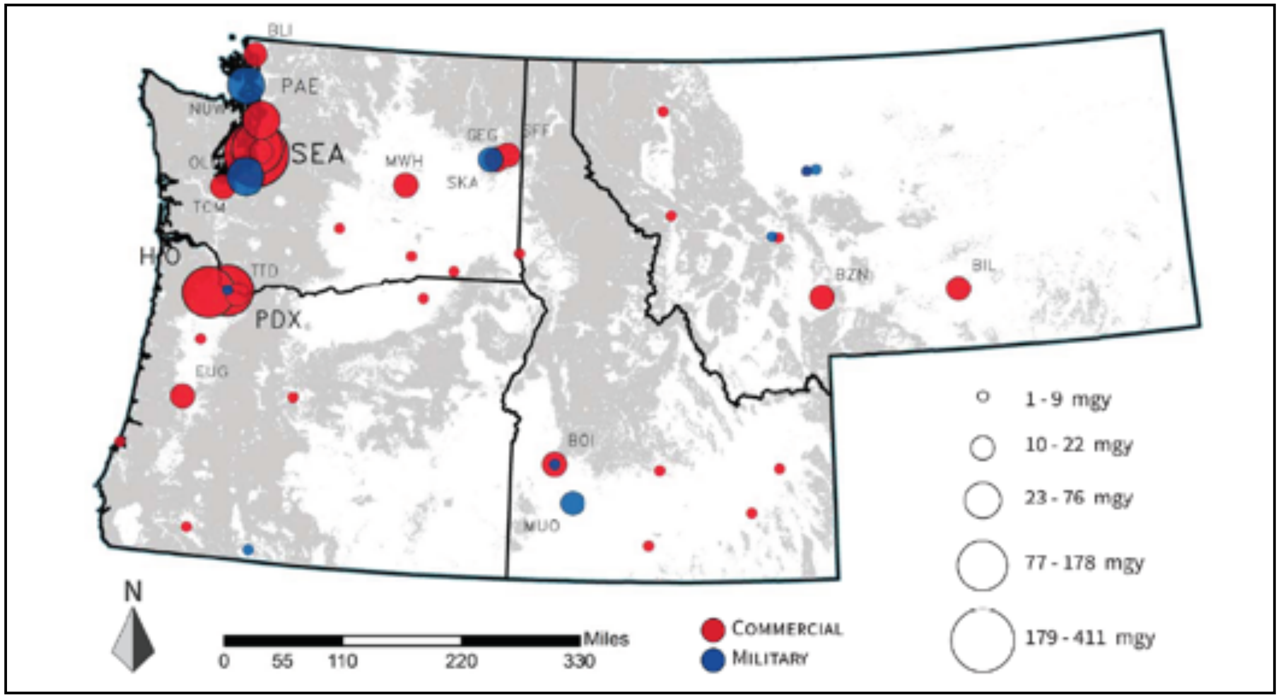


Figure E-3.2. Pacific Northwest Aviation Markets

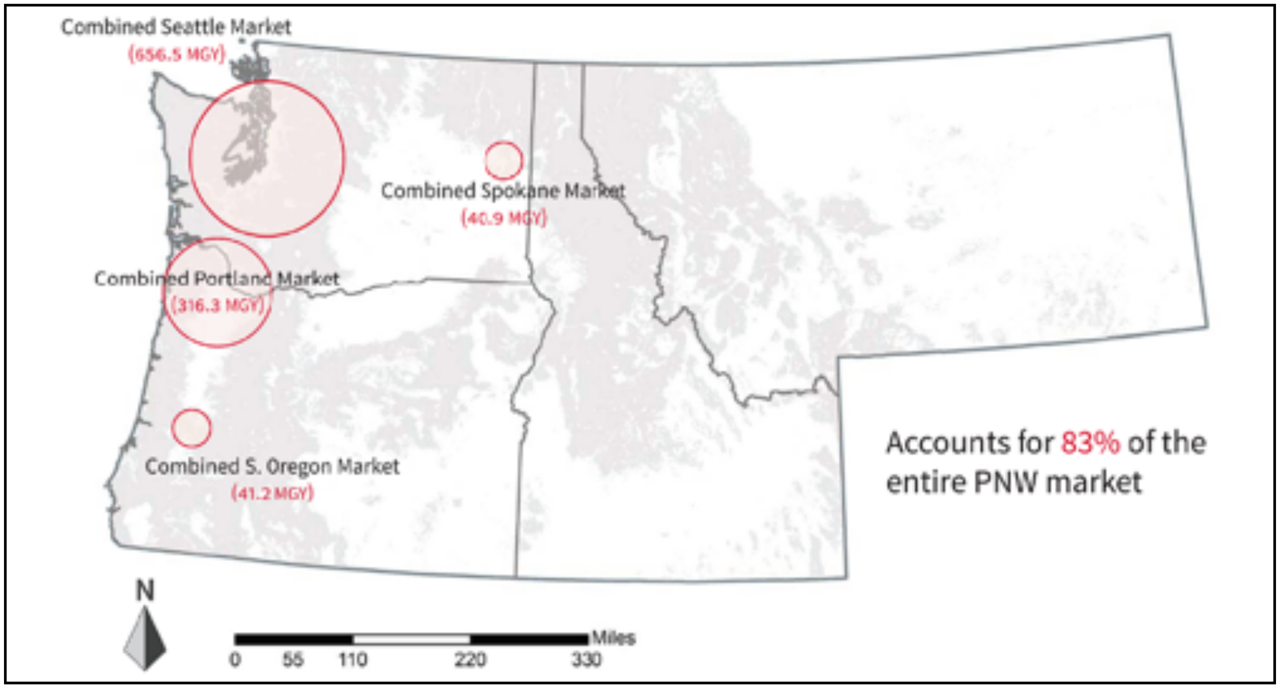


Figure E-3.3. Pacific Northwest Primary Jet Fuel Demand Centers sumption that an IBR, relying on direct haul required 770,000 BDT. However, in a distributed model, where solids or liquids depots supply a conversion facility, the feedstock supply per depot is less. IDX used 250,000 BDT per depot.

IDX further refined facility programming and volume calculations for various site operations and addressed the facility's proximity to the biojet market or demand centers. The original 770,000 BDT volume of biomass used in Years 1-3 analysis was "right-sized" for potential biojet fuel markets throughout the PNW region. This analysis worked backwards from the end of the supply chain, the customer, toward production and feedstock. Figure E-3.2 shows PNW markets; Figure E-3.3 shows PNW market demand.

Conversion efficiency of the current supply chain reports 45 gallons of iso-paraffinic kerosene (IPK) being produced from every bone-dry ton (BDT) of woody biomass. Assessing the local market fuel consumption and using this conversion value (45 gal/BDT) determines the necessary supply of forest residuals needed to sustain the current demand of aviation fuel. The Seattle and Portland demand could be sustained with 770,000 BDT of biomass annually. However, Spokane, Washington's international airport (GEG) consumes around 23 million gallons of jet fuel annually (Sustainable Aviation Fuels Northwest, 2011). Using a 50/50 blend of IPK and petroleum based fuel, GEG could be supported with around 256,000 BDT of woody biomass annually. Table E-3.1 shows the updated supply chain analyses for IDX studies completed in years 2-4.

Table E-3.1. Updated Supply Chain Analyses

IDX Study Year	NARA Sub-region	Model Analyzed	No. of Facilities	Market Demand	Biomass (BDT)
2	Western Montana Corridor (WMC)	Distributed solids depots	1 IBR	41 MG	<400,000
3	Mid-Cascade to Pacific (MC2P)	Distributed liquids (sugar) depots	1 IBR	973 MG	>770,000
3	MC2P	Centralized facility	1 IBR	973 MG	>770,000
4	Pacific Northwest	Centralized facilities (west of the Cascades)	2 IBRs	1,055 MG	>875,000
4	Olympic Peninsula	Centralized facility	1 Conversion	35 MG	<600,000
4	Northern Oregon	Centralized facility	1 Conversion	316 MG	TBD
4	Southern Oregon	Centralized facility	1 Conversion	41 MG	TBD
4	WMC revisited	Centralized facility	1 Conversion	41 MG	TBD

Physical and Intellectual Outputs

PHYSICAL

Database of pulp and paper mills and petroleum refineries in the PNW, with site and asset details.

REFEREED PUBLICATIONS

Martinkus, N., W. Shi, N. Lovrich, J. Pierce, P. Smith and M. Wolcott. 2014. Integrating biogeophysical and social assets into biomass-to-biofuel supply chain siting decisions. Biomass and Bioenergy. 66: 410-418. doi:10.1016/j.biombioe.2014.04.014

Laninga, T., S. Millman and K. Payne. 2014/2015. "From Wood to Wing: Opportunities to Build an Advanced Biofuels Industry in the Pacific Northwest Utilizing its Timber-based Assets." Western Planner. December/January. 35(5): 12-19. http://western-planner.org/wp-content/uploads/2012/03/2014_vol35_05_WesternPlanner_cover.jpg

RESEARCH PRESENTATIONS

Conference Presentations

Laninga, T. and K. Olsen. 2014. "Identifying Suitable Sites for Wood-based Biofuels Facilities in Western Oregon and Washington" (Presentation). Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29. https://www.youtube.com/watch?v=vxlgjQDBB8M

Laninga, T. 2014. NARA's Approach to Social Sustainability. Moderator. NARA Annual Meeting. Seattle, WA. September 16.

Martinkus, N. and M. Wolcott. Assessing Existing Plant Assets for Biorefinery Siting. NARA Annual Meeting. Seattle, WA. September 16.

Moroney, J. and T. Laninga. 2014. The Informed Stakeholder Assessment. NARA Annual Meeting. Seattle, WA. September 16.

Laninga, T. and J. Moroney. 2014. Wood to Wing: Stakeholder Perspectives on a Wood-based Biofuels Industry in the Northwest United States. Associated Collegiate Schools of Planning. Philadelphia, PA. November 1.

Poster Presentations

Laninga, T., M. Payne and S. Millman. 2014. "From Wood to Wing: Opportunities to build an advanced biofuels industry in the Pacific Northwest by utilizing its timber-based assets" (Poster). Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Savas, D., S. Strickler, Elias Hansen. 2014. NARA Liquid Depot. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

McIntyre, V., B. Beaudett, Liz Boyden, Liwei Huang. 2014. Site Specific Design for a Liquid Depot: Weyerhaeuser Bay City Log Yard in Aberdeen, WA. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Zednick, C., J. Bodolay, Jorge Jordan and Nick Kirsch. 2014. IDX- Solid Depot – Bradwood, OR. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Graves, L. 2014. MC2P Site Selection Methodology. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Graves, L., L. Fracas, T. Schlect, D. Irwin, J. Hightree, S. Yoon, M. Wang, Z. Krein. 2014. Site Specific designs for an Integrated biorefinery: Cosmo Specialty Fibers Incorporated in Cosmopolis, WA. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Potter, J. 2014. MC2P Supply Chain Analysis. Northwest Wood-based Biofuels and Co-Products Conference. Seattle, WA. April 29.

Millman, S., M. Payne and T. Laninga. 2014. From Wood to Wing: Opportunities to Build an Advanced Biofuels Industry in the Pacific Northwest Utilizing its Timber-based Assets. Poster. NARA Annual Meeting. Seattle, WA. September 16.

OTHER PUBLICATIONS

IDX. 2014. Mid Cascade to Pacific Analysis Document. http://nararenewables.org/midcascadesto-pacific/docs/Vol2-Analysis.pdf

IDX. 2014. Mid Cascade to Pacific Historical Overview http://nararenewables.org/midcascadestopacific/docs/Vol4-Historical.pdf

IDX. 2014. Mid Cascade to Pacific Supplemental Materials http://nararenewables.org/midcascades-topacific/docs/Vol5-Supplemental.pdf

IDX. 2014. Pacific Northwest Wood-based Biofuels Profile. http://nararenewables.org/pacificnorthwest/docs/Vol1-Profile.pdf

VIDEOS AND WEBINARS

IDX. 2014. Pacific Northwest Supply Chain - Site Selection Webinar. November 19. https://sites.google.com/a/idexstudio.org/class/live/past-webinars

IDX. 2014. Pacific Northwest Supply Chain – Preliminary Site Selection Webinar. October 20. https://sites.google.com/a/idexstudio.org/class/live/past-webinars

TRAININGS, EDUCATION AND OUTREACH MATERIALS

Laninga, T. 2014. "Wood-Based Aviation Biofuels Supply Chains." McCall Outdoor Science School Summer Teacher Workshop. June 17.

IDX Student Presentation. Biorefinery Sites. November 19, 2014. WSU News. https://news.wsu.edu/2014/11/17/nov-19-students-present-potential-biorefinery-sites/#.VHuYzGTF_Ak

TASK E-8: DISTRIBUTED SUGAR MODEL

Key Personnel	Affiliation
Jinwu Wang	Washington State University
Michael Wolcott	Washington State University

Task Description

This task aims to scope, develop and enable distributed production scenarios that can be cost-effectively operated for conversion of biomass to standardized feedstock or sugars. The primary aim of distributed production is to maintain small facility scales and decrease the complexity compared to an integrated biorefinery. Achieving these goals could potentially decrease biomass and labor costs while extending utilization of existing facilities. A techno-economic analysis (TEA) by the NARA systems metrics group in project years 1 and 2 projected that the cost of biomass feedstock contributes substantially to the overall production of biofuels. It is envisioned that decentralized sugar depots that locally transforms bulky biomass into cellulosic sugars provides potential for reducing the biomass transportation cost, which contributes substantially to the overall feedstock cost. If successful, a web of distributed sugar depots could become a key component in a forest residue supply chain for producing fuels. Such cellulosic sugars are versatile intermediate precursors, not only for producing fuels, but also developing valuable platform chemicals and polymers. They can be a “drop in” feedstock for existing and emerging ethanol plants worldwide in solid or syrup. Exploring opportunities to diversify NARA product portfolio to include cellulosic sugar intermediates can insulate from current uncertainties in advancing cellulosic biofuel markets.

Distributed sugar depots located in remote rural areas require a simple conversion process with low capital costs, decreased need for specialized workforce, and low environmental impact. In NARA Years 3 to 5, the feedstock and product characteristics and process performance necessary for analysis of technical feasibility and economical viability of a distributed sugar depot will be investigated in the context of realizing a cost-competitive cellulosic sugar production. We will use a pilot facility at WSU Composite Materials and Engineering Center (CMEC) to simulate the process and generate the necessary data to evaluate performance. A simulated sugar depot in the lab consists of a mechanical size reduction system, dispersive enzyme mixing with milled wood by a conical twin-screw extruder and subsequent enzymatic hydrolysis in a digester, and sugar stream separation and characterization. Specifically, woody biomass from a stakeholder mill in the East Washington and from one of municipal recycling facilities is hammer-milled into a targeted fineness and then pulverized for an optimal period of time. The mechanically activated wood meal is mixed with enzymes using a twin-screw extruder and digested in a reactor. The sugar stream is then separated and characterized.

Biomass comminution holds an analogy to ore comminution in the mining industry, in which about 50-70% energy used for mineral extraction is consumed on ore comminution (*Walkiewicz et al., 1989*). Mining engineering has developed algorithms and methodologies to design and scale-up comminution processes based on the lab-scale experimental data (*Herbst and Fuerstenau, 1980; Herbst et al., 1982; Man, 2001; Morrell and Man, 1997; Morrell, 2009*). For ore, primary size reduction is crushing, while for woody biomass, it is chipping or grinding. But late stages of comminution to the micro-scale level are quite similar to the tumbling mills used with ore. The cases, practices, designs, and process economic analysis in the mature mine comminution will be analyzed and tailored for biomass comminution. The algorithms will be developed linking small systems up to larger ones and used to project scale up production. Specifically, the relationships between comminution energy and product size is predicated on the assumption that the required energy for a differential decrease in size is proportional to the size change (dx) and inversely proportional to the size to some power n (*Jankovic et al., 2010*). One of explicit solutions describing size reduction follows a particular relationship as delineated by the well known “third theory” equation (*Bond, 1952*)): $W=W_i$ $(10/\sqrt{P}-10/\sqrt{F})$, where W is the specific energy expenditure at an industrial scale, Wi is the work index from the standardized laboratory grinding tests, P is the 80% passing size for the product, and F is the 80% passing size for the feed (*Morrell, 2008, 2004*). The total power for a commminution system in a sugar depot can then be projected according to the designed capacity (*Schlanz, 1987*). The potential industrial scale comminution systems will be identified based on the required comminution power.

A sugar depot that prepares biomass into readily fermentable sugars, and ships them to conversion facilities draws various categories of biomass from a smaller fibershed including forest residuals and construction and demolition (C & D) wood waste from municipal solid waste streams. Diversifying the biomass sources could be a way to mitigate supply risks and reduce the supply radius. The viability of sugar depots will be enhanced if they can process multiple feedstocks. The tolerance to feedstock variability and feedstock purity is thus evaluated. Methods and barriers of measuring purity levels are investigated.

This technology is selected because 1) preliminary tests by Weyerhaeuser in Year 2 demonstrated that pulverizing alone can be an effective means of pretreating wood for enzyme hydrolysis, 2) such an approach would eliminate the need for chemicals thereby decreasing environmental permitting, labor cost without a need for chemical engineers, and environmental burdens; 3) mechanical activation can be accomplished at low temperatures and generate fewer inhibitors compared to thermochemical pretreatments under combined action of chemicals, temperature, and pressure; and 4) twin-screw extrusion is a mature "plug and play" technology adaptable for all scales, for mixing, shearing, and processing of high solids concentration reducing water usage in a continuous process mode. The limitation is that this biomass-to-sugar conversion consumes a large quantity of electrical energy for milling. However, it may be a good choice in the Pacific Northwest, where electricity is relatively low cost and large quantities are generated from relatively clean hydro and wind powers. Relevant unit processes will be specifically investigated for energy requirements, evolution of carbohydrate content, digestibility, and sugar specifications. Other unit process alternatives will be identified and integrated to create a novel sugar production line appropriate for a sugar depot. Mechanical pretreatment in combination with moderate chemical treatment may be an alternative to generate synergistic effect to enhance digestibility and lower energy consumption.

EXPECTED TASK OUTPUTS

1) *Design milling systems to achieve desired fineness and sugar recovery rate and yield.* Douglas-fir wood chips from a lumber mill and the C & D wood from one of the municipal recycling facilities in the NARA region are shipped to the CMEC, which are then screened to remove impurities. The accepts are subjected to a two-stage milling: coarse and fine milling. Specifically, wood chips are comminuted to a specific size with a combining milling system, then to activated states with different types of pulverizing machines including ball mill and ring & puck mill in dry or wet modes, or in combination with moderate chemical loading. For the coarse milling, different types of milling circuit processes (closed- vs. open-circuit grinding) are designed and evaluated utilizing a pilot plant comprising two hammermills, one knife mill, and one screener in order to obtain the desired fineness for next stage pulverization. Design and operating variables are related to classification, circulating load, and circuit efficiencies. Energy requirements for milling Douglas-fir wood chips to an optimal fineness at a full-scale sugar depot are projected through a developed algorithm.

2) *Develop metrics to assess milling systems and define specifications of the ground materials.* Process metrics include specific electrical energy consumption, specific surface area increase, comminution ratio and efficiency. Product metrics include digestibility, size and size distribution, bulky density, aspect ratio, powder flow behavior, and slurry rheology. Principal breakup mechanisms (compression, tension, shear, and impact) and biomass breakage modes are investigated to provide an insight in designing innovative grinding and milling processes. Grinding performance parameters and modeling are to be learned from the comminution of the mineral ore.

3) *Design hydrolysis system and evaluate hydrolysis efficiency.* Milled wood meal and enzymes are extruded with a Cincinnati Milacron 55-mm conical twin-screw extruder; the extrudates are then enzymatic hydrolyzed in a digester. The process performance is evaluated in terms of energy requirement and sugar recovery.

4) *Separate and condense sugar stream, and define sugar specifications.* Sugar stream is processed into various product forms (granulate, powder, syrup, or separation of C5 and C6 sugars, crystalline, or amorphous) and characterized in terms of physical and chemical properties (chemical compositions, mixed sugar profile, inhibitors, fermentability etc.).

5) *Analyze sugar depot process economics.* Process economics from wood chips to sugars with respect to depot sizing and unit operations will be analyzed in a low lever techno-economical analysis. Information about comminution capital and operational costs will be collected from pulping and mining industries, literature, and through simulation based on lab experimental data.

6) *Summarize and report the findings.* The results are summarized and disseminated to the NARA leadership team and at the annual conference.

REFERENCES

Bond, F.C., (1952). The 3rd theory of comminution. Trans. Am. Inst. Min. Metall. Eng. 193, 484–494.

Herbst, J. & Fuerstenau, D. (1980). Scale-up procedure for continuous grinding mill design using population balance models. Int. J. Miner. Process., 7, 1–31.

Herbst, J., Rajamani, K., Mular, A. & Jergensen, G. (1982). Developing a Simulator for Ball Mill Scale-up-A Case Study: Design and Installations of Comminution Circuits. AL Mular GV Jergenseneds 325–342.

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D. & Aden, A. (2011). Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol (No. NREL/TP-5100-47764). National Renewable Energy Laboratory, Golden, Colorado 80401.

Jankovic, A., Dundar, H. & Mehta, R. (2010). Relationships between comminution energy and product size for a magnetite ore. J. South Afr. Inst. Min. Metall. 110, 141.

Kwiatkowski, J.R., McAloon, A.J., Taylor, F. & Johnston, D.B. (2006). Modeling the process and costs of fuel ethanol production by the corn dry-grind process. Ind. Crops Prod., 23, 288–296. doi:10.1016/j.indcrop.2005.08.004

Man, Y. (2001). Model-based procedure for scale-up of wet, overflow ball mills part I: outline of the methodology. Miner. Eng., 14, 1237–1246.

Morrell, S. (2009). Predicting the overall specific energy requirement of crushing, high pressure grinding roll and tumbling mill circuits. Miner. Eng., 22, 544–549. doi:10.1016/j.mineng.2009.01.005

Morrell, S. (2008). A method for predicting the specific energy requirement of comminution circuits and assessing their energy utilisation efficiency. Miner. Eng., 21, 224–233. doi:10.1016/j.mineng.2007.10.001

Morrell, S. (2004). Predicting the specific energy of autogenous and semi-autogenous mills from small diameter drill core samples. Miner. Eng., 17, 447–451. doi:10.1016/j.mineng.2003.10.019

Morrell, S. & Man, Y. (1997). Using modeling and simulation for the design of full scale ball mill circuits. Miner. Eng., 10, 1311–1327.

Schlanz, J.W. (1987). Grinding: An overview of operation and design (No. 87-31-P). North Carolina State University Minerals Research Laboratory.

Walkiewicz, J.W., Raddatz, A.E. & McGill, S.L. (1989). Microwave-assisted grinding, in: Industry Applications Society Annual Meeting, 1989., Conference Record of the 1989 IEEE. IEEE, pp. 1528–1532.

Activities and Results

A two-stage mechanical pretreatment of Douglas-fir wood has produced 6-kg of highly digestible milled wood. The process uses an industrial scale hammer mill to reduce the biomass to 230 µm and then employs a pilot planetary ball mill to further reduce the particle size to 30 µm while simultaneously disrupting the cell wall architecture and cellulose crystalline structure. The 6-kg milled wood has been hydrolyzed and fermented using Gevo's proprietary integrated fermentation technology platform. The theoretical sugar yield is comparable with a leading chemical pretreatment. The hydrolyzed mechanically pretreated wood possessed a very low growth inhibition, demonstrated by the ability to grow isobutanol producing yeast at 100% hydrolysate. In contrast, isobutanol producing yeast propagation growth is limited to a maximum of 40% of hydrolysate produced through a thermochemical pretreatment with an admixture of mock media. The dry milling pretreatment produced excellent hydrolysate with almost no impact on isobutanol producing yeasts growth and with enhancement on isobutanol production, all without any delay in isobutanol production. This indicates that clean sugar from the milled wood can be widely used in various bioconversion processes for high value bio-based product production. The sugar yields and specific energy consumptions of the milling and cellulosic sugar production have been measured and used for the techno-economics analysis of sugar and clean fuel lignin pellet productions. Based on current market price of sugar and wood pellet co-product, the preliminary techno-economic analysis indicates that cellulosic sugar production via the dry milling pretreatment route is competitive with the National Renewable Energy Laboratory's dilute acid corn stover process model (*Humbird et al., 2011, Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol*). Modeled on the dry milling corn ethanol production, we envision that dry milling could become a unique depot-size technology for biomass pretreatment and for sugar and lignin fuel production.

Several different lab-scale mills have been used to investigate the milling effects on disruption of the lignocellulosic structure and its influence on enzymatic digestibility and energy efficiency. Images produced from scanning electron microscopy showed that fiber cell walls were fragmented and the hierarchical structures of wood were disrupted with increasing milling time (Figure E-8.1). Multi-technique characterization of Douglas-fir cell wall disruption during mechanical milling was conducted using electronic microscopy (SEM, TEM), confocal laser scanning microscopy (CLSM), atomic force microscopy (AFM), and X-ray diffraction (XRD). Collectively, these techniques elucidate the evolution of cell wall changes. Coincident with the particle size reduction of the wood material during the milling process includes tissue disintegration, cell wall fragmentation, disordering of layered cell wall fragment, and aggregation of disordered cell wall fragments. As evidenced by CLSM, the constituent cell wall polymers are redistributed following the ultrastructure disruption from the mechanical milling. Micro/nano porous structures were visualized by 3D-TEM tomography. XRD results demonstrated the amorphization of the semicrystalline polymers. Cellulose crystallinity of the ball-milled samples gradually decreased with the progress of milling time and approached an amorphous state within 240-min (Figure E-8.2). Chemical compositions of the ball-milled samples did not change with milling time. Enzymatic digestibility increased with milling time and reached around 85% theoretical sugar yields under 120-min milling (Figure E-8.3). The surface and ultrastructure alternation of cell wall contribute to enhancement of enzymatic digestibility by 4-14 folds over that of untreated cell walls depending on the degree of milling pretreatment. Benefits of dry milling pretreatment without chemicals have been demonstrated by the absence of inhibitors in the sugar stream (Figure E-8.4) and an increased reactivity of the lignin residual (Figure E-8.5). Sole dry milling pretreatment led to a light-colored lignin residue (Figure E-8.5., Blank) that was hardened under heating at 103 0C (Figure E-8.5a) indicating its high reactivity and possible condensation, while other thermochemical treated residues produced a dark, loose sandy material apparently without polymerization under heating (Figure E-8.5b).

In the 2015 spring semester, four engineering major undergraduate students are participating in the research involving milling performance evaluation and characterization of feed and ground materials. A team of engineering undergraduate students is conducting process design for the dry milling pretreatment process in conjunction with a capstone project curricular requirement. The project is providing a rare opportunity for undergraduate students to solve the real world problems and acquire integrated design experience. One proposal based on preliminary results was submitted to the Manufacturing Machines and Equipment Program of the NSF Division of Civil, Mechanical and Manufacturing Innovation, titled as Advanced Knowledge That Enable a Cost-effective Dry Milling Pretreatment of Wood for Cellulosic Sugar Production. The grant has partially supported two Ph.D. dissertation projects and one M.S. thesis. Their thesis' titles are listed as follows: (1) Dry Milling Mechanical Pretreatment of Softwood for Enzymatic Hydrolysis at a Distributed Sugar Depot: Multi-Scale Assessment of Structural and Physicochemical Recalcitrance Disruption, 2) Size Reduction and Sulfite Pretreatment of Softwood for Efficient Hydrolysis and High Value Products Yield, and 3) Enhancing the Milled Wood Enzymatic Hydrolysis Through Post-Milling Kneading by a Torque Rheometer.

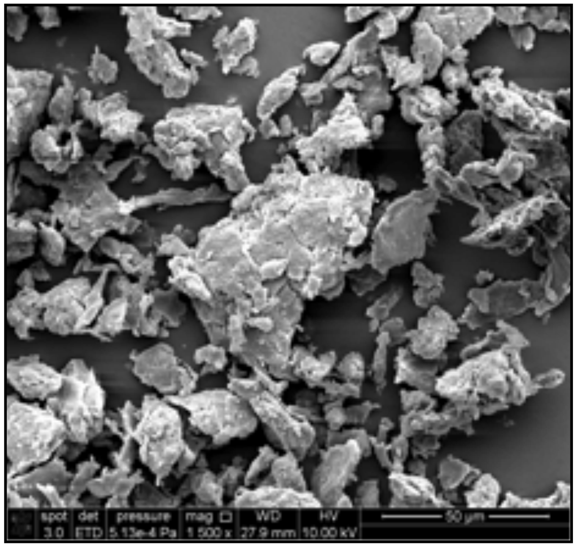


Figure E-8.1. Ball milling for 120min under ambient temperature led to the almost complete disappearance of discernible tissue structures (cell walls, lumens, pits and spiral thickenings).

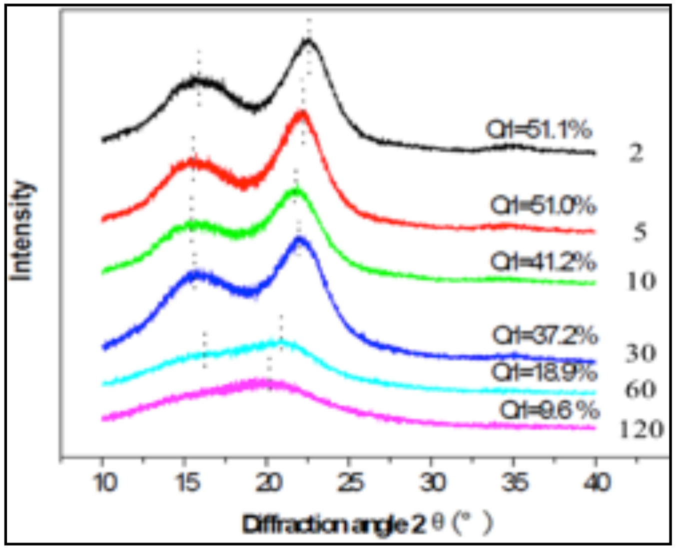


Figure E-8.2. Cellulose crystallinity index decreased with ball milling time under room temperature milling.

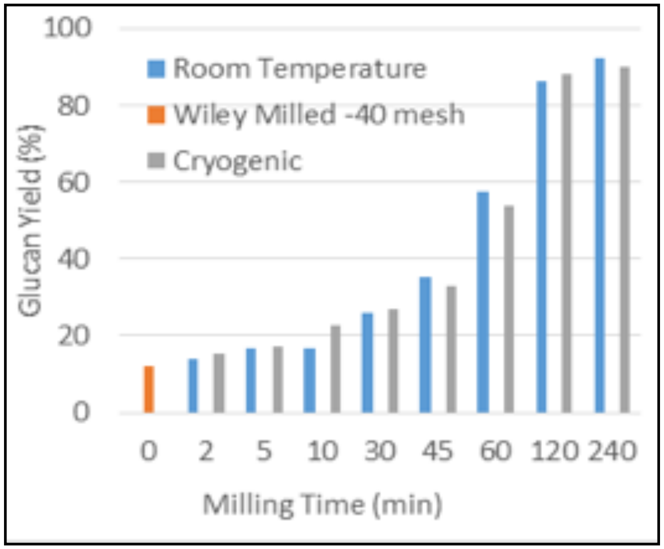


Figure E-8.3. Glucan yields of 72-hour enzymatic saccharification increased with the milling time under different milling conditions (Wiley knife milled, ball milled without controlling chamber temperature, and cryogenic milling)

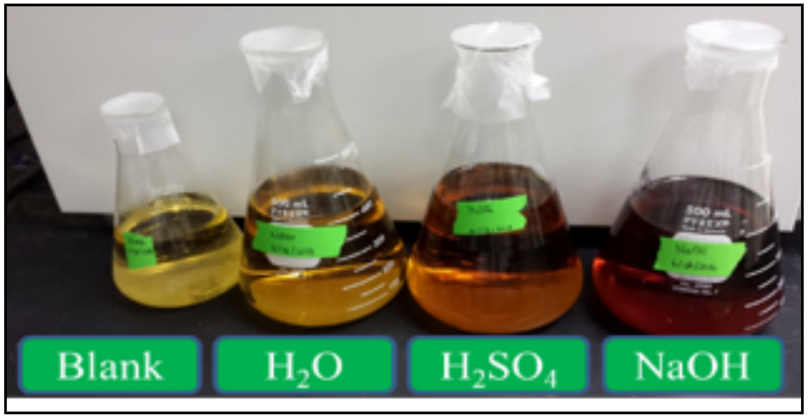


Figure E-8.4. Color difference of clarified enzymatic hydrolyzates. The light color of the hydrolyzate (Blank, mechanical pretreatment) indicated its less inhibitors, confirmed by smaller intensity at 280 nm (furfurals) and by the HPLC analysis.

Figure E-8.5. Wet lignin residues after vacuum filtration. The color of the lignin residual without chemical treatments (Blank) is lighter. After dried at 103 ^{0}C overnight, it hardened into chunks (a) while other thermochemical treated residues looked like loose sandy materials (b).

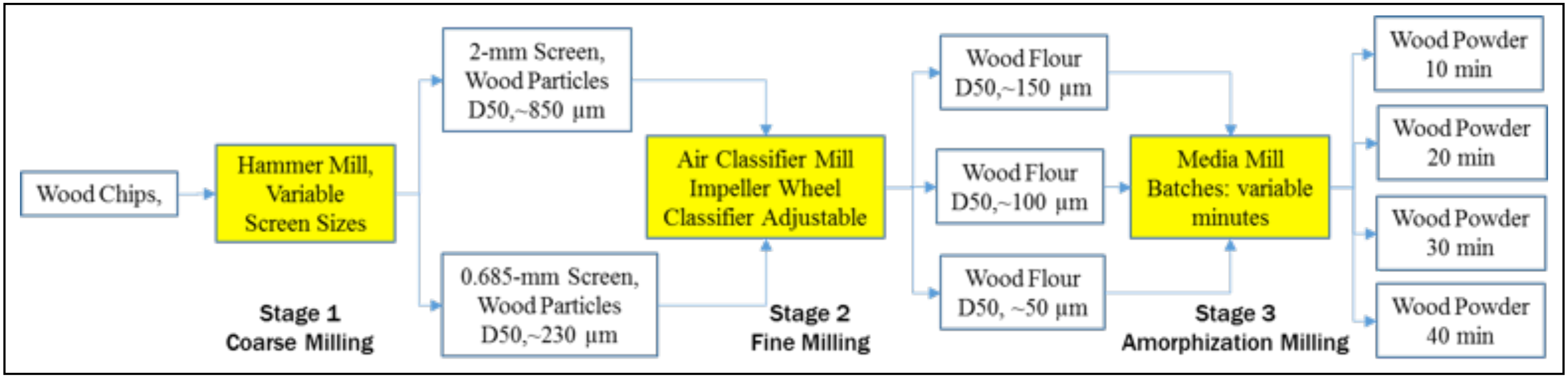


Figure E-8.6. An experimental design of the three-stage milling process for the dry milling mechanical pretreatment, D50, median particle size.

Recommendations | Conclusions

Conclusions

Several distinctive advantages of the mechanical pretreatment have been proved including generating pure and clean sugar stream with substantial less inhibitory compounds to subsequent fermentation, producing reactive lignin residues with little chemical alteration, using substantial less water, and minimizing capital and operational costs. Wood milling presents a promising alternative wood deconstruction method to produce fermentable sugar for biofuel applications and shows the potential to be deployed in a distributed sugar depot system.

Recommendation 1: Evaluate an industrial scale three-stage milling process for production of highly digestible wood.

Coarse milling of wood to 400 µm typically uses a hammer mill due to its high efficiency. However, the existing wood industry does not have experience in micronizing wood to a median size of 20 µm nor does it disrupt cellulose crystalline structure on a large scale. The dry milling pretreatment has been found to be an energy intensive if accomplished by using one comminution mechanism to reduce wood chips into amorphous digestible powders. This is an area to which we are expected to bring superfine comminution technologies and innovations from mineral and chemical milling science to innovate a cost-effective solution to biomass micronization. A three-stage milling process, namely coarse, fine, and amorphization milling has been designed to take advantages of different size reduction principles to decrease milling energy and cost (Figure E-8.6). Size reduction is achieved by the hammer mill and the air classifier mill; disruption of the cell wall ultrastructure, cellulose crystalline structure, and lignocellulosic polymer assemblies are achieved by the media mill or a compression mill. The architecture and construction of a hammer mill and an air classifier mill systems are designed to break down particles with minimum friction heating, whereas an air classifier mill is more efficient than a hammer mill below 200 µm. A media mill induces the breakage across microfibril orientation due to the high amount of compressive force that disrupts the cellulose crystalline structure and reduces the recalcitrance to enzymatic hydrolysis. In NARA Year-5, a ACM 15 air classifier mill (Hosokawa Micron Powder Systems, Summit, NJ) will be used for stage 2 fine milling, and stage 3 amorphization milling will be tested with a VikroKinetic Energy Mill (Micro Grinding Systems, Inc., Little Rock, AR), a compression milling (to be identified), and an eccentric vibrating mill (TEMA Systems, Cincinnati, OH). The companies have agreed to provide services with minimum cost charges. These milling machines were identified among a large pool of comminution technologies for their great potential to be successful in the new process. The data is then analyzed, reduced, and modeled to provide a comprehensive understanding and new insights of process design and engineering of the dry milling mechanical pretreatment.

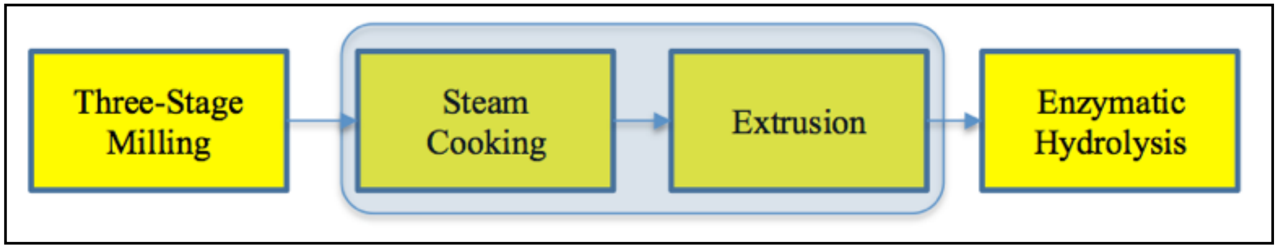


Figure E-8.7. Post-Milling Treatments

Recommendation 2: Enhance enzymatic saccharification through post-milling extrusion and steam injection cooking.

The mechanical pretreatment through the three-stage milling process is expected to render wood to be highly digestible. To reduce the requirements of the milling process, we have investigated additional post-milling physical treatments under the NARA Year 4 task (Figure E-8.7). Until now, the initial results demonstrated that post-milling extrusion treatments of the milled wood greatly unfold the structures in wood particles, dramatically increase dissolution in water, and increase viscosity of slurry. These observations show that post-milling treatments have a great potential to improve sugar yield and reduce requirements to the milling process. For the NARA Year-5 task, this study will optimize extrusion parameters such as compression ratio, screw speed, screw elements, and barrel temperature as well as water content on the sugar recovery in tandem with a digester. In addition, we have installed and commissioned the use of a direct steam injector in collaborating with an investigator in the WSU Food Science Department. Steam cooking is a unit process after hammer milling of corn in the dry milling corn ethanol production. Modeled on this process, we will also investigate the effect of post milling steam cooking of the digestible milled wood on its physiochemical properties and digestibility.

Recommendation 3: Improve milling efficiency through chemical-assisted milling.

Chemical grinding aids or additives to the mill during grinding can minimize the effects of moisture in the feed material, function as a lubricant between particles to prevent agglomeration, reduce grinding energy, and/or enhance the downstream sugar yield, or effect on powder property development.

Recommendation 4: Characterize and valorize saccharification residual solids (SRS) obtained from the enzymatic hydrolysis of the mechanical pretreated wood.

One distinctive advantage of the mechanical disruption of biomass recalcitrance over chemical pretreatments is the potential to persevere the physiochemical properties of native lignin. It is worthwhile to characterize this lignin residue and find its potential application. We are expected to fractionate SRS, extract powdered alpha-cellulose and nanocellulose and characterize and valorize the purified lignin.

Physical and Intellectual Outputs

PHYSICAL

- 6 kg hydrolysable milled wood powder was produced and characterized
- 2 kg saccharification residual lignin solids were obtained
- Industrial milling trial sites were established

RESEARCH PRESENTATIONS

1. Jiang, J.X., Wang, J.W. and Wolcott, M.P. 2014. The Development of Physical Properties and Correlation of Feed and Product Sizes and Energy Consumption During Vibratory Ring & Puck Fine Milling of Douglas-fir Wood Particles, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014

2. Liu, Y.L., Wang, J.W. and Wolcott, M.P. 2014. Size Effect on Mild bisulfite pretreatment performance on Douglas-fir, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014

3. Liu, H.N., Wang, J.W. and Wolcott, M.P. 2014. Effect of Initial Mixing on Enzymatic Hydrolysis of Ball Milled Wood, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014

4. Seals, R., Wu, E., Jiang, J.X., Liu, Y.L., Liu, H.N., Wang, J.W. and Wolcott, M.P. 2014. Testing Residual Lignin as an Binder for Wood Pellets, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014

5. Wu, E., Seals, R., Jiang, J.X., Liu, Y.L., Liu, H.N., Wang, J.W. and Wolcott, M.P. 2014. Ball Milling: Effective Pretreatment Leading to A Clean Cellulosic Sugar Conversion, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014

6. Zhou, X., J. Wang and M. Wolcott. 2014. Evaluating the Use of Ball-milling on the Douglas-fir Particles, Poster at the Annual Meeting of Northwest Advanced Renewables Alliance, Seattle, WA, Sep. 15-17, 2014
7. Eileen Wu, Rodney Seals, Jinwu Wang, Michael Wolcott, Yalan, Liu, Jinxue, Jiang, and Huinan Liu. 2014. Ball milling: effective pretreatment leading to a clean biomass to cellulosic sugar conversion, The WSU Summer 2014 Undergraduate Research Poster Symposium

8. Rodney Seals, Eileen Wu, Jinwu Wang, Michael Wolcott, Yalan, Liu, Jinxue, Jiang, and Huinan Liu. 2014. Lignin residue as wood pellet binder and energy enhancer for energy applications, The WSU Summer 2014 Undergraduate Research Poster Symposium

SUBTASK E-8: DISTRIBUTED SUGAR MODEL

Key Personnel	Affiliation
Xiao Zhang	Washington State University

Task Description

This subtask will conduct a techno-economic analysis (TEA) to determine process economics and identify the economics bottlenecks in the distributed sugar depot model based on pulverized wood. SuperPro Designer software will be used to construct TEA model of a distributed sugar depot. A schematic illustration of the main unit operations and process flow is shown in Figure SubE-8.1. SuperPro Designer has gained increasing use for applications in TEA simulation of biomass conversion processes. Several TEA models of a lignocellulosic biorefinery using SuperPro Designer have been recently developed by DOE Joint BioEnergy Institute (JBEI)1,2. SuperPro Designer incorporates several mechanical treatment unit operations (e.g. grinding, shredding, nano and high pressure milling) that are applicable to the main process steps in the distributed sugar depot process. However the default cost estimates in SuperPro associated with these unit operations are not currently based on wood as substrates. Mechanical deconstruction of woody biomass and ore comminution are common technologies used in the paper and mining industries respectively. We will identify appropriate equipment and associated cost data to be incorporated into SuperPro Designer. Dr. Zhang has a considerable amount of experience with pulping processes and biomass deconstruction methods. In this project, we will work with paper and mining companies to obtain commercial operational data in feedstock procurement, handling, transportation, storage and associated equipment as well as operational cost in pulping and cost of environmental compliances for a typical biorefinery.

In this subtask, we will first construct a SuperPro Designer model to simulate the process shown in Figure E-8.1. We will then work with Drs. Wang and Wolcott's team to import the data and metrics developed from lab studies on mechanical treatment and high consistency enzymatic hydrolysis. Several scenarios will be established to compare different size reduction technologies (grinding, shredding, milling etc.) and process configuration in order to optimize energy efficiency, substrate digestibility and process economics. A graduate student will be working on this subtask supervised by Drs. Zhang, Wang, and Wolcott.

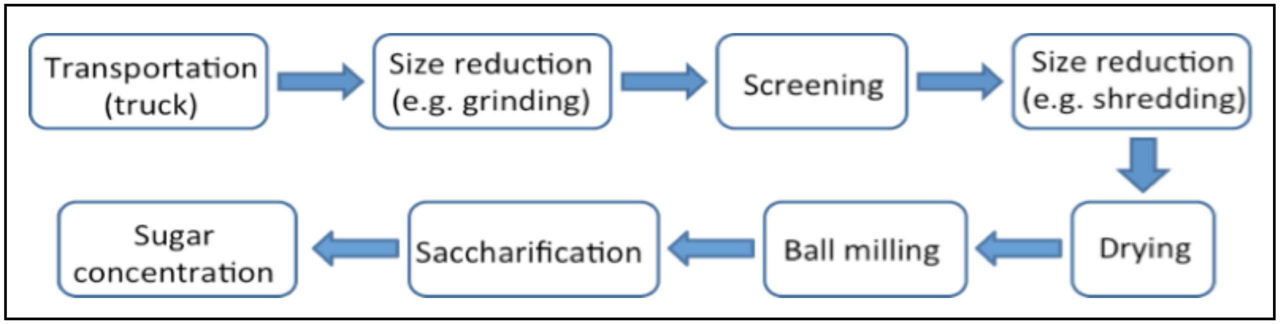


Figure SubE-8.1. A schematic illustration of main unit operations and process flow in a distributed sugar depot.

REFERENCES

1. Klein-Marcuschamer, D., Oleskowicz-Popiel, P., Simmons, B. A., Blanch, H. V. "Technoeconomic analysis of biofuels: A wiki-based platform for lignocellulosic biorefineries," Biomass and Bioenergy (2010), 34(12):1914–1921
2. Klein-Marcuschamer, D., Simmons, B. A., Blanch, H. V. "Techno-economic analysis of a lignocellulosic ethanol biorefinery with ionic liquid pre-treatment," Biofuels, Bioproducts, & Biorefining (2011); 5(5):562–569

Activities and Results

A process flow model of a distributed sugar depot was constructed in SuperPro Designer as a base case test model, sized to an operating throughput of 250,000 tons/year (Figure SubE-8.2). The appropriate primary unit operations were evaluated, and established with specifications based on industry standards and pilot scale data. Process parameters for the milling operation and hydrolysis conversion were informed by ongoing lab tests. Equipment sizing was generated by the SuperPro program, supplemented with vendor data. Combined with the calculated mass and energy balance, this allowed for preliminary evaluations of the factors contributing to the total cost as different unit operation scenarios were considered.

The initial results have shown that:

1. SuperPro is suitable for evaluating this model and is unique compared to Aspen in its built in unit operations appropriate for mechanical treatment based bioconversion process.

2. TEA analysis by SuperPro can provide insight in delineating the cost factors of the process, allowing for better optimization of the depot conversion process.

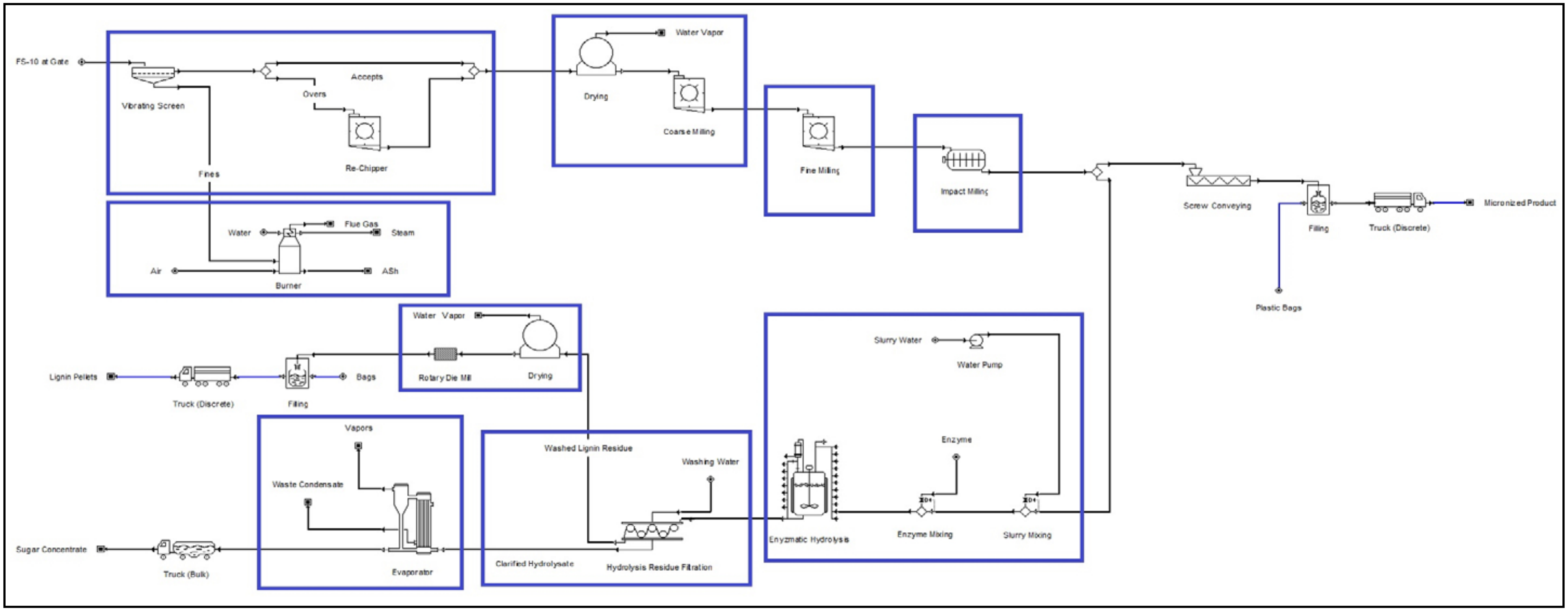


Figure SubE-8.2. A process flow model of a distributed sugar depot

Recommendations | Conclusions

Preliminary TEA analysis with SuperPro has shown that the sugar depot refinery model has several potential advantages over large-scale stand-alone biorefinery facility. The lack of chemical pretreatment not only removes the operating costs associated with chemical treatment and neutralization, it also eliminates the need for corrosive resistant reactors, greatly reducing the CAPEX associated with these processes. Evaluation of the output streams suggests that process water needs little additional processing, eliminating the need for a dedicated wastewater treatment facility. The simplified process flow allows for more flexible operability, and the compartmentalization of the primary unit operations allows for the exploration of alternative uses for the product streams.

Our work in the next year is to refine the SuperPro TEA model by improving the detail of the unit operations and completing ancillary areas such as emissions control, feed handling, and heat recovery. Furthermore, continued investigations in milling and hydrolysis technologies will update the model with more accurate energy requirements and conversion factors. We plan to survey several typical scenarios of sugar depot operations in detail, accounting for variations in feed composition, depot location, feedstock supply chain and market demands. As we fine tune our process specifications, we will construct the model in ASPEN Plus to validate the thermodynamic calculations.

Physical and Intellectual Outputs

A SuperPro based TEA model was constructed.

TASK E-7: FEEDSTOCK SUPPLY CHAIN ANALYSIS - MSW

Key Personnel	Affiliation
Karl Englund	Washington State University

Task Description

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 and accessible inventory of the woody 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.

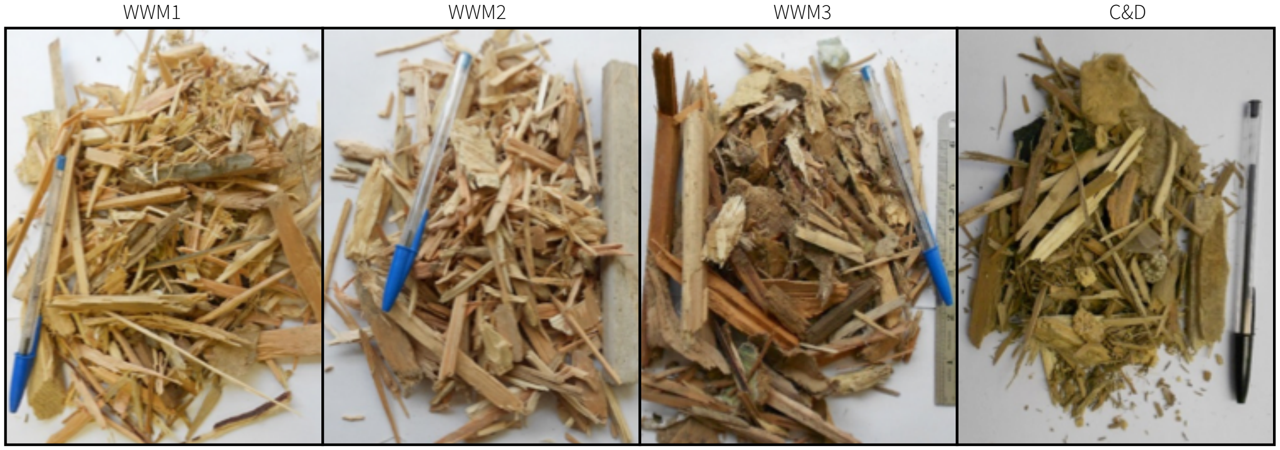


Figure E-7.1. Images of the materials (as received) used for the study.

Activities and Results

The work in the last year has been focused on characterizing waste wood residues from three material recovery facilities (MRFs) in the NARA region for their potential use as a feedstock for the production of sugars/biofuels via enzymatic hydrolysis. Four samples of the various MRFs (Figure E-7.1) have been characterized to determine ash content, presence of metals and alkalines, elemental composition, and carbohydrates content. Results showed that, when compared with “clean” wood (ponderosa pine–PPine and sugar maple–SMaple), some of the MRF wood specimens i) contained high amounts of ash (Table E-7.1), ii) possessed high amounts of alkalines and metals, including heavy metals (Figure E-7.2), and iii) showed carbohydrates content that is in the range of values reported in literature (Table E.7.1). No sulfur was detected in the samples (Table E-7.2).

For sugars production, the process consisted of acid pretreatment (SPORL process at 165°C, 75 min) followed by enzymatic hydrolysis. The materials were first classified to remove both large and relatively small particles by using two sieves with 25 and 12.5 mm holes dimensions. This process helped to remove some contaminants, especially earth and rocks, which would likely be done at a potential biorefinery. The pretreatment was performed in a 1-liter Parr reactor, using 40 g of wood for each run (in duplicate), and acid solution (9.8% H_2SO_4 and 4.6% $NaHSO_3$ (w/w, odb). The solution/wood ratio was 3:1. Since the tests showed that it takes a relatively long time to reach the set temperature for the process, the degradation that occurs during the preheating step was corrected using a time-temperature correction factor (tT). Activation energy of the feedstocks used for tT computation was 180000 kJ/mol. Yields of pretreated solids were: 78.7% for WWM1, 85.9% for WWM2, 80.3% for WWM3, and 81.6% for C&D.

After pretreatment the solids were washed with tap water and the prehydroysate was collected for sugars content determination. The washed pretreated solids were dried (70°C, 24 h), ground (40 mesh), and subjected to enzymatic hydrolysis. The enzymatic hydrolysis process was conducted at 10% (w/w) solids concentration in 250 mL flasks, using a 50 mM buffer acetate, and adjusted to pH~5. Enzyme loadings were 5% of CTec2 and 0.5% of HTec2 enzymes (dry pretreated wood basis). The process occurred at 50°C and 200 rpm, for 72 h. An aliquot of the hydrolysate of each sample was collected for analyses. Both the hydrolysate and prehydrolysate were characterized using Ion Chromatography.

Carbohydrates content of both the raw materials and the pretreated solids was determined following the NREL method. These results were used for computing the yields of sugars obtained via enzymatic hydrolysis. Although most results are available, computations for the mass balance of the sugars production are in progress. In addition, a paper showing the results is being prepared. It appears that removal of small particles, as required for the SPORL pretreatment, helps to limit the presence of alkalines and heavy metals in MRFs used for sugars production.

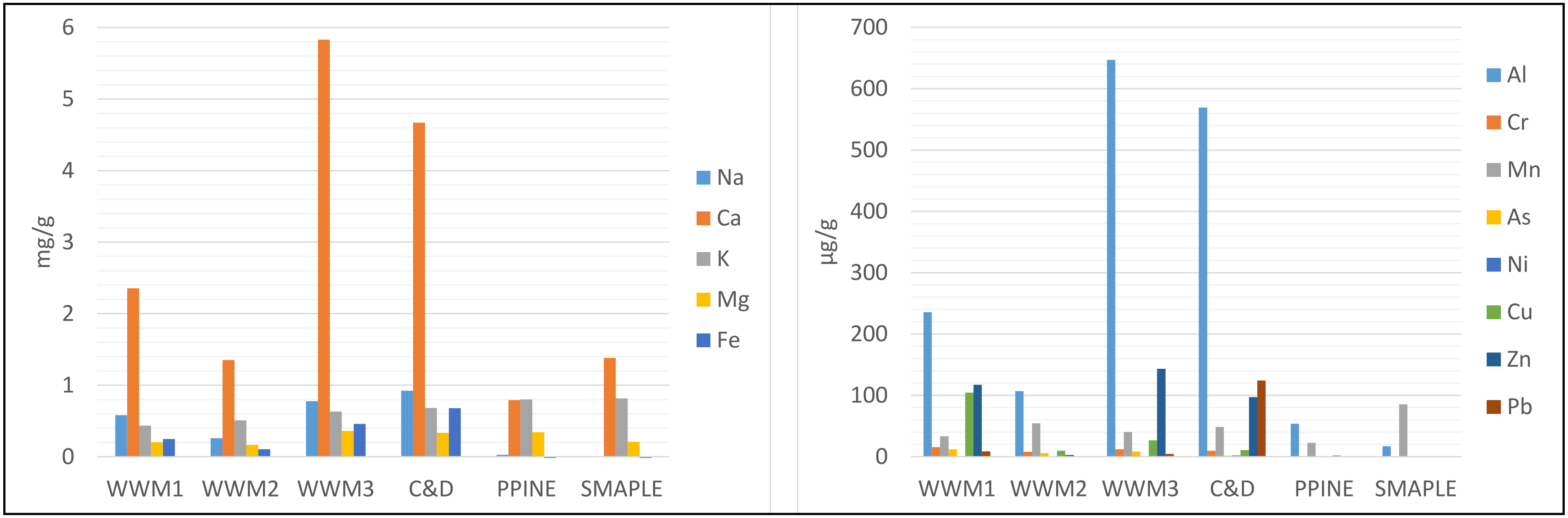


Figure E-7.2. ICP-MS results. It is observed that MRFs contain higher percentages of alkalines and metals than ponderosa pine and sugar maple (which were used for comparison). Presence of small amounts of Pb in C&D (right) could result from the presence of paints in this sample.

Table E-7.1. Feedstock carbohydrate composition and ash content (%, material as received)

Polymer sugar of biomass	WWM1	WWM2	WWM3	C&D
Arabinan (%)	0.78	0.95	0.70	0.84
Galactan (%)	2.49	2.38	1.79	2.40
Glucan (%)	43.22	45.57	43.87	41.69
Xylan/Mannan (%)	14.40	15.50	15.21	14.75
Total carbohydrates (%)	60.88	64.41	61.58	59.67
Ash (%)	1.3	0.7	3.4	2.8

Table E-7.2. Elemental composition of the samples used in this work (in ash and moisture free basis). Composition of ponderosa pine and sugar maple is provided for comparison only.

Sample	C (%)	H (%)	N (%)	O* (%)
WWM1	48.72±0.73	5.64±0.06	0.44±0.02	45.20±0.79
WWM2	46.01±0.98	5.42±0.09	0.19±0.01	48.38±1.07
WWM3	42.26±0.77	5.08±0.08	0.42±0.01	52.24±0.86
C&D	49.79±0.07	5.74±0.01	0.84±0.02	43.63±0.04
Sugar maple	48.94±0.16	5.88±0.15	0.25±0.04	44.93±0.05
Ponderosa pine	50.44±0.41	6.36±0.03	0.19±0.01	43.01±0.44
Note: No S was detected in the samples analyzed.				

* By difference.

Recommendations | Conclusions

Much of the work in the last four months will be validated with repeat runs to ensure accurate data. We will continue to provide more analysis of the feedstock and submit a referred journal article sometime this summer on the results provided. We will also identify a pathway and the logistics to identify the renewable content for RINS credits with this material.

Physical and Intellectual Outputs

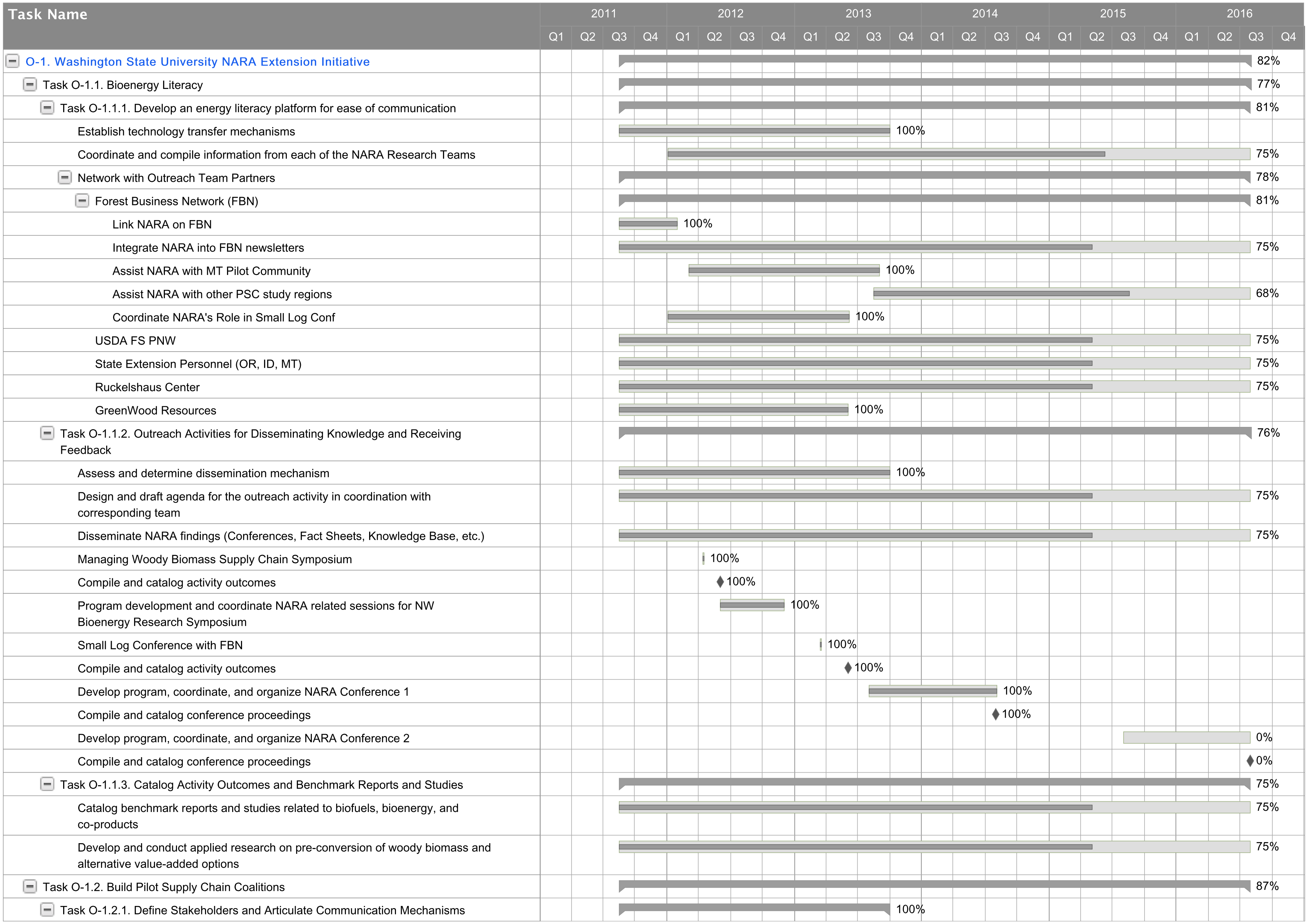
PHYSICAL

- 4 residue streams from 3 stakeholders in the NARA region are being analyzed for a potential feedstock in Biojet

RESEARCH PRESENTATIONS

Pelaez-Samaniego, M.R. and K. Englund. Characterization of waste wood materials for the production of biofuels. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

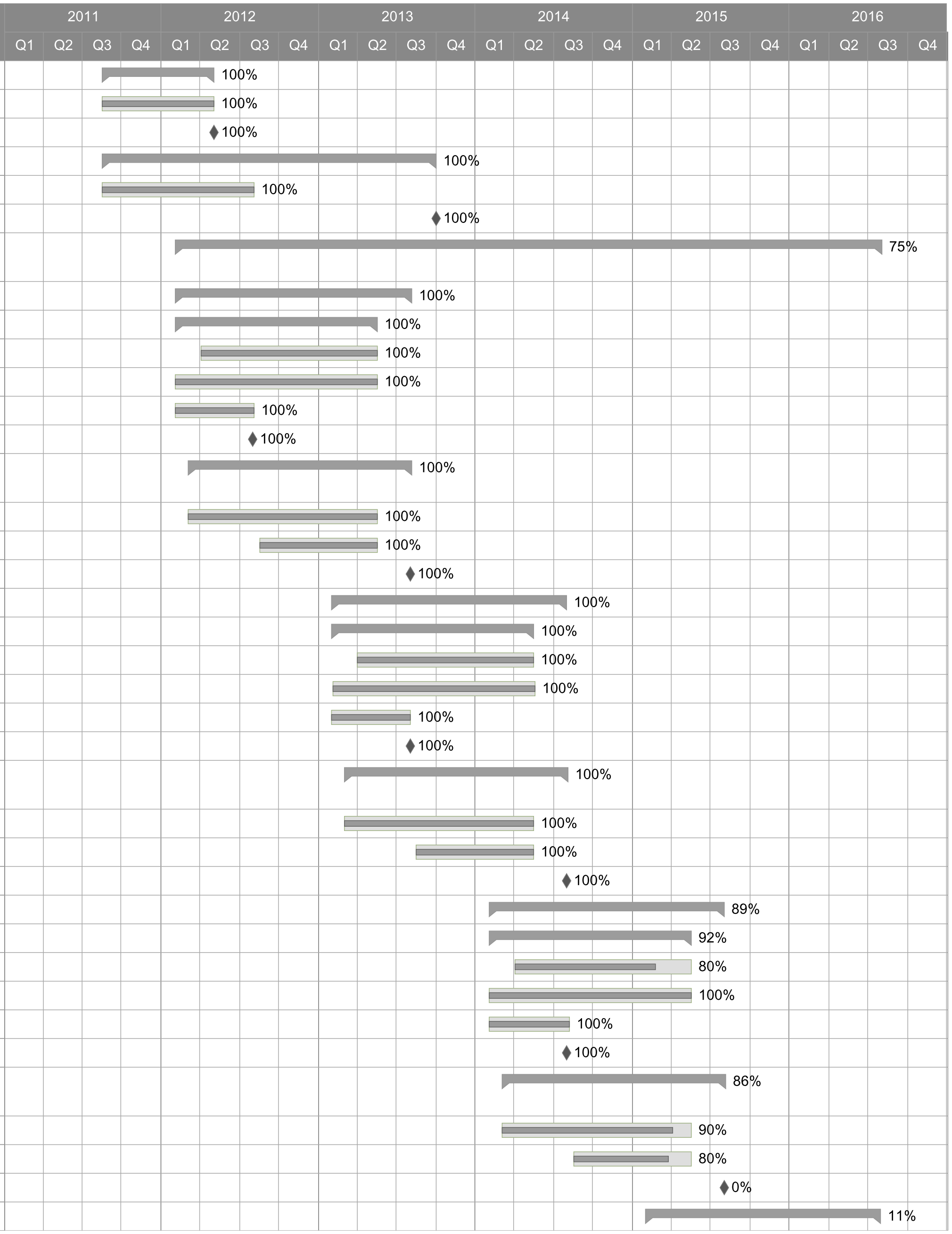
Outreach_Yadama_Englund



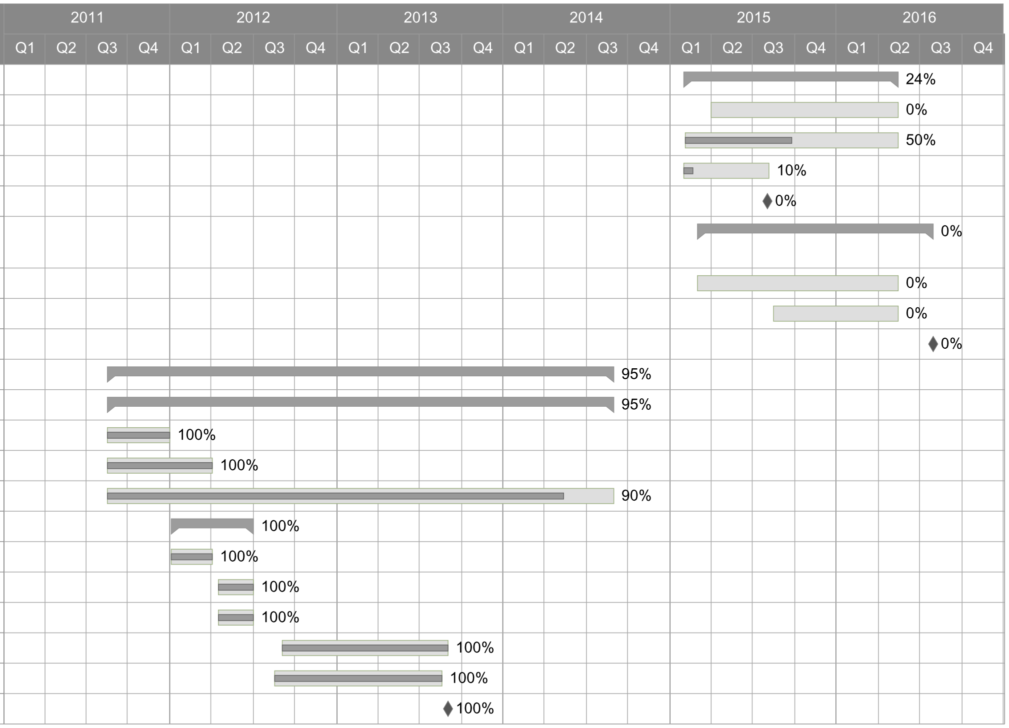
	Task Name	
1	O-1. Washington State University NARA Extension Initiative	82%
2	Task O-1.1. Bioenergy Literacy	77%
3	Task O-1.1.1. Develop an energy literacy platform for ease of communication	81%
4	Establish technology transfer mechanisms	100%
5	Coordinate and compile information from each of the NARA Research Teams	75%
6	Network with Outreach Team Partners	78%
7	Forest Business Network (FBN)	81%
8	Link NARA on FBN	100%
9	Integrate NARA into FBN newsletters	75%
10	Assist NARA with MT Pilot Community	100%
11	Assist NARA with other PSC study regions	68%
12	Coordinate NARA's Role in Small Log Conf	100%
13	USDA FS PNW	75%
14	State Extension Personnel (OR, ID, MT)	75%
15	Ruckelshaus Center	75%
16	GreenWood Resources	100%
17	Task O-1.1.2. Outreach Activities for Disseminating Knowledge and Receiving Feedback	76%
18	Assess and determine dissemination mechanism	100%
19	Design and draft agenda for the outreach activity in coordination with corresponding team	75%
20	Disseminate NARA findings (Conferences, Fact Sheets, Knowledge Base, etc.)	75%
21	Managing Woody Biomass Supply Chain Symposium	100%
22	Compile and catalog activity outcomes	100%
23	Program development and coordinate NARA related sessions for NW Bioenergy Research Symposium	100%
24	Small Log Conference with FBN	100%
25	Compile and catalog activity outcomes	100%
26	Develop program, coordinate, and organize NARA Conference 1	100%
27	Compile and catalog conference proceedings	100%
28	Develop program, coordinate, and organize NARA Conference 2	0%
29	Compile and catalog conference proceedings	0%
30	Task O-1.1.3. Catalog Activity Outcomes and Benchmark Reports and Studies	75%
31	Catalog benchmark reports and studies related to biofuels, bioenergy, and co-products	75%
32	Develop and conduct applied research on pre-conversion of woody biomass and alternative value-added options	75%
33	Task O-1.2. Build Pilot Supply Chain Coalitions	87%
34	Task O-1.2.1. Define Stakeholders and Articulate Communication Mechanisms	100%

Exported on April 23, 2015 3:22:45 PM PDT

	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	75%
42	1st Pilot Supply Chain Study(PSC) Region	100%
43	Coordinate with and assist Education team in the 1st PSC (WMC)	100%
44	Compile pilot community resources and assets	100%
45	Identify and engage key SHs	100%
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	100%
49	Compile a list of regional SHs	100%
50	Disseminate PSC research findings	100%
51	Document PSC study findings Region 1	100%
52	2nd Pilot Supply Chain Study(PSC) Region	100%
53	Coordinate with and assist Education team in the 2nd PSC	100%
54	Compile pilot community resources and assets	100%
55	Identify and engage key SHs	100%
56	Determine/develop community Leadership Team	100%
57	Leadership Team formed/identified	100%
58	Form regional coalitions and assist Education and EPP teams 2nd PSC region with data collection and SH engagement	100%
59	Compile a list of regional SHs	100%
60	Disseminate PSC research findings	100%
61	Document PSC study findings Region 2	100%
62	3rd Pilot Supply Chain Study(PSC) Region	89%
63	Coordinate with and assist Education team in the 3rd PSC	92%
64	Compile pilot community resources and assets	80%
65	Identify and engage key SHs	100%
66	Determine/develop community Leadership Team	100%
67	Leadership Team formed/identified	100%
68	Form regional coalitions and assist Education and EPP teams 3rd PSC region with data collection and SH engagement	86%
69	Compile a list of regional SHs	90%
70	Disseminate PSC research findings	80%
71	Document PSC study findings Region 3	0%
72	4th Pilot Supply Chain Study(PSC) Region	11%



	Task Name	
73	Coordinate with and assist Education team in the 4th PSC	24%
74	Compile pilot community resources and assets	0%
75	Identify and engage key SHs	50%
76	Determine/develop community Leadership Team	10%
77	Leadership Team formed/identified	0%
78	Form regional coalitions and assist Education and EPP teams 4th PSC region with data collection and SH engagement	0%
79	Compile a list of regional SHs	0%
80	Disseminate PSC research findings	0%
81	Document PSC study findings Region 4	0%
82	Task O-1.2.3. Assist EPP with PSC Selection Process and Support Index Study	95%
83	Coordinate with EPP in PSC Selection	95%
84	Develop criteria for selection	100%
85	Develop PSC selection process	100%
86	Assist compiling community resources and assets for GIS development	90%
87	Develop long-list of potential PSC regions in the region	100%
88	Develop and survey NARA Outreach members to nominate PSC regions	100%
89	Conduct and analyze the survey results	100%
90	Compile long list of PSC regions	100%
91	Assist EPP with surveys in potential PSC regions	100%
92	Assist EPP to synthesize and analyze assets of PSC regions	100%
93	Identify potential PSC regions	100%

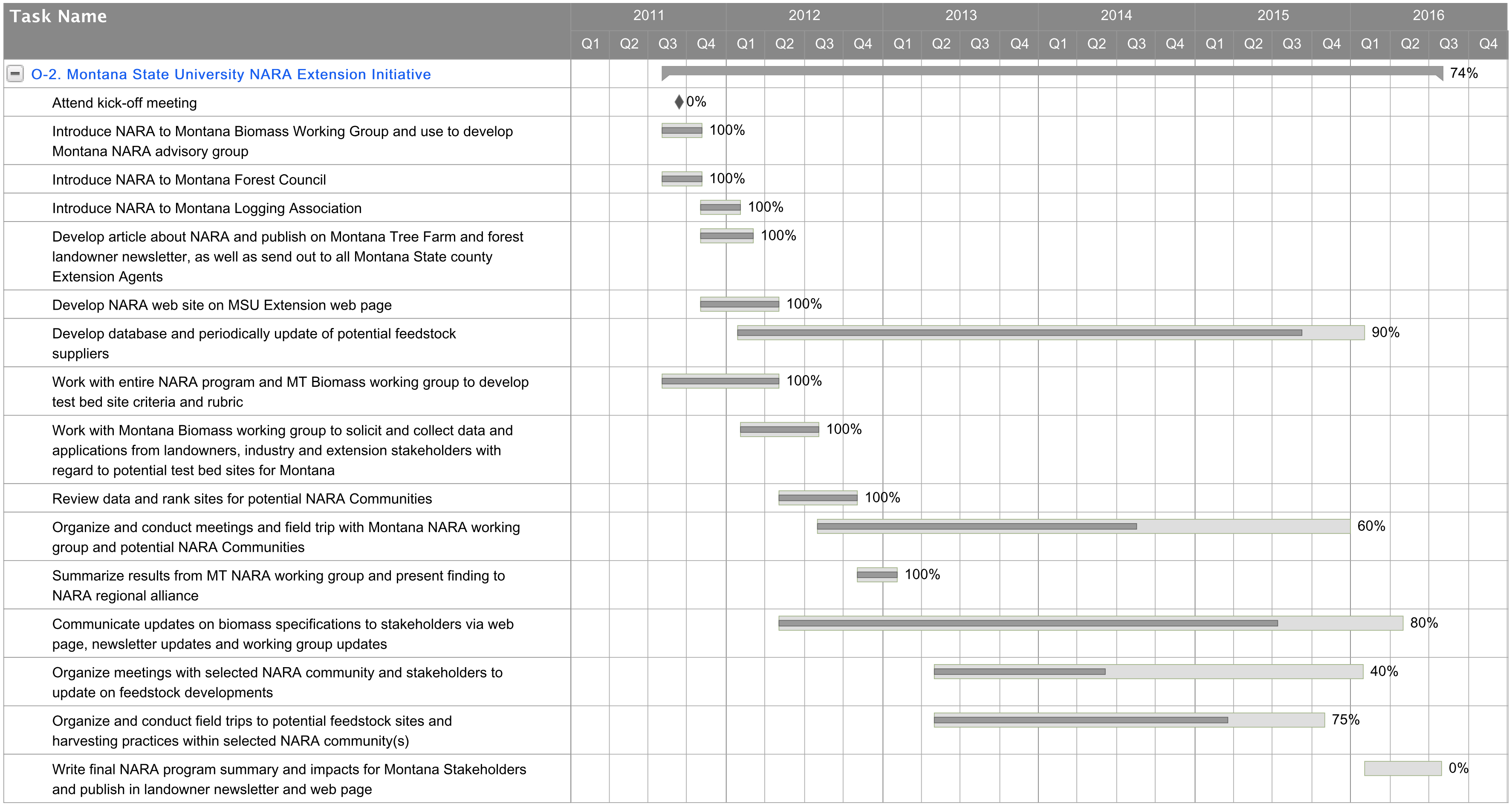


Exported on April 23, 2015 3:22:47 PM PDT

Page 3 of 3

Outreach_Kolb

NARA

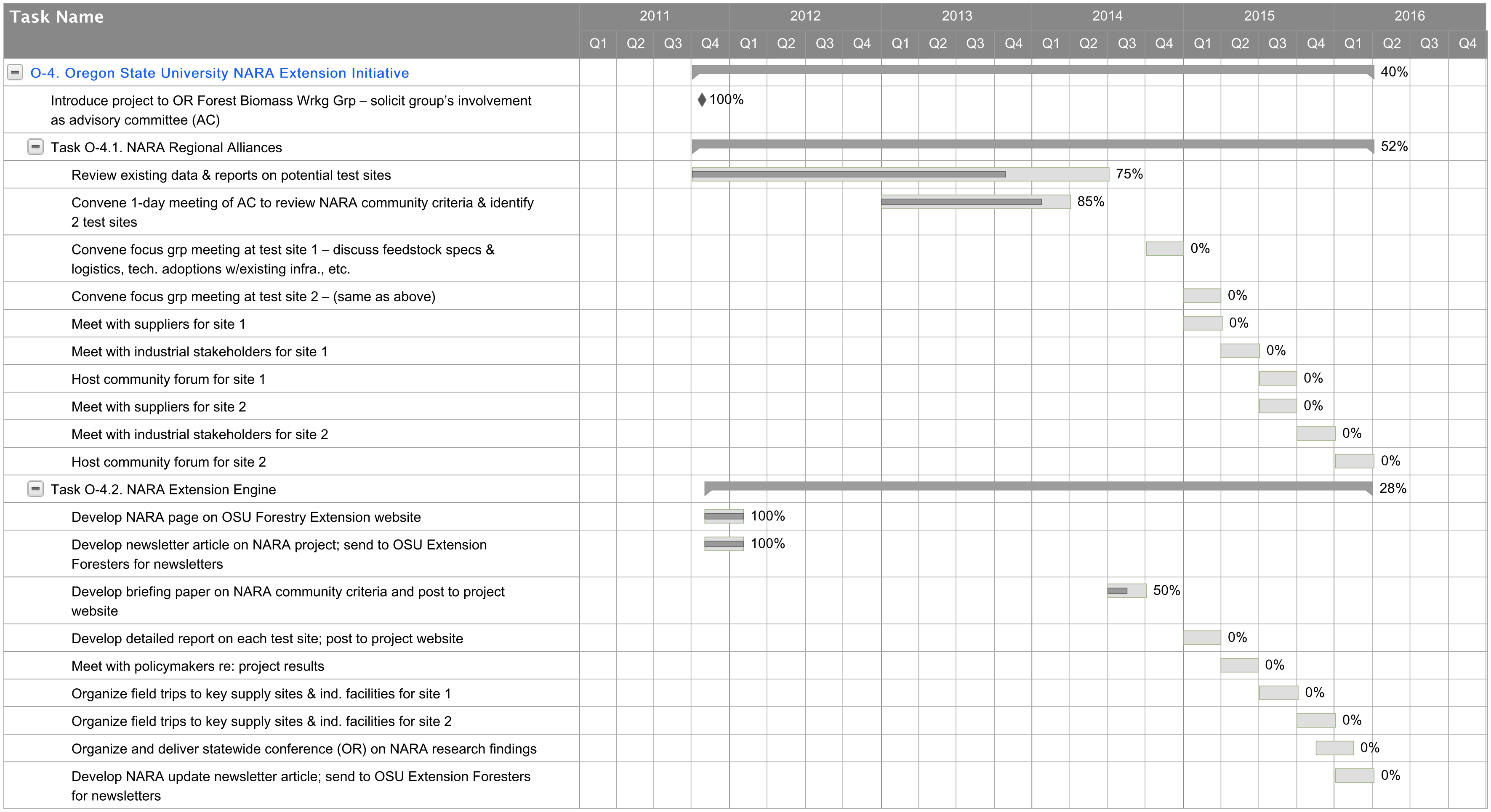


	Task Name	
1	O-2. Montana State University NARA Extension Initiative	74%
2	Attend kick-off meeting	0%
3	Introduce NARA to Montana Biomass Working Group and use to develop Montana NARA advisory group	100%
4	Introduce NARA to Montana Forest Council	100%
5	Introduce NARA to Montana Logging Association	100%
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	90%
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	100%
11	Review data and rank sites for potential NARA Communities	100%
12	Organize and conduct meetings and field trip with Montana NARA working group and potential NARA Communities	60%
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	80%
15	Organize meetings with selected NARA community and stakeholders to update on feedstock developments	40%
16	Organize and conduct field trips to potential feedstock sites and harvesting practices within selected NARA community(s)	75%
17	Write final NARA program summary and impacts for Montana Stakeholders and publish in landowner newsletter and web page	0%

Exported on April 23, 2015 1:32:47 PM PDT

Page 1 of 1

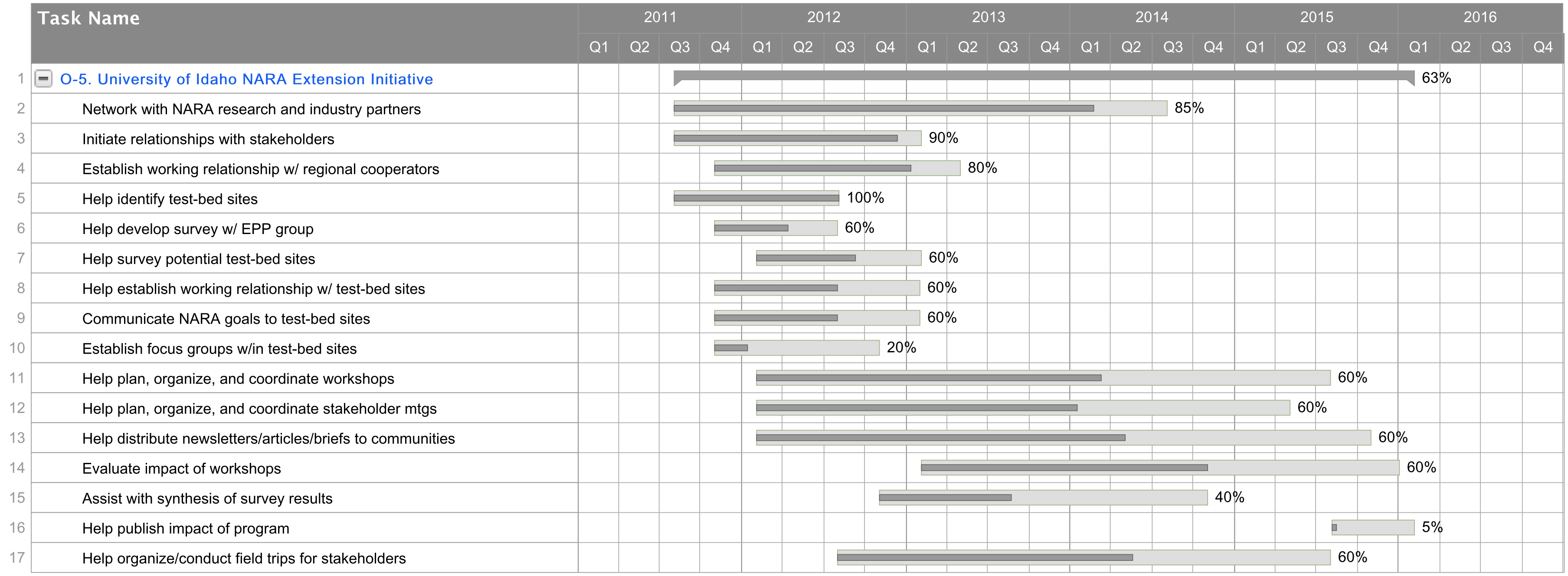
Outreach_Leavengood



	Task Name	
1	O-4. Oregon State University NARA Extension Initiative	40%
2	Introduce project to OR Forest Biomass Wrkg Grp – solicit group's involvement as advisory committee (AC)	◆ 100%
3	Task O-4.1. NARA Regional Alliances	52%
4	Review existing data & reports on potential test sites	75%
5	Convene 1-day meeting of AC to review NARA community criteria & identify 2 test sites	85%
6	Convene focus grp meeting at test site 1 – discuss feedstock specs & logistics, tech. adoptions w/existing infra., etc.	0%
7	Convene focus grp meeting at test site 2 – (same as above)	0%
8	Meet with suppliers for site 1	0%
9	Meet with industrial stakeholders for site 1	0%
10	Host community forum for site 1	0%
11	Meet with suppliers for site 2	0%
12	Meet with industrial stakeholders for site 2	0%
13	Host community forum for site 2	0%
14	Task O-4.2. NARA Extension Engine	28%
15	Develop NARA page on OSU Forestry Extension website	100%
16	Develop newsletter article on NARA project; send to OSU Extension Foresters for newsletters	100%
17	Develop briefing paper on NARA community criteria and post to project website	50%
18	Develop detailed report on each test site; post to project website	0%
19	Meet with policymakers re: project results	0%
20	Organize field trips to key supply sites & ind. facilities for site 1	0%
21	Organize field trips to key supply sites & ind. facilities for site 2	0%
22	Organize and deliver statewide conference (OR) on NARA research findings	0%
23	Develop NARA update newsletter article; send to OSU Extension Foresters for newsletters	0%

Exported on April 23, 2015 2:59:07 PM PDT

Outreach_Brooks



	Task Name	
1	O-5. University of Idaho NARA Extension Initiative	63%
2	Network with NARA research and industry partners	85%
3	Initiate relationships with stakeholders	90%
4	Establish working relationship w/ regional cooperators	80%
5	Help identify test-bed sites	100%
6	Help develop survey w/ EPP group	60%
7	Help survey potential test-bed sites	60%
8	Help establish working relationship w/ test-bed sites	60%
9	Communicate NARA goals to test-bed sites	60%
10	Establish focus groups w/in test-bed sites	20%
11	Help plan, organize, and coordinate workshops	60%
12	Help plan, organize, and coordinate stakeholder mtgs	60%
13	Help distribute newsletters/articles/briefs to communities	60%
14	Evaluate impact of workshops	60%
15	Assist with synthesis of survey results	40%
16	Help publish impact of program	5%
17	Help organize/conduct field trips for stakeholders	60%

Exported on April 14, 2015 1:43:34 PM PDT

Page 1 of 1

Outreach_Lowell

NARA

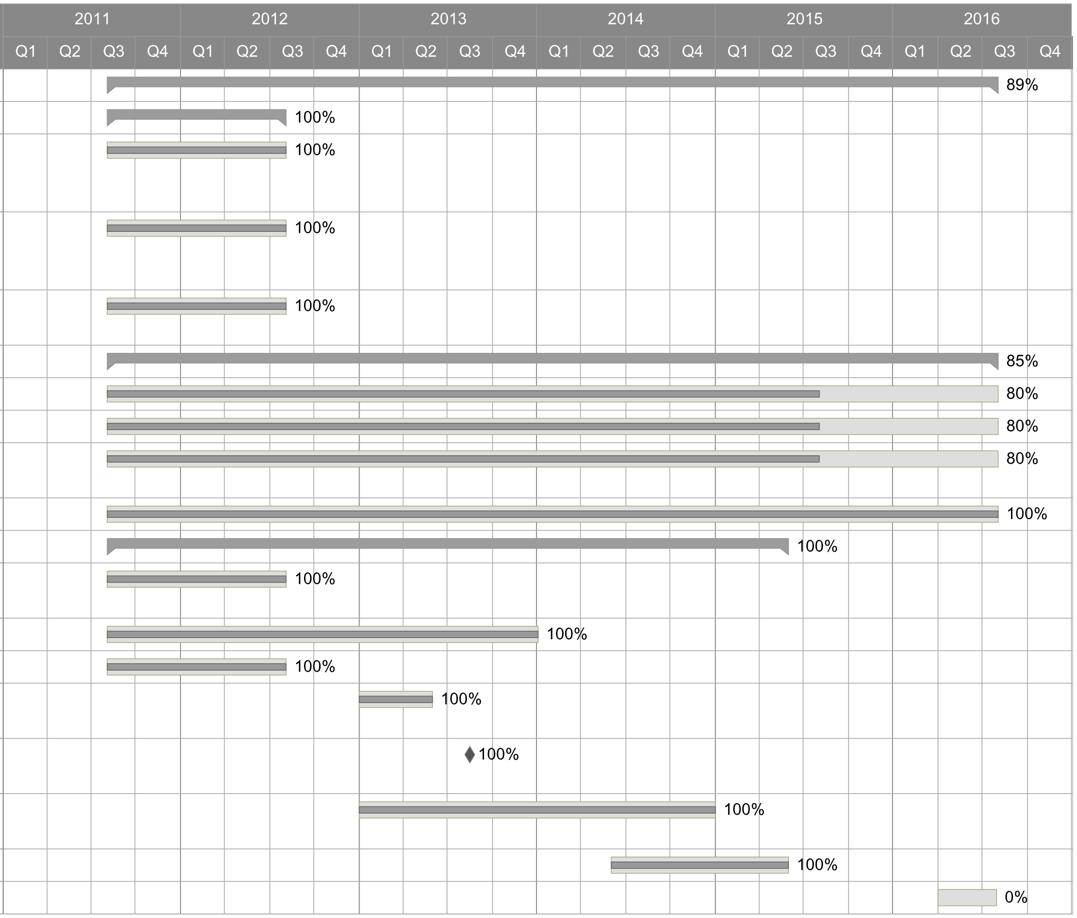
	Task Name	%
1	O-6. Forest Service - Pacific NW Research Station	66%
2	Task O-6.1. NARA Regional Alliances	75%
3	Opening meeting	100%
4	Network with other NARA teams	70%
5	Initiate relationships with regional stakeholders and partnerships	70%
6	Assist in development of decision criteria for test bed selection	95%
7	Identify candidate test bed sites near timber dependent communities	90%
8	Participate in screening of test bed communities	75%
9	Meet with clients and stakeholders at test bed communities	75%
10	Convene Focus Group at each test bed site	75%
11	Facilitate Focus Group meetings	70%
12	Identify and/or organize potential field visits and demonstrations	55%
13	Task O-6.2. NARA Extension	56%
14	Assist in organization of workshops	60%
15	Produce newsletter/one-page briefing papers	60%
16	Serve on Planning Committee for NARA First Conference	100%
17	Publish Proceedings as PNW-GTR	0%
18	Serve on Planning Committee for NARA Second Conference	0%
19	Publish Proceedings as PNW-GTR	0%

Exported on April 23, 2015 2:08:12 PM PDT

Page 1 of 1

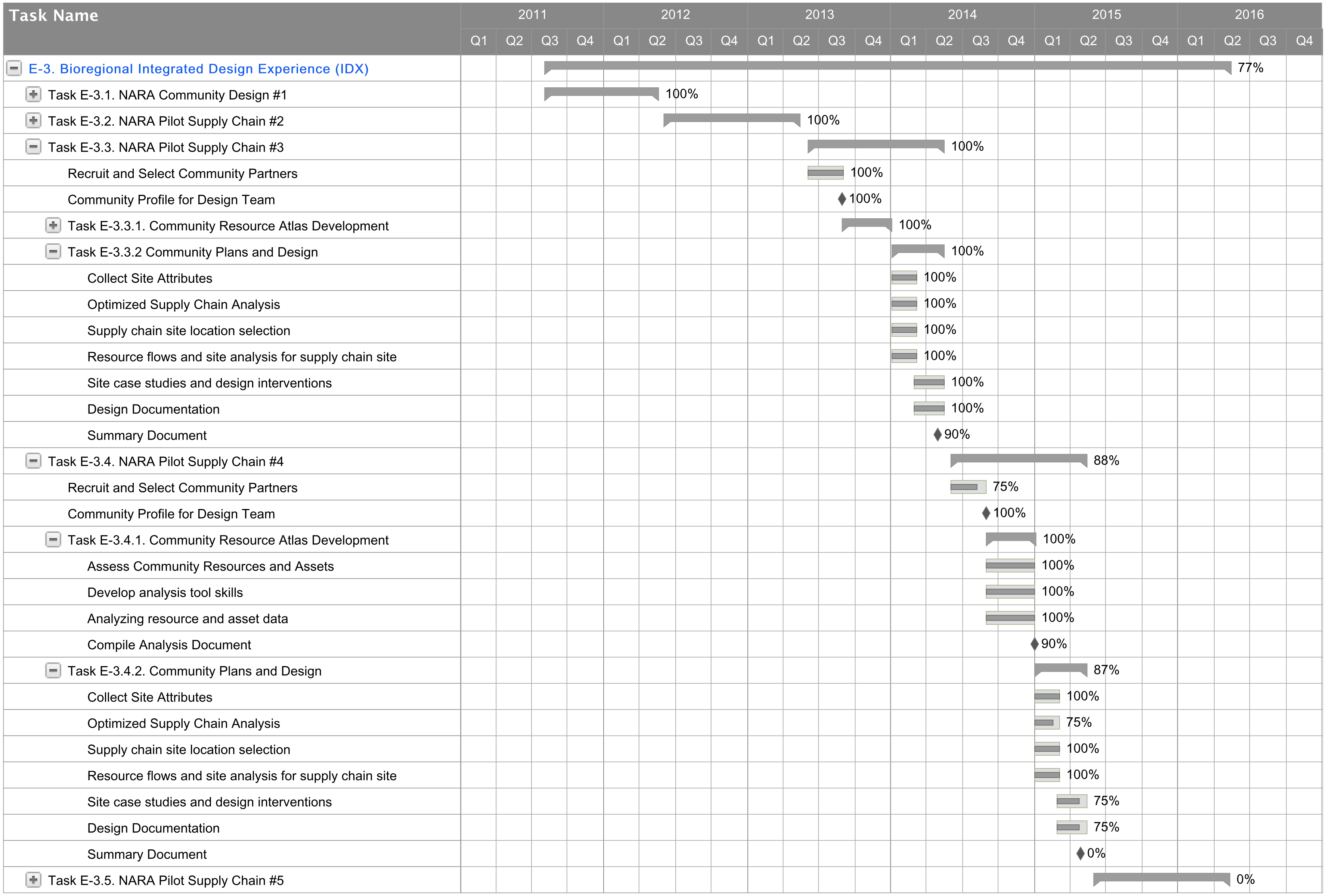
Outreach_RuckelshausCtr

	Task Name	
1	**O-7. William D. Ruckelshaus Center**	89%
2	Task O-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 O-7.2. Meeting Facilitation and Informing Policy Makers	85%
7	Monthly meetings of the Leadership Team	80%
8	Quarterly meetings of the Stakeholder Advisory Committee	80%
9	Quarterly newsletters, web updates and legislative liaison packages from information provided by Project Directors and Leadership Team	80%
10	Annual Project Assessment Meetings to include Stakeholders	100%
11	Task O-7.3. Assessment & Survey	100%
12	Participate in assessment of public perceptions to "connect social and technical aspects" of the project	100%
13	Quantitative surveys	100%
14	Focus groups	100%
15	Inventory and assess applicability of existing DGSS survey data sets for use in the ground-truthing process	100%
16	Complete data extraction, formatting and consolidation to support ground-truthing using DGSS survey data sets	♦ 100%
17	DGSS will work with the EPP team to analyze DGSS and National Data Sets to accomplish the ground-truthing	100%
18	Use newly-collected primary data to validate CAAM model	100%
19	Final report	0%



Exported on April 23, 2015 2:35:31 PM PDT

Education_Wolcott_Laninga

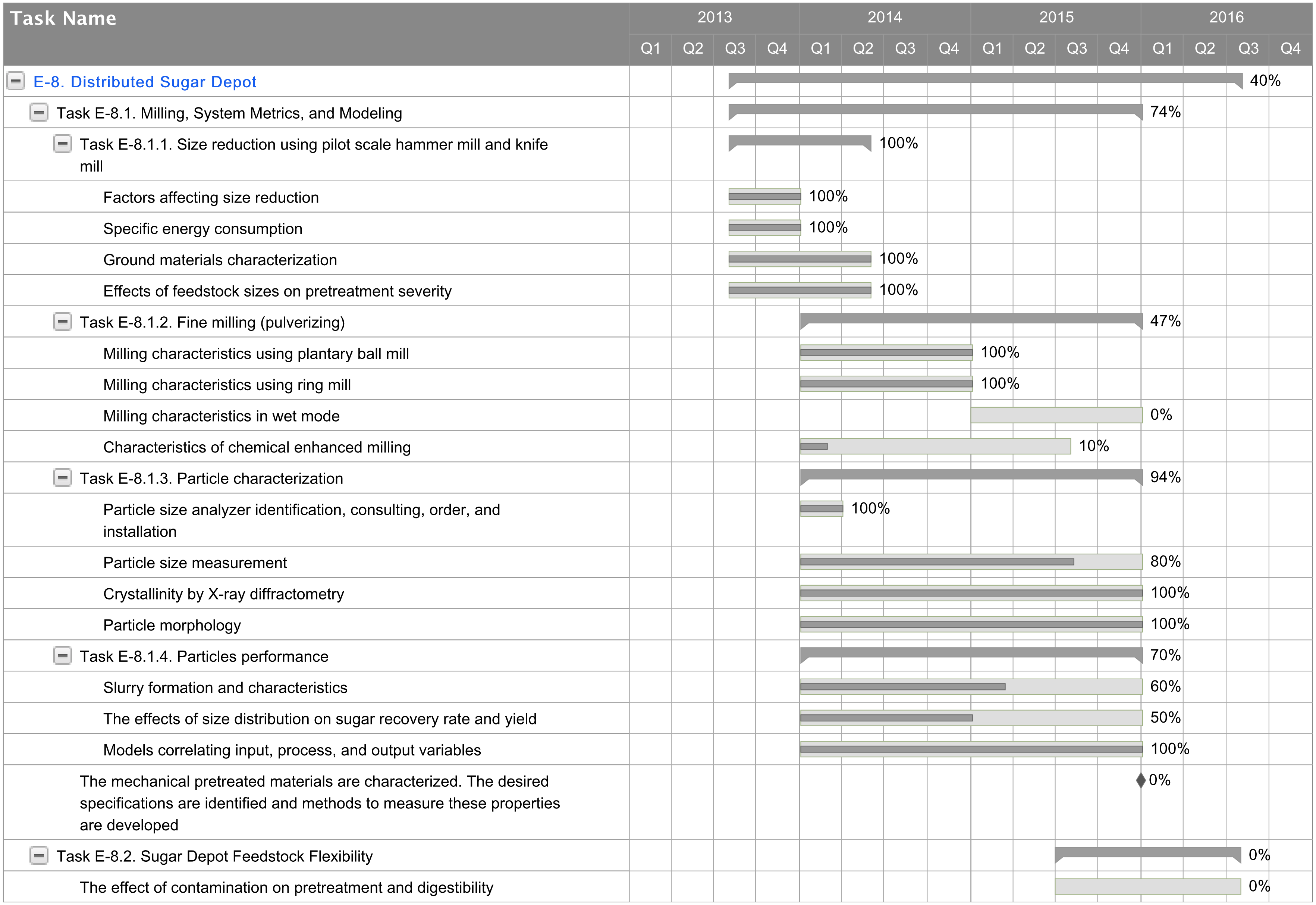


	Task Name	
1	E-3. Bioregional Integrated Design Experience (IDX)	77%
2	Task E-3.1. NARA Community Design #1	100%
21	Task E-3.2. NARA Pilot Supply Chain #2	100%
40	Task E-3.3. NARA Pilot Supply Chain #3	100%
41	Recruit and Select Community Partners	100%
42	Community Profile for Design Team	100%
43	Task E-3.3.1. Community Resource Atlas Development	100%
48	Task E-3.3.2 Community Plans and Design	100%
49	Collect Site Attributes	100%
50	Optimized Supply Chain Analysis	100%
51	Supply chain site location selection	100%
52	Resource flows and site analysis for supply chain site	100%
53	Site case studies and design interventions	100%
54	Design Documentation	100%
55	Summary Document	90%
56	Task E-3.4. NARA Pilot Supply Chain #4	88%
57	Recruit and Select Community Partners	75%
58	Community Profile for Design Team	100%
59	Task E-3.4.1. Community Resource Atlas Development	100%
60	Assess Community Resources and Assets	100%
61	Develop analysis tool skills	100%
62	Analyzing resource and asset data	100%
63	Compile Analysis Document	90%
64	Task E-3.4.2. Community Plans and Design	87%
65	Collect Site Attributes	100%
66	Optimized Supply Chain Analysis	75%
67	Supply chain site location selection	100%
68	Resource flows and site analysis for supply chain site	100%
69	Site case studies and design interventions	75%
70	Design Documentation	75%
71	Summary Document	0%
72	Task E-3.5. NARA Pilot Supply Chain #5	0%

Exported on April 24, 2015 4:01:27 PM PDT

Page 1 of 1

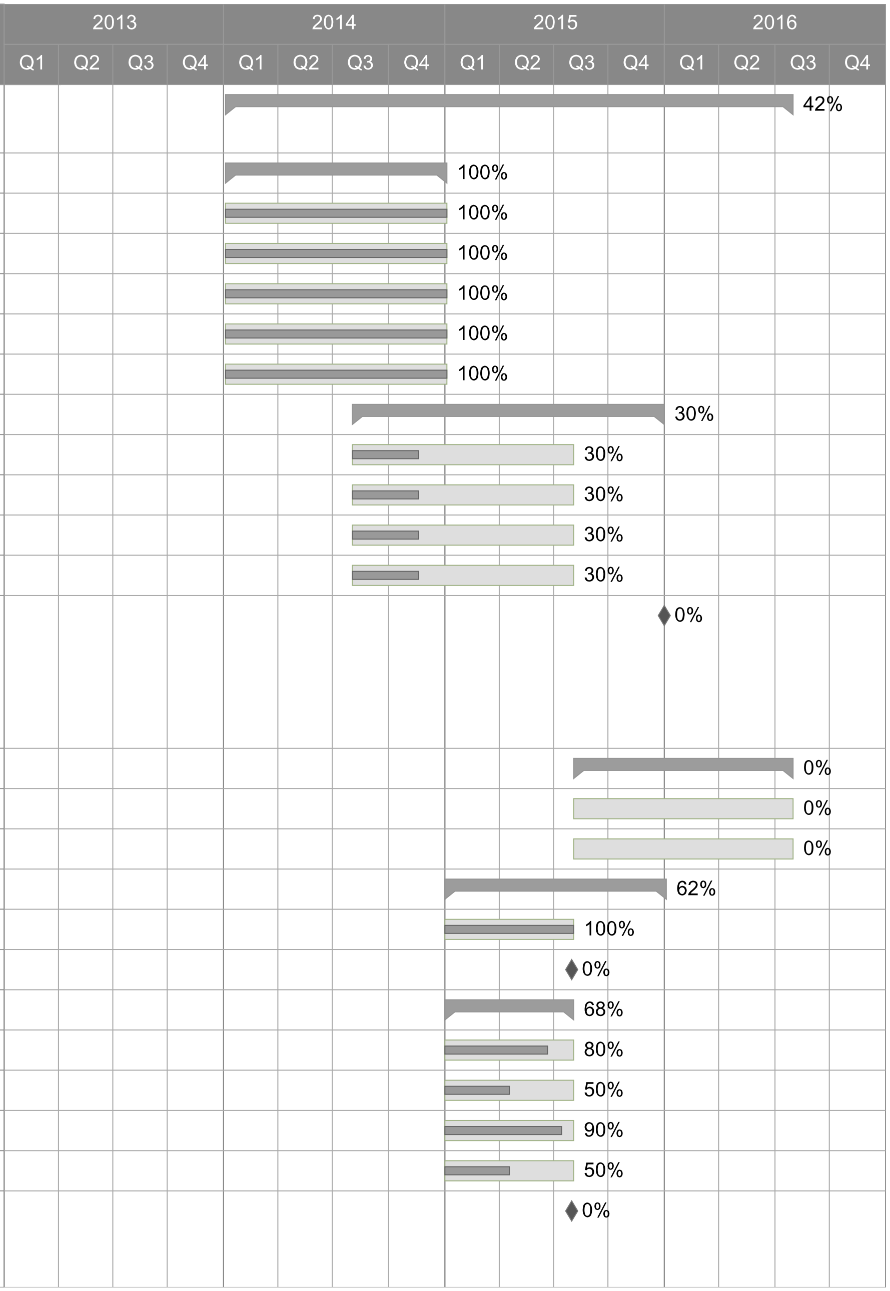
Education_Wang_Wolcott_XZhang



	Task Name	
1	E-8. Distributed Sugar Depot	40%
2	Task E-8.1. Milling, System Metrics, and Modeling	74%
3	Task E-8.1.1. Size reduction using pilot scale hammer mill and knife mill	100%
4	Factors affecting size reduction	100%
5	Specific energy consumption	100%
6	Ground materials characterization	100%
7	Effects of feedstock sizes on pretreatment severity	100%
8	Task E-8.1.2. Fine milling (pulverizing)	47%
9	Milling characteristics using plantary ball mill	100%
10	Milling characteristics using ring mill	100%
11	Milling characteristics in wet mode	0%
12	Characteristics of chemical enhanced milling	10%
13	Task E-8.1.3. Particle characterization	94%
14	Particle size analyzer identification, consulting, order, and installation	100%
15	Particle size measurement	80%
16	Crystallinity by X-ray diffractometry	100%
17	Particle morphology	100%
18	Task E-8.1.4. Particles performance	70%
19	Slurry formation and characteristics	60%
20	The effects of size distribution on sugar recovery rate and yield	50%
21	Models correlating input, process, and output variables	100%
22	The mechanical pretreated materials are characterized. The desired specifications are identified and methods to measure these properties are developed	0%
23	Task E-8.2. Sugar Depot Feedstock Flexibility	0%
24	The effect of contamination on pretreatment and digestibility	0%

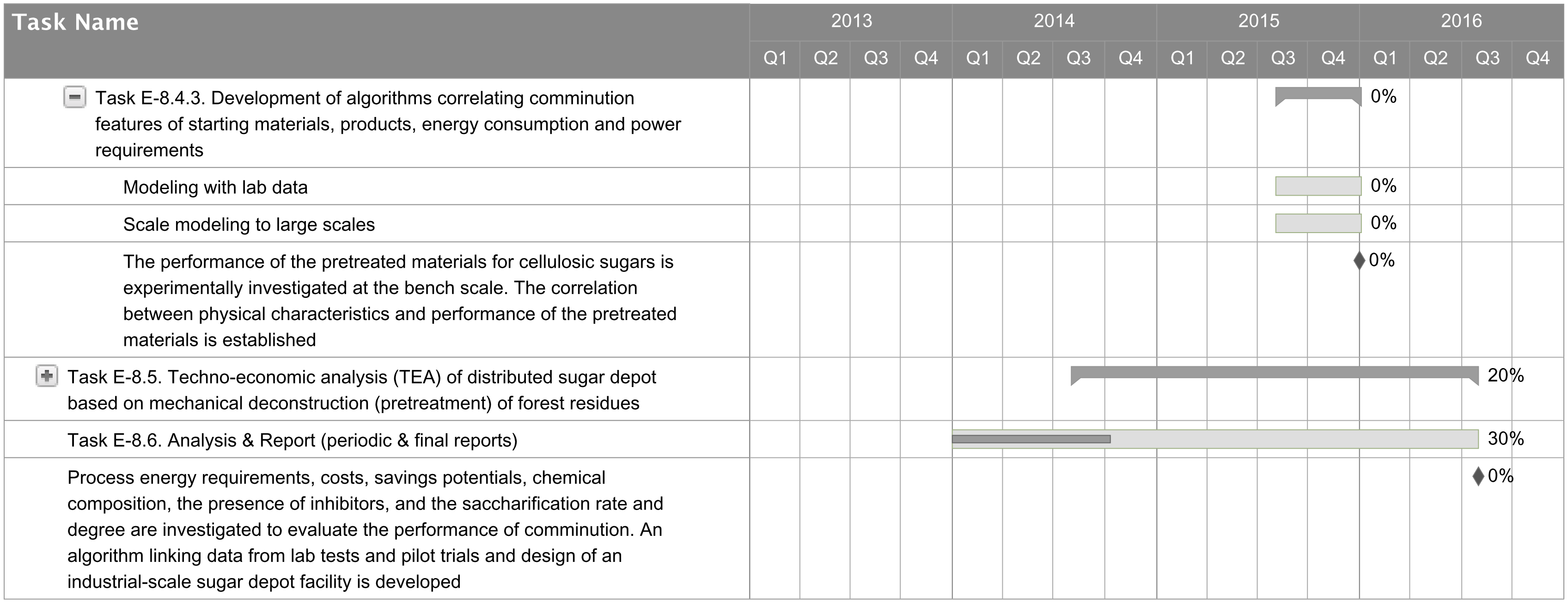
Exported on May 4, 2015 1:53:10 PM PDT

	Task Name	
25	Task E-8.3. Hydrolysis Design, Process, Metrics Development, and Sugar Specification	42%
26	Task E-8.3.1. Hydrolysis kinetics using a torque rheometer	100%
27	Effect of solid contents on rheology	100%
28	Rheology change with enzymatic hydrolysis time	100%
29	Particle size changes with enzymatic hydrolysis time	100%
30	Energy consumption	100%
31	Sugar hydrolysis rates and yield	100%
32	Task E-8.3.2. Hydrolysis with an extruder	30%
33	Pre-extrusion treatments enhancing extrusion process	30%
34	Extrusion variables optimization	30%
35	Post-extrusion treatments	30%
36	Extrudates sacharification	30%
37	Pretreated materials are enzymatic hydrolyzed via an extrusion system. Process performance such as viscosity, flowability, and energy consumption relating to handling of the mechanical pretreated materials is assessed. Conditions of enzymatic hydrolysis are optimized	0%
38	Task E-8.3.3. Sugar Specification	0%
39	Sugar streams separation and condense	0%
40	Sugar formats optimization and characterization	0%
41	Task E-8.4. Sugar Depot Process Economics	62%
42	Task E-8.4.1. Milling technology in wood and pulping industry review	100%
43	Potential industrial scale milling systems are identified	0%
44	Task E-8.4.2. Milling technologies in the mining engineering review	68%
45	Research, development, and design methodology	80%
46	Modeling, simulation, and design	50%
47	Milling equipment and case study	90%
48	Identify methods and modeling for wood milling research	50%
49	Pilot milling trials are carried out and optimal milling schemes and parameters are found. Required energy consumptions at optimum milling conditions are measured	0%



Exported on May 4, 2015 1:53:11 PM PDT

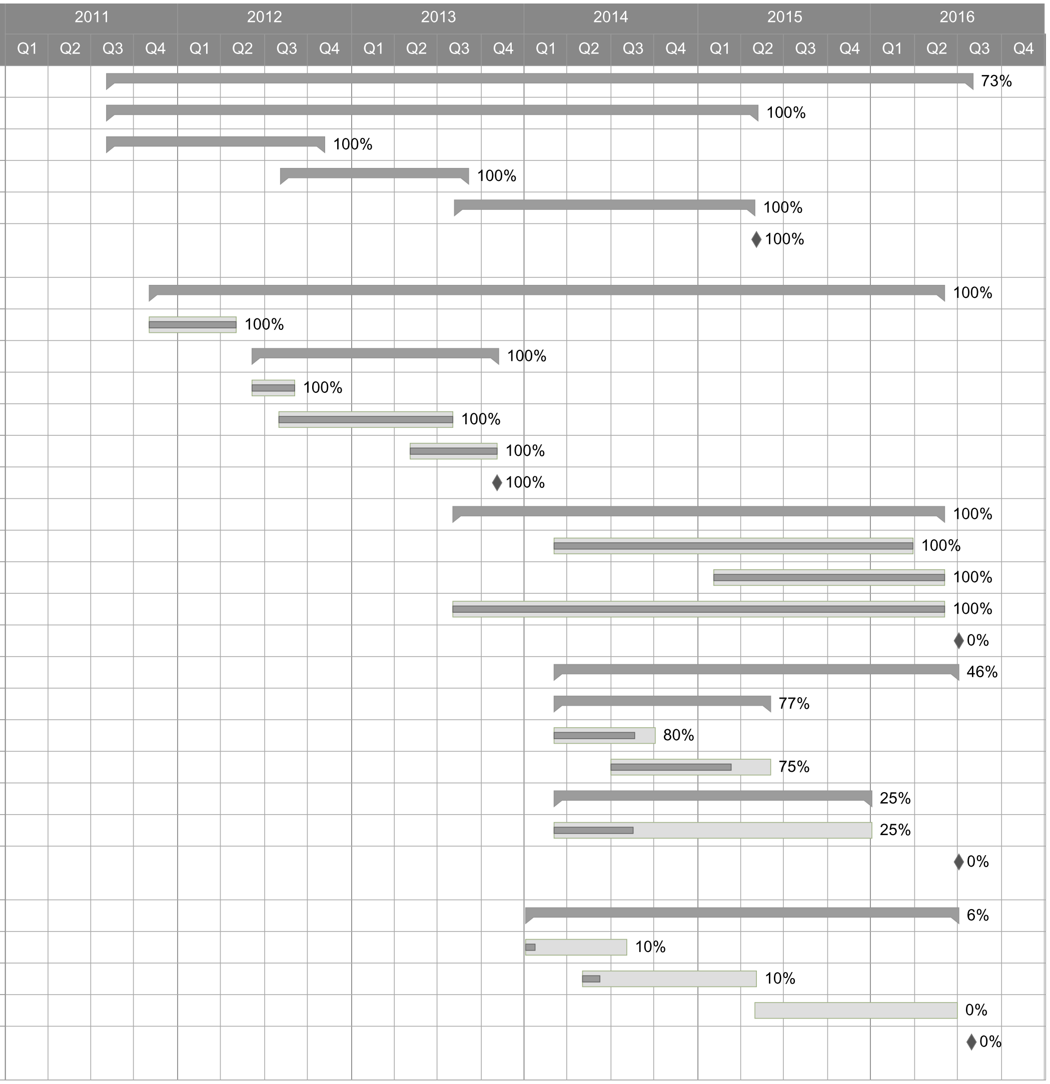
Page 2 of 3



	Task Name	
50	Task E-8.4.3. Development of algorithms correlating comminution features of starting materials, products, energy consumption and power requirements	0%
51	Modeling with lab data	0%
52	Scale modeling to large scales	0%
53	The performance of the pretreated materials for cellulosic sugars is experimentally investigated at the bench scale. The correlation between physical characteristics and performance of the pretreated materials is established	0%
54	Task E-8.5. Techno-economic analysis (TEA) of distributed sugar depot based on mechanical deconstruction (pretreatment) of forest residues	20%
59	Task E-8.6. Analysis & Report (periodic & final reports)	30%
60	Process energy requirements, costs, savings potentials, chemical composition, the presence of inhibitors, and the saccharification rate and degree are investigated to evaluate the performance of comminution. An algorithm linking data from lab tests and pilot trials and design of an industrial-scale sugar depot facility is developed	0%

Education_Englund

	Task Name	
1	E-7. Feedstock Supply Chain Analysis - MSW	73%
2	Task E-7.1. Develop MSW/C&D woody biomass inventory in NARA region	100%
3	Task E-7.1.1. Identify and collect exisiting MSW and C&D data - by states	100%
8	Task E-7.1.2. Establish model for woody biomass inventory in NARA regions	100%
13	Task E-7.1.3. Validate model with surveys and on-site inventories	100%
17	Develop inventory of wood waste in MSW throughout NARA region based on existing data and model results	100%
18	Task E-7.2. Inventory of NARA Communities (NC)	100%
19	Work with Extension team to develop NC criteria	100%
20	Task E-7.2.1. Develop extensive inventory for 1st NC	100%
21	Identify geographical range	100%
22	Identify all sources of MSW and C&D	100%
23	Collect data and normalize for summation	100%
24	Finalized data entered into GIS database	100%
25	Task E-7.2.2. Inventory analysis of remaining NCs	100%
26	Identify all sources of MSW and C&D	100%
27	Collect data and normalize for summation	100%
28	Finalized data entered into GIS database	100%
29	Final Inventory assessment of NCs	0%
30	Task E-7.3. Develop strategies to utilize woody biomass from C&D for biofuel feedstocks	46%
31	Task E-7.3.1 Categorize incoming wood materials to select NARA-based MRFs	77%
32	Identify and categorize major contaminants for fuel production	80%
33	Determine contaminant levels in wood wastes	75%
34	Task E-7.3.2. Develop specifications for "allowable materials" for biofuel usage	25%
35	Identify procedure for providing MRF RINS credits	25%
36	Provide pathway for MRF EPA recongnized renewable woody biomass feedstock for biofuels	0%
37	Task E-7.4. Develop wood composition model	6%
38	Collect initial data/info on wood materials in MSW	10%
39	Address historical data on wood materials in building construction	10%
40	Model wood material types in the C&D stream	0%
41	Final report on quality control and specifications for using MSW and C&D wood as biofuel	0%



Exported on April 24, 2015 3:27:05 PM PDT

Page 1 of 1

NARA Goal Five

3RD Cumulative Report

April 2014 - March 2015

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.

Danica Hendrickson, curriculum director at Facing the Future, introduces curriculum units to high school teachers. Photo courtesy of MOSS.

K-12 STUDENTS AND EDUCATORS

Programs targeted to K-12 students and teachers provide curriculum development and educational programs. The McCall Outdoor Science School (MOSS) provides over 2500 K-12 students courses to develop energy literacy. For this reporting period, members of the NARA Education and Outreach team developed and administered a middle school energy literacy assessment tool based on energy literacy tests given to students before and after their experience at MOSS. Initial results show that students who attend the MOSS training show a significant increase in energy literacy (Task E-2). To provide a portal to teachers for energy literacy resources, 160 assets were added to the NARA matrix (energyliteracyprinciples.org; Task O-9).

This reporting year, a webinar series and workshop were provided to middle and high school teachers who planned to mentor students for the Imagine Tomorrow Competition (Task E-2). Fifteen teachers are participating in the 2015 webinars, which include presentations from NARA researchers, and 17 teachers participated on site, plus 20 teachers participated in an online version, of a four-day workshop. Surveys report that both teachers and NARA presenters benefitted from the webinars and workshop.

The bioenergy lesson plan Fueling our Future was published during NARA Year-3. As of April 7, 2015, 319 copies of Fueling our Future (FOF) (176 middle school and 143 high school) have been distributed, and 225 free individual lessons (77 middle school and 148 high school) have been downloaded from FTF's website, reaching over 16,000 students. A considerable outreach effort to promote FOF continues with email marketing, workshops and professional conference attendance (Task E-2).

Again this year, NARA was a major sponsor for the Imagine Tomorrow (IT) program. This event engages high school students to develop creative solutions to society's energy challenges. The 2014 event showed an increase in total student teams (140 student teams in 2014 to 133 in 2013), with a total of 542 students participating. The assessments initiated in NARA Year-3 were further refined to reflect student interest in the Imagine Tomorrow competition and in STEM related careers. A very significant observation from the assessment is that males and females score equally (Task E-4).

UNDERGRADUATE AND GRADUATE STUDENTS

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 2014, 52 students applied and five were selected. The number of applications increased by 36% over the second year (summer of 2013), indicating better recruitment efforts. The applicants for the third year were also very diverse. Demographics of 2014 applicants were 48% women, 52% men; and 6% Hispanic, 6% Native American, 31% Asian, 12% African American, 37% Caucasian. To date, over 90 applicants are available for 2015 SURE placements (Task E-5).

In NARA Year-4, additional undergraduate and graduate student training opportunities were provided through the IDX course (Task E-3), MOSS (Task E-2) and the Tribal Partnership Program (Task E-1).

PUBLIC BIOENERGY LITERACY

To promote bioenergy literacy opportunities to the public, portals and materials were provided to explain and disperse the project's outputs. During this annual reporting period, the NARA website reached 11,893 individual users throughout the world, of which, 57.6% were new users. Additional NARA webpages were maintained at Oregon State University, Montana State University, and PNW Research Station . NARA maintained an active blog, Facebook, Twitter, and You-Tube presence plus directed newsletter stories to 976 email subscribers. NARA's repository of unbiased scientific knowledge on wood-based biased biofuels and co-products (Knowledge Base) was converted to a stakeholder resource; over 950 users throughout the world have accessed the site since it was established in 2014 (Task O-1).

SIGNIFICANT INTERNAL OUTPUTS REPORTED THIS PERIOD FOR NARA TEAMS INVOLVED WITH PROMOTION ENERGY LITERACY

- Thirty-seven newsletter stories were distributed to 976 email subscribers with an average viewing percentage at 27.3 % (Task O-1).
- Seventeen videos describing NARA research were posted on the NARA YouTube channel (Task O-1).
- 77 NARA blog and 104 Facebook posts were placed (Task O-1).
- An infographic was developed to articulate the broad impacts provided by NARA Education and Outreach activities, and three fact sheets were developed to highlight the NARA's Tribal Partnership Program, NARA education programs and the supply chain flow and products derived from the production of biojet fuel from forest residuals (Task O-1).
- Four research briefs were generated and posted covering Oregon State University NARA research (Task O-4).
- A survey of logging contractors was conducted to assess attitudes and beliefs towards utilizing woody biomass as a biofuel (Task O-5).
- A Congressional Briefing Paper was prepared for the PNW Research Station Director to take to Washington, DC (April 2015) for meetings with Congressional members and staff and other stakeholders (Task O-6).
- Quarterly briefing papers aimed at informing 1,500+ policy-makers in Washington, Oregon, Idaho, Montana and Northern California about the project's progress were sent (Task O-7).
- A historical document concerning the PNW timber industry was created and posted (Task E-3).
- A peer-reviewed manuscript (Langfitt et al) was published titled "Artifact Based Energy Literacy Assessment Utilizing Rubric Scoring" doi:10.1061/(ASCE)EI.1943-5541.0000210 (Task E-4).
- A peer-reviewed manuscript (Langfitt et al) was published titled "Refinement of an Energy Literacy Rubric for Artifact Assessment and Application to the Imagine Tomorrow High School Energy Competition" ISSN: 2151-7452 (Task E-4).
- A peer-reviewed manuscript (Eitel et al) was published titled "Teacher Professional Development for Energy Literacy: A Comparison of Two Approaches" ISSN: 2151-7452 (Task O-8).
- A peer-reviewed manuscript (Hougham et al) was published titled "From the forest to the classroom: Energy literacy as a co-product of biofuels research" ISSN: 2151-7452 (Task E-2).
- A peer-reviewed manuscript (Hendrickson et al) was published titled "Global Sustainability: An Authentic Context for Energy Education." ISSN: 2151-7452 (Task E-2).
- A peer-reviewed manuscript (DeWaters et al) was published titled "Beyond Conservation: Reimagining the Purpose of Energy Education." Link (Task O-8).
- 2014 Imagine Tomorrow Competition: http://imagine.wsu.edu/past/2014/default.html
- Five webinars featuring NARA research were posted on MOSS website. Link

SIGNIFICANT OUTCOMES

- Due to the success of the Imagine Tomorrow (IT) with Biofuels, there is interest in using the format for other regional competitions in the U.S.. Currently, funding for launching IT nationally, with associated assessment and management, is being considered for the second regional site in Missouri (Task E-4).

TRAINING

Name	Affiliation	Role	Contribution
Aaron Boyles	UI	Graduate Student	Co-coordinator of webinar series
Ashlee Fliney	UI	Graduate Student	Co-coordinator of webinar series
Jim Casey	UI	Graduate Student	Energy literacy curriculum development
Will Stubblefield	UI	Graduate Student	Energy literacy assessment
Justin St. Onge	UI	Graduate Student	Energy literacy assessment
Jessica Beaver	WSU	Graduate Student	STEM Assessment Research Assistant
Quinn Langfitt	WSU	Graduate Student (PhD)	Energy Literacy Assessment Research Assistant
Brandon Werner	WSU	Undergraduate student	Energy Literacy Assessment Research Assistant
Cassandra Sanders	WSU-TC	SURE Student Undergraduate	Mechanistic kinetics study of biomass derived inhibitory compounds on cellulase hydrolysis of biomass substrate
Rodney Seals	Univ. Arkansas	SURE Student Undergraduate	Lignin residue as Wood Pellet Binder and Energy Enhancer for Energy Applications
Eric Sorensen	Humboldt State	SURE Student Undergraduate	Spatial Distribution of Grain Sizes in Sampling Heterogeneous Stream Beds
Preenaa Venugopal	Penn State	SURE Student Undergraduate	Potential Technological Pathways for the Production of Alternative Jet Fuel
Eileen Wu	U.C. Berkeley	SURE Student Undergraduate	Ball Milling: Effective Pretreatment Leading to A Clean Biomass to Cellulosic Sugar Conversion
Ike Nwaneshiudu	Univ of Washington	Post-Doc	LCA, Biomass technologies
Karl Oleson	Univ of Washington	Graduate Student (PhD)	Extractives and role in emissions from a sulfite sugar plant
Blake Hough	Univ of Washington	Graduate Student (PhD)	Forestry residues at CSKT, and pyrolysis modeling for value-added products
Burdette Birdinground (Crow)	Univ of Washington	Graduate Student (MS)	Federal forest residue volumes adjacent to CSKT
Katie Moore-Drougas (Crow)	Univ of Washington	MPA Student	Analysis of TFPA vs EISA: conflicts between federal policy to support tribal economies and ecosystems
Emile Delucca	Univ. of Montana	Summer Intern	Summer program 2014
Calvin Silas (Navajo)	New Mexico State Univ	Summer Intern	Withdrew from program, returned home due to death in immediate family.
Cody Sifford (Navajo)	Univ of Washington	Summer Intern	Grad student affiliated with NARA TPP
Clarence Smith (Blackfeet)	Univ of Washington	Summer Intern	Summer intern 2014
Shawn Defrance (CSKT)	Salish Kootenai College	Summer Intern	Summer intern, placed with John Bailey (NARA OSU) 2014
Breanna Gervais (Penobscot)	Portland State Univ	Summer Intern	Summer intern 2014, recent PSU Graduate 2015.

RESOURCE LEVERAGING

Resource Type	Resource Citation	Amount	Relationship or Importance to NARA
Perc H. Shelton and Gladys A. Pospisil Fund of the Idaho Community Foundation	Fizzell, G. 2014. Valley County Outreach Programs	$3,000.00	Support to deliver energy literacy curriculum to local McCall-Donnelly schools
Steven Leuthold Family Foundation	Fizzell, G. 2014. K-12 Residential Outdoor Science Program General Support	$10,000.00	General operating support to deliver energy literacy curriculum to MOSS audience.
Whittenberger Foundation	Fizzell, G. 2014. iSTEM Initiative	$4,000.00	Support to deliver energy literacy curriculum to Title I schools in Southwest Idaho.
EPSCoR National Science Foundation	Vierling, L., K Eitel, G. Fizzell and B. Miller. 2014. Support for MOSS K-12 Adventure Learning Programs	$70,000.00	
Donations			NARA partially supports the cost of the Imagine Tomorrow program, leveraging over $150,000 in other private donations and grants to run and assess the program.
WSU internal sources		$3,000	The program for presenting undergraduate work was sited with the existing summer undergraduate research poster session at WSU-Pullman on Aug. 1. The staffing and support for this event (on the order of $3000) is covered from WSU internal sources, and not charged to NARA.
State	Salary support, Schwartz	About $20,000 per year	Schwartz spends time on NARA, without taking salary the past two years.
State	TA Support, Hough	One quarter, about $11,000	Part of educational requirement to advance degree. Continued working on research.
State	TA Support, Oleson	One quarter, about $11,000	Part of educational requirement to advance degree. Continued working on research.

BIOENERGY LITERACY

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 resources, ecologic, and economic development needs of a community. To accomplish this, we work with tribes, tribal organizations, and each partner campus to offer up to 3 grad student tribal research projects. Specifically, student teams will work collaboratively with Northwest Native American tribes to provide integrative research on technical issues tied to feedstocks, their sustainable production and logistics, and conversion to value-added products. System metrics assess the overall performance of the integrated student design. Students benefit from outstanding training in interdisciplinary communications and research. Tribes 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 makes several trips to the partner tribe's reservation. We seek to complement the IDX team corridor-scale activities by incorporating detailed landscape scale information provided by major forested landholding tribes. To have maximum impact and credibility in Indian Country, 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

- Continued tribal research projects that support tribal interests in forest restoration, resilient forest management, air and water quality-related issues with biorefining, and new technologies to generate economic development from un-merchantable biomass residues.
- Continued direct outreach and support to Tribal Nations within the NARA region
- Established 2015 Summer Internship program. Recruited students at the American Indian Science & Engineering Society conference and have made 10 tribal student selections to date for the summer of 2015. Students will be participating in research at Western Washington University's Huxley School, Facing the Future, and on the University of Washington's campus and at two field sites.
- Douglas-fir biomass residues were acquired from the Muckleshoot Tribe and the Confederated Salish Kootenai Tribes to participate in the production of the 1,00 gallons of biojet fuel that NARA produces. Product were delivered to Lane Forest Products in Eugene, OR.
- Continue to collaborate with Tribal Nations via the Intertribal Timber Council.

Recommendations | Conclusions

We continue to provide research support to one of the largest Tribes in the Pacific Northwest, as an extension to the Western Montana Corridor (WMC) project. The Confederated Salish & Kootenai Tribes (CSKT) have requested and received a complete inventory of their available biomass residues for their next ten years of harvest management activities. We are investing forestry residue potential from existing tribal stewardship sites in adjacent federal lands, as well as the overall residue potential of a ten mile buffer around the reservation, which is nominally available to the tribe through the Tribal Forest Protection Act. We are also looking at the policy conflict between the Tribal Forest Protection Act and the prohibitions against using RIN credits to support biomass extraction form federal forests. Finally, we are investigating emissions from a sulfite-based sugar processing depot on the reservation, one of the potential options proposed for the western Montana corridor. The CSKT also contributed forest residues (in forest chipping with transfer to Oregon collection site) to NARA's 1,000 gallon goals. We've also been able to pull in one of the newest Tribal forest landowners in Indian Country with the addition of the Muckleshoot Indian Tribe (MIT) to the NARA Tribal Partnership projects. Muckleshoot also contributed forest residues (in-forest collection and transfer to chipping site, then delivered to Oregon collection site) via their current forest managers, Hancock Forest Management. Dr. John Sessions from NARA OSU assisted us in gaining tribal participation by providing a quick assessment and approval of their residues. NARA TPP provided the funding support to get Dr Sessions out to CSKT and MIT and to hire tribal contractors and trucking to deliver the residues. This is a major event for our tribal partners. Finally, Charles Burke and Vikram Yadama assisted this effort by capturing the residue collection on video at both the Montana and Washington sites. Video interviews were completed by: Jim Durglo (CSKT Forestry Department Head), Rod Couture (CSKT Forester), Louie Ungaro (MIT Tribal Councilman) and Lefi Tasauga (Hancock Forest Management representative). Student interviews were completed by Blake Hough (University of Washington) and Cody Sifford (University of Washington).

Table E-1.1. Students enrolled in the 2015 Tribal Partnership Projects (TPP) summer internship program.

Cody Sifford	University of Washington	2015 Summer Intern	Will continue work on air quality in relation to burning of slash piles – intended fall 2015 graduate.
Clarence Smith			Spring 2014 Graduate, will mentor new Tribal Partnership undergraduate in 2015 summer program.
Julia Wilson Peltier Turtle Mountain Chippewa)	Western Washington University	2015 Sumer Intern	Will work with Steve Hollenhorst as a TPP Summer Intern
Ryan Contreras (Yakama)	Bellevue Colelge	2015 Summer Intern	Will work with UW SEFS on biochar related research
Daylen Isaac (Yakama)	Heritage University	2015 Summer Intern	Will work with UW SEFS on biochar related research
Barb Wolfin (Pit River Nation)	Haskell Indian Nations University	2015 Summer Intern	Will work on NARA Tribal projects related research
Autumn Charley (Navajo)	University of Arizona	2015 Summer Intern	Will work on biomas conversion processes at UW SEFS
Nina Nez	University of Arizona	2015 Summer Intern	Will work on biomass conversion processes at UW SEFS
Charmayne Smith	Fort Lewis College	2015 Summer Intern	Will work on curriculum development with Facing the Future
Waynetta Dennison	University of New Mexico	2015 Summer Intern	Will work on current research in UW Engineering

In terms of where we are going, we've recently selected 10 students to participate in the Tribal Partnership Projects summer internship program for 2015. All 10 students are tribally enrolled and listed below in Table E-1.1.

Physical and Intellectual Outputs

- Two chip vans of biomass were collected from the Confederated Salish & Kootenai Tribes and transported to Oregon.
- One chip van of biomass was collected from the Muckleshoot Indian Tribe and transported to the Oregon collection site.
- Attempts were unsuccessful to collect forest residues at Yakama Nation (no chipping operation available), Warm Springs (resources unavailable), Nez Perce (currently not harvesting), and Spokane Tribe (only Ponderosa pine was available).
- Scheduled TPP participation by Blake Hough in Montana Roundtable, May 8, Missoula

REFEREED PUBLICATIONS

Co-authored Draft of Education at the Speed of Research: An Overview of the NARA approach to BioEnergy Literacy, Journal of Sustainability Education (theme issue for Energy Education)

Ikechuwku Nwaneshiudu and Daniel Schwartz, "Rational design of polymer-based absorbents: Application to the fermentation inhibitor furfural" Accepted, Biotech for Biofuels (2015).

Blake Hough, Tom Richards, Laurel James, Jim Durglo, and Daniel Schwartz, "Management of tribal timberlands for ecological and community goals can produce economic value streams comparable to industrial forestry in Western Montana USA" paper in preparation, draft on NARA website.

Karl Olson and Daniel Schwartz, "Process flows for extractive components of Douglas fir biomass residues during mild bisufite pretreatment and concentration", paper in preparation.

RESEARCH PRESENTATIONS

Blake R. Hough, Cody Sifford, Laurel James, Tom Richards, Jim Durglo and Daniel T. Schwartz. Biomass supply estimates for the Confederated Salish and Kootenai Tribes based on harvest planning and management goals. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Karl Olson and Daniel Schwartz. Tribal Communities Care about Effluents: Tracking Extractives, Inhibitors & Reaction Products in Bisulfite Processing. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Laurel James and Daniel Schwartz. NARA Education - Tribal Partnership Projects. Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Cody Sifford, Indroneil Ganguly, Ernesto Alvarado and Ivan Eastin. Developing an Impact Assessment of Local Air Quality as a Result of Biomass Burns.

Poster presented at the 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

- 4 Presentations given at the NARA UW—WSU Presentation of Research, held at the UW School of Environmental and Forest Sciences July 29-30, 2014.
    - o Emile Delucca
    - o Cody Sifford
    - o Clarence Smith
    - o Burdette Birdinground

- 5 Presentations and posters given at the National Indian Timber Symposium, held at the Coeur d'Alene Resort Casino June 23-26, 2014.

Calvin Silas did not present a poster, as planned. He withdrew from the NARA Intenrship and the ITC conference due to a death in his immediate family. Aside from Calvin, the posters are the same as listed above for the Presentation of Research, except for the addition of Shawn Defrance – attached. Presentations available at website for Breanna Gervais and Burdette Birdinground: http://www.itcnet.org/resources/

OTHER PUBLICATIONS

- Contributed NARA newsletter article entitled NARA and Pacific Northwest Tribes

- Contributed to NARA one-page document sent to PNW policy makers

- NARA Graduate Fellow, Blake Hough had his final report for the Confederated Salish & Kootenai Tribe's biomass assessment published to the NARA website.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

- Field days arranged and accommodations provided for Dr. John Sessions to review and approve biomass at CSKT & MIT. Dates of travel, March 14-16, 2015.

- Field day and media day arranged for Charles Burke, Vik Yadama, Cody Sifford and Laurel James at the Confederated Salish & Kootenai Tribes. Dates of Travel March 18-20, 2015.

- Field day and media day arranged for Charles Burke, Dan Schwartz, Blake Hough and Cody Sifford with the Muckleshoot Indian Tribe and Hancock Forest Management Group. Dates of Travel, March 26, 2015.

TASK E-2: GREENSTEM K-12 INITIATIVES

Key Personnel	Affiliation
Tammi Laninga	University of Idaho
Danica Hendrickson	Facing the Future

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 GreenSTEM is to increase the capacity of the region for a transition to biofuels. This will be accomplished through four interrelated objectives:

1. Meet the workforce needs of the bio-energy/bio-products 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 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 University of Idaho'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 renown 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 more knowledgeable about biofuels, biofuels research, and energy.
2. K12 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. K12 teachers apply knowledge in energy literacy to help their students successfully develop an approach to answering a problem-based energy issue.
5. 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 webinar series for 15 - 30 middle school to high school teachers. Teachers participating in the webinar series are supported as coaches for the Imagine Tomorrow (IT) competition while developing their own energy literacy through a series of lectures and discussions with NARA research scientists. 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

MOSS graduate students teach K-12 energy literacy education to over 2500 students at MOSS with an emphasis on biofuels. Graduate students develop and implement new lessons every semester. All K-12 students take an Energy Literacy pretest upon arriving at MOSS, a posttest before leaving, and a one-month posttest after returning to their schools. Members of the Education and Outreach team developed a middle school energy literacy assessment tool. Spring 2015 activities include collecting data on at least 500 K-12 students to further examine the validity of the assessment instrument. Students showed a positive and statistically significant increase from assessment intervals Time 1 (mean 6.72) to Time 2 (mean 7.5) to Time 3 (mean 8.12).

MOSS delivered teacher professional development, through a monthly webinar series for teachers coaching teams for the Imagine Tomorrow Competition, and a four-day intensive summer workshop. Fifteen teachers are participating in the 2015 webinars that have included presentations from NARA researchers John Petrie, Scott Holub and Indroneil Ganguly. Seventeen teachers participated on site, and 20 teachers participated in an online version of a four-day workshop featuring presentations from NARA researchers Tammi Laninga and Jim Casey (NARA grad student working with Randy Brooks) and pre-recorded lectures and webinars from NARA researchers Michael Wolcott, Indroneil Ganguly, Carter Fox and Ian Dallemeyer. In addition to the videos from the NARA YouTube channel, we used seven different NARA newsletter articles, the NARA Knowledge Base, the Energy Literacy Matrix, two lessons from Facing the Future's Fueling our Future curriculum, four previously tested lessons designed by MOSS staff and grad students, and two new lessons designed for the workshop to support the workshop. Teachers reported gaining content for their classrooms, incorporating new pedagogical models and increasing their personal energy literacy. The NARA researchers reported gaining communication skills, developing more refined ideas, an opportunity to gain support from the public for their work.

Table E-2.1. Distribution of Fueling Our Future in the Pacific Northwest

STATE	Idaho	Montana	Oregon	Washington
Number of Teacher's Guides and Free Lessons	32	2	43	54
Potential Student Reach	960	60	1290	1620

FACING THE FUTURE (FTF) CURRICULUM DEVELOPMENT

As of April 7, 2015, 319 copies of Fueling our Future (FOF) (176 middle school and 143 high school) have been distributed, and 225 free individual lessons (77 middle school and 148 high school) have been downloaded from FTF's website, reaching over 16,000 students (Table E-2.1).

Elementary energy lessons (grades 3 through 5) are currently being copy-edited. The lessons are vertically aligned to the middle and high school versions of FOF and have been piloted and reviewed by teachers.

FTF PROFESSIONAL DEVELOPMENT

- 12 workshops for over 400 teachers have been conducted (see Physical and Intellectual Outputs).

FTF EVALUATION & OUTREACH

- Emails to 30,000 educators and 5,000 new teachers highlighting FOF.
- Planning for impact assessment of FOF on Energy Literacy (3 teachers currently committed)
- Creation of peer educator program focused on energy
- Attendance at national conference on Energy Education and Climate Change
- Conversations with United Nations about partnering to promote Lesson #5 from FOF, which is focused on the UN Sustainable Energy for All initiative.

Recommendations | Conclusions

We will continue to focus on sustainability issues in our teacher professional development and K-12 educational initiatives as we continue to have many questions from students and teachers about the overall sustainability of biomass residuals as a feedstock for jet fuel.

We will continue to incorporate emerging research into our webinars, workshops and curriculum. NARA-produced newsletters have been very helpful in this task.

Our educational efforts in the next year will focus on telling the story of the creation of 1000 gallons of biojet and the overall NARA process.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Hougham, R.J., Eitel, K.B., Miller, B.G., (2015). Technology-enriched STEM Investigations of Place: Using Technology to Extend the Senses and Build Connections to and between Places in Science Education. Journal of Geoscience Education. (In press).

Eitel, K. B., Hougham, R. J., Laninga, T., Fizzell, G., Schon, J. & Hendrickson, D. (2015). Teacher Professional Development for Energy Literacy: A comparison of two approaches. Journal of Sustainability Education, 8(1).

Schon, J.A., Eitel, K.B., Hougham, R.J., Hendrickson, D. (2015). Creating a research to classroom pipeline: closing the gap between science research and educators. Journal of Sustainability Education, 8(1).

Hougham, R. J., Hollenhorst, S., Schon, J., Eitel, K., Hendrickson, D., Gotch, C., Laninga, T., James, L., Hough, B., Schwartz, D., Preslley, S., Olsen, K., Hasselbach, L., Langitt, Q., Moslemi, J. (2015). Education at the Speed of Research: an overview of the NARA approach to BioEnergy Literacy. Journal of Sustainability Education,8(1).

Hendrickson, D., Corrigan, K., Keefe, A., Shaw, D., Jacob, S., Skelton, L., Schon, J., Eitel, K.B., Hougham, R.J. (2015). Global Sustainability: An Authentic Context for Energy Education. Journal of Sustainability Education, 8(1).

RESEARCH PRESENTATIONS

Eitel, K., Schon, J., Vierling, L. and Fizzell, G. Developing STEM Identity through Place-based Field Science Inquiry. Idaho Conference on STEM Education Challenges and Innovative Solutions: Overcoming STEM Education Barriers in Rural States, Boise, ID, 28 May 2014

Hendrickson, D., D. Shaw, S. Jacob, A. Keefe and L. Skelton. Fueling our Future: Exploring Sustainable Energy Use – Middle and High School Interdisciplinary Energy Curricula. Poster presented at 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Schon, J., R.J. Hougham, K. Eitel, D. Hendrickson, T. Laninga, C. Gotch, S. Pressley, L. Haselbach and S. Hollenhorst. The Energy Literacy Feedstock. Poster presented at 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Eitel, K., T. Laninga, J. Schon, R.J. Hougham, D. Hendrickson and S. Hollenhorst. Teacher Professional Development: An Energy Literacy Supply Chain. Poster presented at 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

VIDEOS AND WEBINARS

MOSS (http://teachingadventurelearningatmoss.wordpress.com/media-archive/)

Webinar 1: Introduction to the NARA Project and the MOSS Imagines Tomorrow Webinar Series, Dr. Karla Eitel. December 10, 2014

Webinar 2: Coaching an Imagine Tomorrow Team, Dr. Andrew Morozov, January 28, 2015.

Webinar 3: How do residual biomass removals affect long-term forest productivity?:

Long-term Soil Productivity (LTSP) studies. Dr. Scott Holub, February 18, 2015.

Webinar 4: Rivers Channel Changes: Impacts of Forest Management, Dr. John Petrie, March 11, 2015.

Webinar 5: Environmental assessment of Woody biomass based bio-jet fuel, Dr. Indroneil Ganguly April 8, 2015.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

K. Eitel, J. Schon, D. Hendrickson and R.J. Hougham, Adventures in Bioenergy. Workshop held at UI CNR McCall Outdoor Science School, June 16 – 20, 2014. McCall, Idaho.

D. Hendrickson, J. Hougham. Energy Education in the Classroom in Wisconsin Dells, Wisconsin, 8 teachers, Upham Woods Outdoor Learning Center) and the Wisconsin K-12 Energy Education Program (KEEP) from the University of Wisconsin-Stevens Point)

D. Hendrickson, Fueling Our Future at the WA Corrections Center for Women, 43 women in partnership with the Evergreen State College and Washington State Department of Corrections' Sustainability in Prisons Project

D. Hendrickons, Interdisciplinary & Interconnected: Social Studies Takes On Energy, 7 teachers, Washington State Council for the Social Studies in Chelan, WA

TASK E-4: IMAGINE TOMORROW WITH BIOFUELS

Key Personnel	Affiliation
Liv Haselbach	Washington State University

Task Description

The NARA Imagine Tomorrow (IT) 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

During this period, the 2014 competition was held in May 2014. Forty-five schools attended sending 140 teams, with a total of 542 students participating. 138 judges participated. Post competition, additional assessment activities evaluated STEM perceptions and energy literacy, resulting in reports to the steering and executive committees. The perceptions are summarized in Figures E-4.1 and E-4.2.

The energy literacy work resulted in another journal paper and acceptance of a conference paper for June 2015, both papers on the modified energy literacy rubric as seen in Figure E-4.3. A very significant outcome of the assessment is seen in the analyses with respect to gender. These analyses showed similar scores between males and females. Not only has the format of the Imagine Tomorrow competition attracted both genders similarly, but it also affects similar learning, even if there are differences in the challenges entered by gender.

An additional output was the invitation for the winning team from the Biofuels challenge to attend the Biomass 2014 in July 2014 in Washington DC, as funded by the BETO office of the Department of Energy. Preparation for the 2015 competition has begun, with marketing and other material developed and distributed, and registration for the 2015 teams completed. The competition judging and award structure was slightly modified to encourage and award more diverse participation, including an additional specialty award for teamwork.

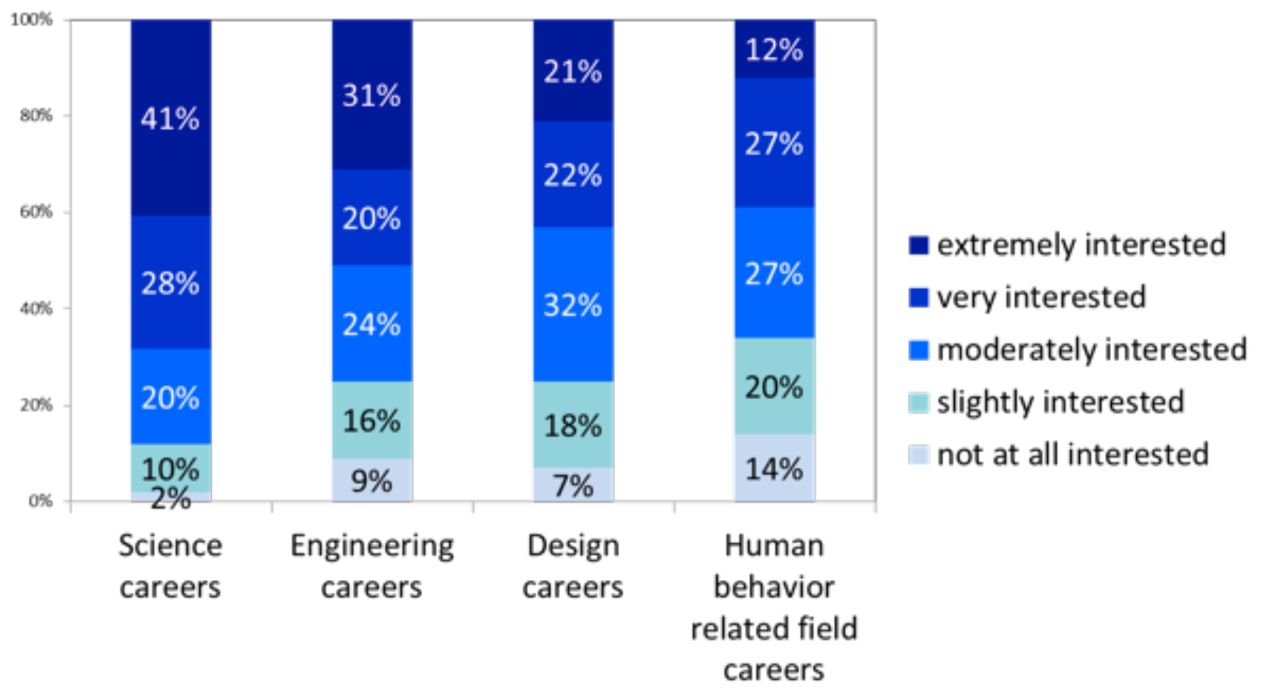


Figure E-4.1. Results of Imagine Tomorrow Student Survey in June 2014 on Careers (Beaver, J., Gotch, C. and French, B., Impact and Experiences of Imagine Tomorrow 2014, Submitted to the Executive Strategy Committee and the Internal WSU Imagine Tomorrow Steering Committee)

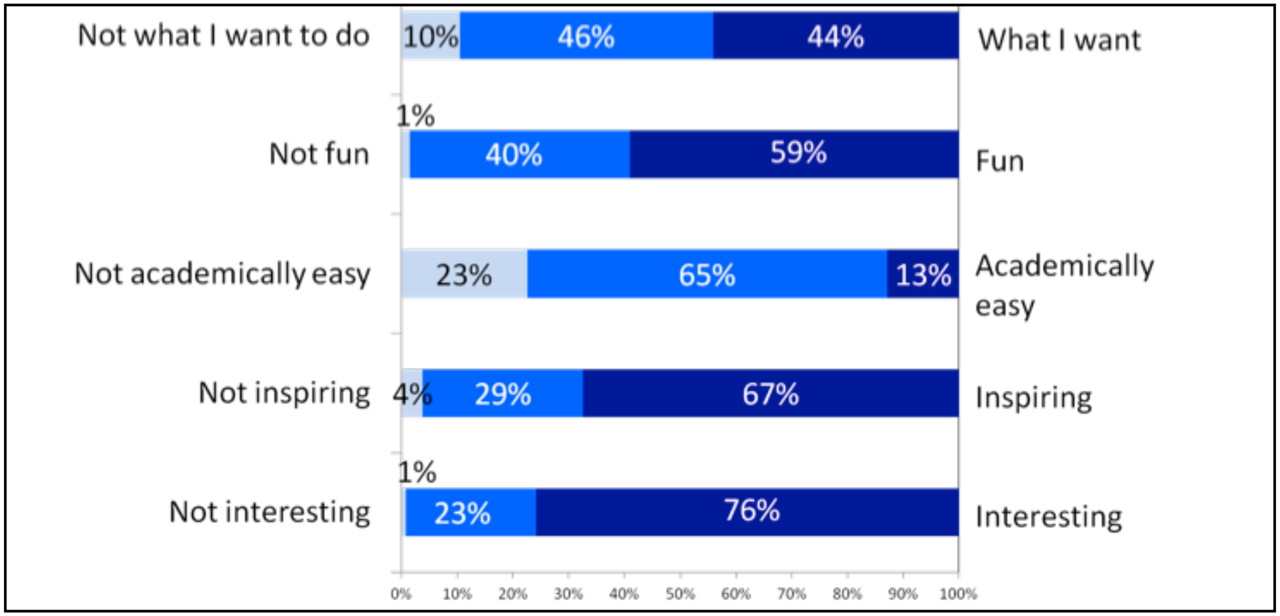
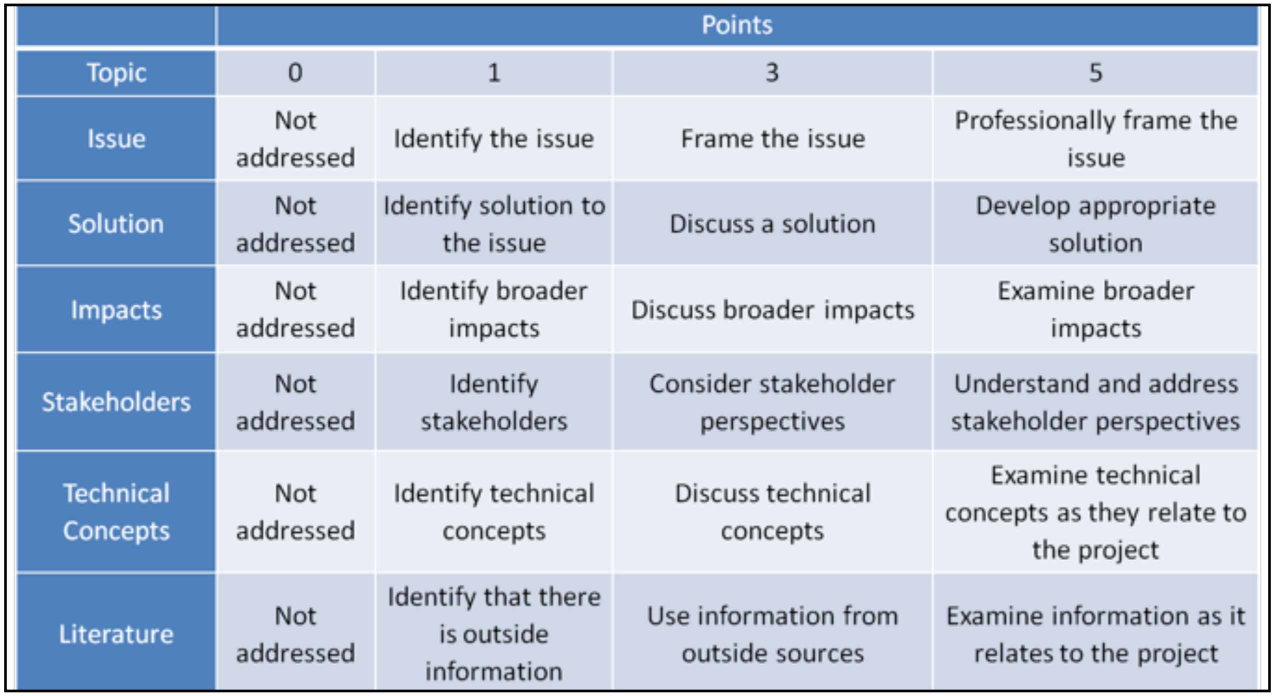


Figure E-4.2. Results of Imagine Tomorrow Student Survey in June 2014 on Competition Topic (Beaver, J., Gotch, C. and French, B., Impact and Experiences of Imagine Tomorrow 2014, Submitted to the Executive Strategy Committee and the Internal WSU Steering Committee).



	Points			
Topic	0	1	3	5
Issue	Not addressed	Identify the issue	Frame the issue	Professionally frame the issue
Solution	Not addressed	Identify solution to the issue	Discuss a solution	Develop appropriate solution
Impacts	Not addressed	Identify broader impacts	Discuss broader impacts	Examine broader impacts
Stakeholders	Not addressed	Identify stakeholders	Consider stakeholder perspectives	Understand and address stakeholder perspectives
Technical Concepts	Not addressed	Identify technical concepts	Discuss technical concepts	Examine technical concepts as they relate to the project
Literature	Not addressed	Identify that there is outside information	Use information from outside sources	Examine information as it relates to the project

Figure E-4.3. Modified Energy Literacy rubric used for assessing the 2014 competition projects (Langfitt, Q. and Haselbach, L. Imagine Tomorrow High School Energy Competition 2014 Energy Literacy and Biofuels Literacy Assessment of Abstracts and Posters, Submitted to the IT Steering Committee, September 2014).

Recommendations | Conclusions

Due to the success of the Imagine Tomorrow with Biofuels there is interest in perhaps using the format for other regional competitions nationally. Currently, funding for launching IT nationally with associated assessment and management is being considered, with interest for the second regional site in Missouri.

Physical and Intellectual Outputs

PHYSICAL

- 2014 Imagine Tomorrow High School Energy Competition in Pullman, WA May 30, 2014.

REFEREED PUBLICATIONS

Langfitt, Q., Haselbach, L., & Hougham, R.J. (2014) Artifact Based Energy Literacy Assessment Utilizing Rubric Scoring. J. Prof. Issues Eng. Educ. Pract. , 10.1061/(ASCE)EI.1943-5541.0000210 , C5014002.

Langfitt, Q., Haselbach, L. & Hougham, R.J. (2015) Refinement of an Energy Literacy Rubric for Artifact Assessment and Application to the Imagine Tomorrow High School Energy Competition, Journal of Sustainability Education, 8.

CONFERENCE PROCEEDINGS AND ABSTRACTS FROM PROFESSIONAL MEETINGS

Gotch, C., French, B., Langfitt, Q. and Haselbach, L. Determining Reliability of Scores from an Energy Literacy Rubric, accepted proceedings and presentation: American Society for Engineering Education, ASEE 2015 conference June 2015.

RESEARCH PRESENTATIONS

Langfitt, Q., L. Haselbach and R.J. Hougham. Artifact based energy literacy assessment utilizing rubric scoring. Poster presented at 2014 NARA Annual Meeting, Seattle, WA, September 15-17, 2014.

Liv Haselbach was an invited presenter at Biomass 2014 on July 30th, 2014 in Washington DC. She participated in the panel discussion on: "Building Market Confidence and Understanding III: Engaging Key Audiences in Bioenergy"

VIDEOS AND WEBINARS

Langfitt, Q. and Haselbach, L., Imagine Tomorrow High School Energy Competition, The Department of Energy National Town Hall on Energy Literacy, August 5, 2014.

TRAININGS, EDUCATION AND OUTREACH MATERIALS

2014 Imagine Tomorrow competition website: http://imagine.wsu.edu/past/2014/default.html

TASK E-5: SUMMER UNDERGRADUATE RESEARCH EXPERIENCES (BF-SURE)

Key Personnel	Affiliation
Shelley Pressley	Washington State University

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 (ten 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 third year (summer of 2014) there were a total of 52 applicants resulting in 5 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. The number of applications increased by 36% over the second year (summer of 2013), indicating better recruitment efforts. The applicants for the third year were also very diverse. Demographics of 2014 applicants were 48% women, 52% men; and 6% Hispanic, 6% Native American, 31% Asian, 12% African American, 37% Caucasian and the rest did not identify with a specific ethnic group.

SURE Experience

Students were selected based on their applications and skills (relative to the proposed projects). Students were placed at three different NARA locations: WSU Pullman (3), WSU-TC (1), and Penn State (1). The students were paid a stipend of $5000 for the 9.5 week experience of conducting research full time, with additional costs for housing or tuition added for students depending on location and on–site needs. The students (Figure E-5.1) conducted research during this reporting period (May 29 – Aug 1, 2014) and all students participated in the poster session on August 1 in Pullman. The list of 2014 students and their associated research topic is provided in Table E-5.1. Additionally, all students participated in a meeting at University of WA in Seattle on July 30 to share their research results with UW students conducting NARA research. Presentations included poster presentations by the WSU-SURE students, and oral/power point presentations by the UW students. UW student presenters were Burdette Birdinground, Cody Sifford, Emile DeLuca and Clarence Smith. The nine students enjoyed meeting each other, sharing lunch together and hearing about each other's research.

Recruit and Select SURE Students

The fourth group of SURE students is currently being recruited and accepted for the summer 2015 program. The application pool is very strong with over 90 applications to date. Applications are currently being reviewed and students will be notified shortly about acceptance.

Additional recruiting efforts were continued during Fall 2014/Spring 2015. An informational flyer advertising NARA SURE was developed and distributed at the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) and the American Meteorological Society (AMS) Annual Meeting. In addition, a notice was posted on the Institute for Broadening Participation: Pathways to Science website (http://www.pathwaystoscience.org/).

Two additional recruitment efforts were done this reporting period. One at the American Indian Science and Engineering Society (AISES) Annual Conference which was held in Orlando, FL Nov 13-15. One of the NARA SURE students, Cody Sifford, placed 2nd in the Graduate Student poster category. Cody Sifford and Laurel James (UW) also recruited potential students for the 2015 SURE experience at a recruiting booth during the conference. The second was January 3-5, 2015 when Shelley Pressley recruited students during the American Meteorological Society (AMS) Annual Meeting in Phoenix, AZ.

Figure E-5.1. 2014 NARA Biofuels-SURE participants Left to right: Rodney Seals, Preenaa Venugopal, Cassandra Sanders, Eric Sorensen, and Eileen Wu

Recommendations | Conclusions

Recruitment of students is not a problem. This summer we received over 90 applications. So over the past four years application numbers have gone from 11 to 38 to 52 to 91. The pressing issue is finding mentors willing to work with students during the summer. Efforts were increased for the summer 2015 period, and there are some new mentors on board. However, efforts will need to be increased again for the summer of 2016.

Table E-5.1. 2013 NARA SURE students, their home institution, the title of their research, and their advisor

SURE student	Home Inst.	Research Title	Primary Advisor(s)
Cassandra Sanders	Washington State University - TC	Mechanistic kinetics study of biomass derived inhibitory compounds on cellulose hydrolysis of biomass substrate	Xiao Zhang
Rodney K. Seals	University of Arkansas	Testing lignin as an additive to wooden pellets	Jinwu Wang / Michael Wolcott
Eileen D. Wu	University of California, Berkeley	Ball Milling: Effective pretreatment leading to a clean biomass to cellulosic sugar conversion	Jinwu Wang / Michael Wolcott
Eric Sorensen	Humboldt State University	Spatial distribution of grain sizes in sampling heterogeneous stream beds	Jon Petrie
Preenaa Venugopal	The Pennsylvania State University	Potential technological pathways for the production of alternative jet fuel	Paul Smith

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Zhang, J., Laguna*, A., Clemons, C., Wolcott, M.P., Gleisner, R., Zhu, J.Y., & Zhang, X. (2015) Effect of hot-pressing temperature on the subsequent enzymatic saccharification and fermentation performance of SPORL pretreated forest biomass. Bioenerg. Res. 8:464-470

*indicates undergraduate researcher from the NARA SURE program

RESEARCH PRESENTATIONS

Pressley, S. and M. Wolcott. NARA SURE Summer Undergraduate Research Experience. Poster presentation at the NARA Annual Meeting. Seattle, WA. Sept 15-17, 2014.

NARA 2014 SURE Posters: http://www.nararenewables.org/features/posters#sure

OTHER PUBLICATIONS

WSU News Story “WSU Hosts Eight Summer Research Programs for Undergraduates” http://universitycollege.wsu.edu/units/undergraduateresearch/News-Events/headlines/summerresearchkickoff/

WSU News Story “WSU Poster Symposium Friday, Aug. 1, for 59 Undergraduate Researchers from 37 Universities” http://universitycollege.wsu.edu/units/undergraduateresearch/News-Events/headlines/2014PosterPreview/

TRAININGS, EDUCATION AND OUTREACH MATERIALS

Summer 2014 Undergraduate Research Poster Symposium at Washington State University – abstract book. http://universitycollege.wsu.edu/units/undergraduateresearch/photos-docs-pdfs/2014_REU_Abstract-Booklet_LowRes.pdf

TASK E-6: SUMMER UNDERGRADUATE RESEARCH EXPERIENCES (SURE-SKC)

Key Personnel	Affiliation
Adrian Leighton	Salish Kootenai College
Richard Everett	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.

Summer Undergraduate Research Experiences (SURE) participants engage in a full time research experiences for a summer (ten 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

Task E-6.1. Recruit and Select SURE Students
Three SKC students completed internships funded by NARA during this time period: one on fire frequencies in mixed conifer stands (mentored by Everett), and two assessing tribal forest road networks and impacts in changes to hydrology due to climate change (mentored by Leighton). All three students successfully completed their internships, and one of them is currently analyzing results to be used in his Senior Thesis.

Recommendations | Conclusions

No recommendations at this time: internships continue to assist tribal forestry in answering important research questions while giving students meaningful research experience in NARA related fields.

BIOENERGY LITERACY

OUTREACH TEAM

TASK O-9: EDUCATION AT THE SPEED OF RESEARCH: NARA ASSESSMENT AND WEB-BASED RESOURCES

Key Personnel	Affiliation
R. Justin Hougham	University of Wisconsin

Task Description

Fundamentally, integrated approaches to energy literacy must be developed to effectively cross disciplines, include all stakeholders, and situate energy literacy into the consciousness of learners of all ages (Hougham et al. 2012). Meaningful approaches to this challenge address education at all levels—students, teachers, and public. The approaches found in the NARA project need to meaningfully address and align assessments as well as web-based content to communicate the exciting research in biofuels, while enriching the greater public understanding of energy literacy through media-enhanced curriculum. Addressing many entry points into the developing biomaterials economy of tomorrow while supporting an online collection of materials, supports learners and provides the infrastructure for education at the speed of research (Hougham et al. 2012). Assessing the outcomes and all education efforts is integral to the success of the NARA project's goal of enhancing energy literacy.

1. Lead Energy Literacy Assessment coordination efforts with support of Education and Outreach teams as well as stakeholders.

NARA Education and Outreach teams seek aligned assessment efforts to 1) internally align energy literacy assessment tools, and 2) create, vet, validate and deliver energy literacy assessments that communicate the impact of NARA energy literacy efforts, as well as contribute to the larger energy literacy landscape. The Learning Performance and Research Center (LPRC) at WSU will support development and refinement of energy literacy tools.

2. Lead Matrix web development efforts and coordinate population of relevant data into NARA web resources.

Development work for NARA Matrix, which includes the development of Literacy Assessment for Biofuels, can be delivered through energyliteracyprinciples.org. Additionally, the Energy Literacy Matrix and Web products will be developed and NARA project products will be organized into an online infrastructure. MagMag LLC will provide ongoing support of web-based tools, including refinement of energyliteracyprinciples.org

Activities and Results

Year 4 progress includes the completion of 2 energy literacy assessment tools, guest editor of Energy Education issue for Journal of Sustainability Education (featuring a collection of NARA articles), continued enhancement of NARA Matrix (676 assets to date, including 160 added this year), and wide dissemination of NARA efforts in stakeholder venues.

Recommendations | Conclusions

Year 5 will see finalized stakeholder literacy tool, coordination of summit in April 2016 featuring NARA education, support for 1000 gallon storyboard development and dissemination, continued enhancement of NARA Matrix, support for woodtobiofuel site, supporting workshops for teachers, and leveraging energy literacy assets into further work.

Physical and Intellectual Outputs

REFEREED PUBLICATIONS

Langfitt, Q., Haselbach, L., & Hougham, R.J. (2014). Artifact Based Energy Literacy Assessment Utilizing Rubric Scoring. Journal of Professional Issues in Engineering Education and Practice (2014).

Langfitt, Quinn, Liv Hasselbach, and Justin R Hougham. (2015) Refinement of an Energy Literacy Rubric for Artifact Assessment and Application to the Imagine Tomorrow High School Energy Competition. Journal of Sustainability Education (8) 2015.

Hougham, R. Justin, Steve Hollenhorst, Jennifer A Schon, Karla B Eitel, Danica Hendrickson, Chad Gotch, Tammi Laninga, Laurel James, Blake Hough, Dan Schwartz, Shelley Preslley, Karl Olsen, Liv Haselbach, Quinn Langfitt, and Jennifer Moslemi. From the forest to the classroom: Energy literacy as a co-product of biofuels research. Journal of Sustainability Education (8) 2015.

Schon, A. Jennifer, Karla B Eitel, R Justin Hougham, and Danica Hendrickson. Creating a research to classroom pipeline: closing the gap between science research and educators. Journal of Sustainability Education (8) 2015.

Eitel Karla, Justin Hougham, Tammi Laninga, Greg Fizzell, Jenny Schon, and Danica Hendrickson. Teacher Professional Development for Energy Literacy: A Comparison of Two Approaches. Journal of Sustainability Education (8) 2015.

Hendrickson, Danica, Kimberly Corrigan, Alicia Keefe, Danielle Shaw, Sheeba Jacob, Laura Skelton,

Jennifer Schon, Karla Bradley Eitel and Justin Hougham. Global Sustainability: An Authentic Context for Energy Education. Journal of Sustainability Education (8) 2015.

DeWaters, Jan, Justin Hougham, Clare Hintz and Larry Frolich. Beyond Conservation: Reimagining the Purpose of Energy Education. Journal of Sustainability Education (8) 2015.

RESEARCH PRESENTATIONS

Hougham, R. Justin (2015) Education at the Speed of Research: An Overview of the NARA Approach to BioEnergy Literacy. 2015 National Extension Educator Summit, Seattle, WA, April 7th.

Schon, Jenny, Karla Eitel, R Justin Hougham, Jim Casey and Mike Wang-Belt. Engaging Energy in an Outdoor Learning Center. Poster Abstract. National Extension Energy Summit, Seattle WA, April 7 2015.

Hougham, R. Justin, Jenny Schon, Karla Eitel, William Stubblefield, and Justin St. Onge. Assessing Energy Literacy in an Outdoor Learning Center. Poster Abstract. National Extension Energy Summit, Seattle WA, April 7 2015.

Eitel, Karla, R. Justin Hougham, Jenny Schon, Aaron Boyles, and Ashlee Fliney. Professional Development for Energy Literacy. Poster Abstract. National Extension Energy Summit, Seattle WA, April 7 2015.

O'Brien, Kevin and Hougham, R.J. (2015) Value of a Tree. 2015 Wisconsin Society of Science Teachers Annual Meeting, Wisconsin Dells, WI March 6th.

Hougham, R. Justin, Jenny Schon, Karla Eitel, Danica Hendrickson, Tammi Laninga, Chad Gotch, Shelley Pressley, Liv Haselbach and Steven Hollenhorst. (2014) Education at the Speed of Research: An Overview of the NARA Approach to BioEnergy Literacy (Poster). 2014 NARA Annual Meeting, Seattle, WA, September 15-17.

Hougham, R. Justin, et al. (2014) Education at the Speed of Research: BioEnergy Literacy. North American Association for Environmental Education, Ottawa ON.

Hougham, R. Justin (2014) Exploring Energy Literacy: Wood based biofuels and co-products. Wisconsin Association for Environmental Education, Stevens Point, WI.

Hougham, R. Justin. (2014). Education at the Speed of Research: Bio-Energy Literacy Northwest Wood-Based Biofuels + Co-Products Conference, Seattle WA, April 2014

VIDEOS AND WEBINARS

"NARA BioEnergy Literacy" Department of Energy Webinar Series, Energy 101

"Nara BioEnergy Literacy and energyliteracyprinciples.org" Department of Energy Webinar Series, Energy Town Hall

TRAININGS, EDUCATION AND OUTREACH MATERIALS

NARA Matrix, which includes the development of Literacy Assessment for Biofuels, can be delivered through energyliteracyprinciples.org.

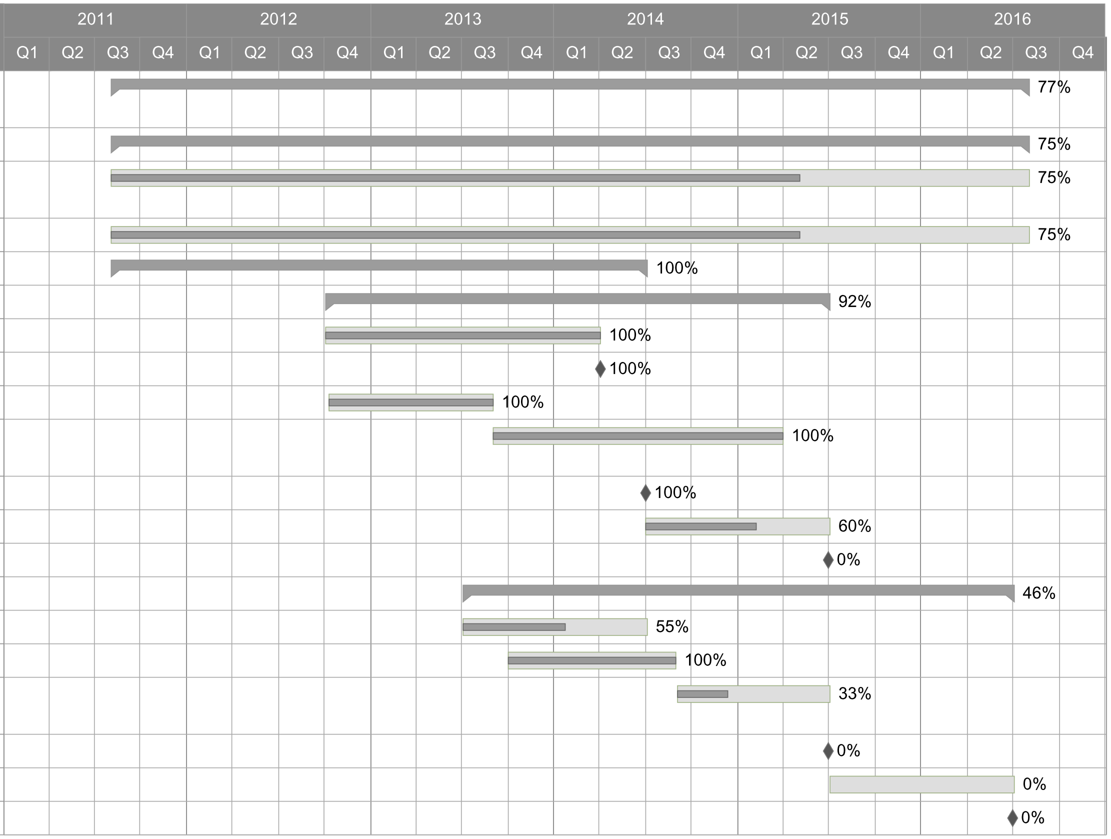
11/8-9/2014 Energy Workshop, Value of a Tree with K-12 Energy Education Project and Facing the Future.

NARA information table, 3 days, Midwest Renewable Energy Association "BioEnergy Literacy" Midwest Renewable Energy Association

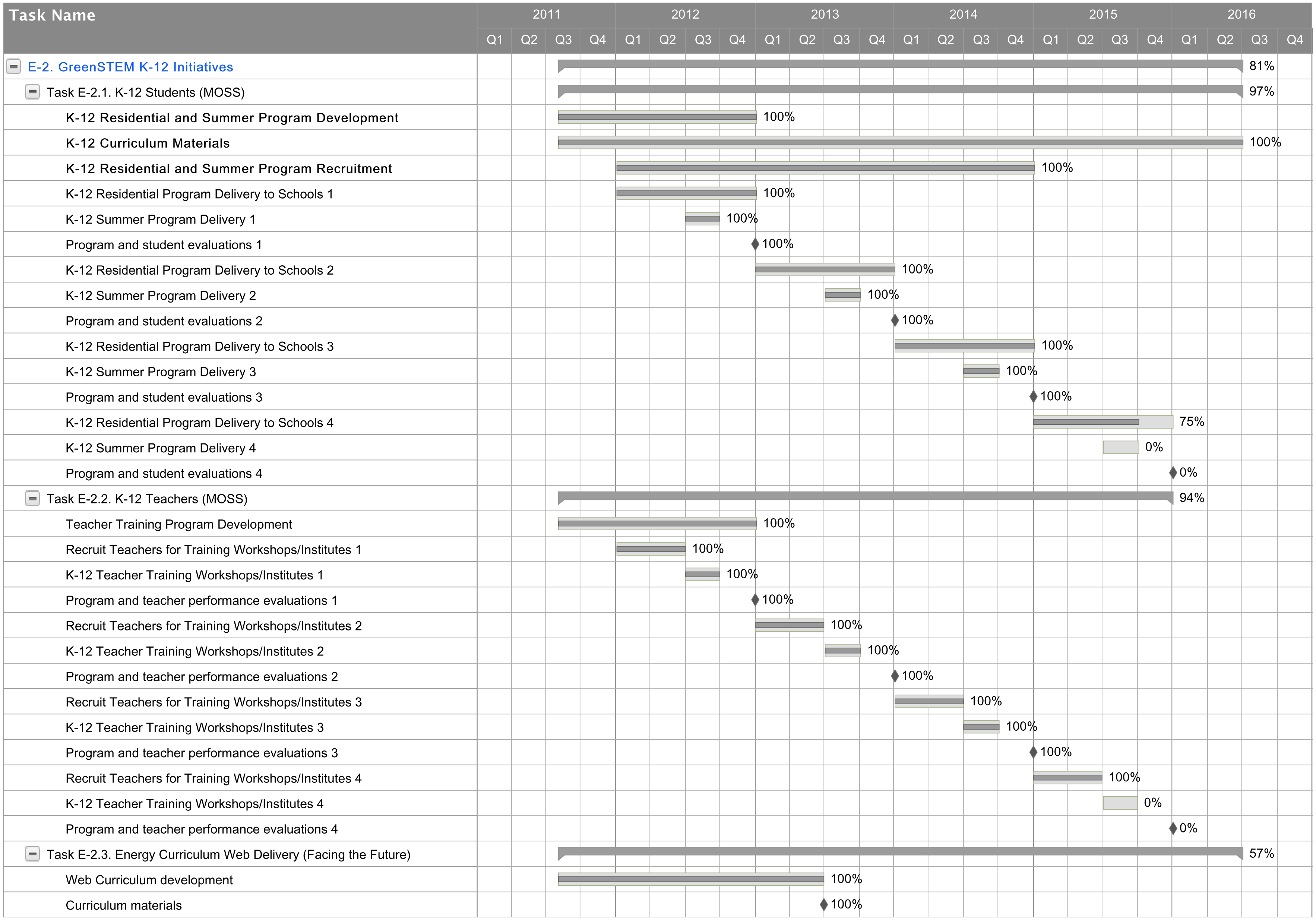
"BioEnergy Literacy" Wisconsin Association for Environmental Education

Education_Schwartz

	Task Name
1	⊟ E-1. Bioenergy and Bioproducts Graduate Education and Research in Partnership with Northwest Tribes
2	⊟ Task E-1.1. Liaison functions with Tribes, Tribal Organizations, Campuses
3	Annual coordination with research sub-committee of Intertribal Timber Council
4	Annual coordination with campus Native American liaison officers
5	⊞ Task E-1.2. Tribal energy research project 1
13	⊟ Task E-1.3. Tribal energy research project 2
14	Establish research collaboration agreement and scope with tribal partner 2
15	Collaboration agreement and scope documents
16	Student Selection for project 2
17	Student activities: Field Trip, Statement of work, research, reporting (oral, written)
18	Student project reports published to web
19	Publications: tribal review, peer review, edit, publish
20	Publication of project final report and journal manuscripts
21	⊟ Task E-1.4. Tribal energy research project 3
22	Establish research collaboration agreement and scope with tribal partner 3
23	Student Selection for project 3
24	Student activities: Field Trip, Statement of work, research, reporting (oral, written)
25	Student project reports published to web
26	Publications: tribal review, peer review, edit, publish
27	Publication of project final report and journal manuscripts



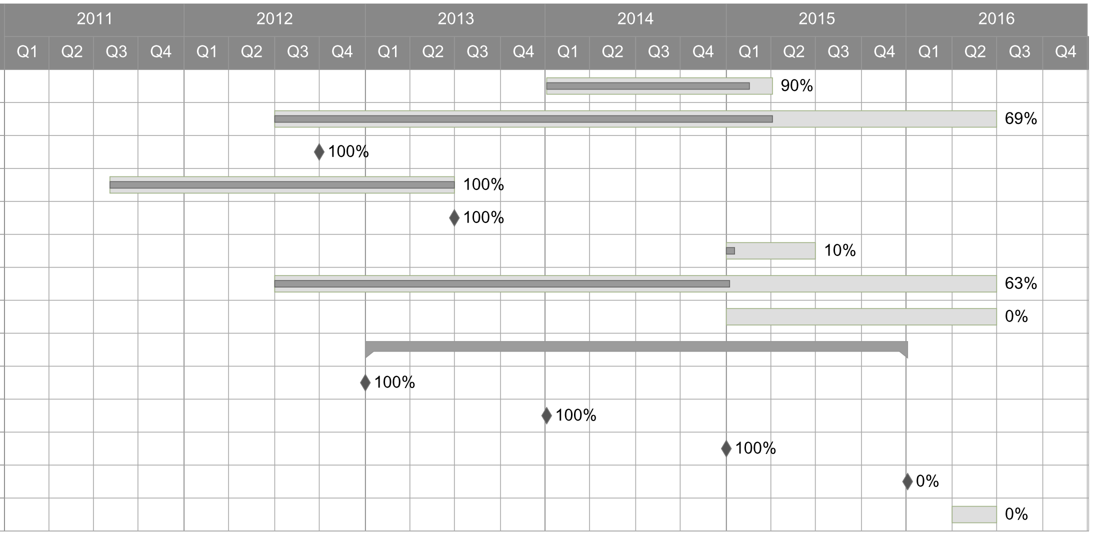
Education_Laninga



	Task Name	
1	E-2. GreenSTEM K-12 Initiatives	81%
2	Task E-2.1. K-12 Students (MOSS)	97%
3	K-12 Residential and Summer Program Development	100%
4	K-12 Curriculum Materials	100%
5	K-12 Residential and Summer Program Recruitment	100%
6	K-12 Residential Program Delivery to Schools 1	100%
7	K-12 Summer Program Delivery 1	100%
8	Program and student evaluations 1	100%
9	K-12 Residential Program Delivery to Schools 2	100%
10	K-12 Summer Program Delivery 2	100%
11	Program and student evaluations 2	100%
12	K-12 Residential Program Delivery to Schools 3	100%
13	K-12 Summer Program Delivery 3	100%
14	Program and student evaluations 3	100%
15	K-12 Residential Program Delivery to Schools 4	75%
16	K-12 Summer Program Delivery 4	0%
17	Program and student evaluations 4	0%
18	Task E-2.2. K-12 Teachers (MOSS)	94%
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 1	100%
23	Recruit Teachers for Training Workshops/Institutes 2	100%
24	K-12 Teacher Training Workshops/Institutes 2	100%
25	Program and teacher performance evaluations 2	100%
26	Recruit Teachers for Training Workshops/Institutes 3	100%
27	K-12 Teacher Training Workshops/Institutes 3	100%
28	Program and teacher performance evaluations 3	100%
29	Recruit Teachers for Training Workshops/Institutes 4	100%
30	K-12 Teacher Training Workshops/Institutes 4	0%
31	Program and teacher performance evaluations 4	0%
32	Task E-2.3. Energy Curriculum Web Delivery (Facing the Future)	57%
33	Web Curriculum development	100%
34	Curriculum materials	100%

Exported on April 24, 2015 4:17:13 PM PDT

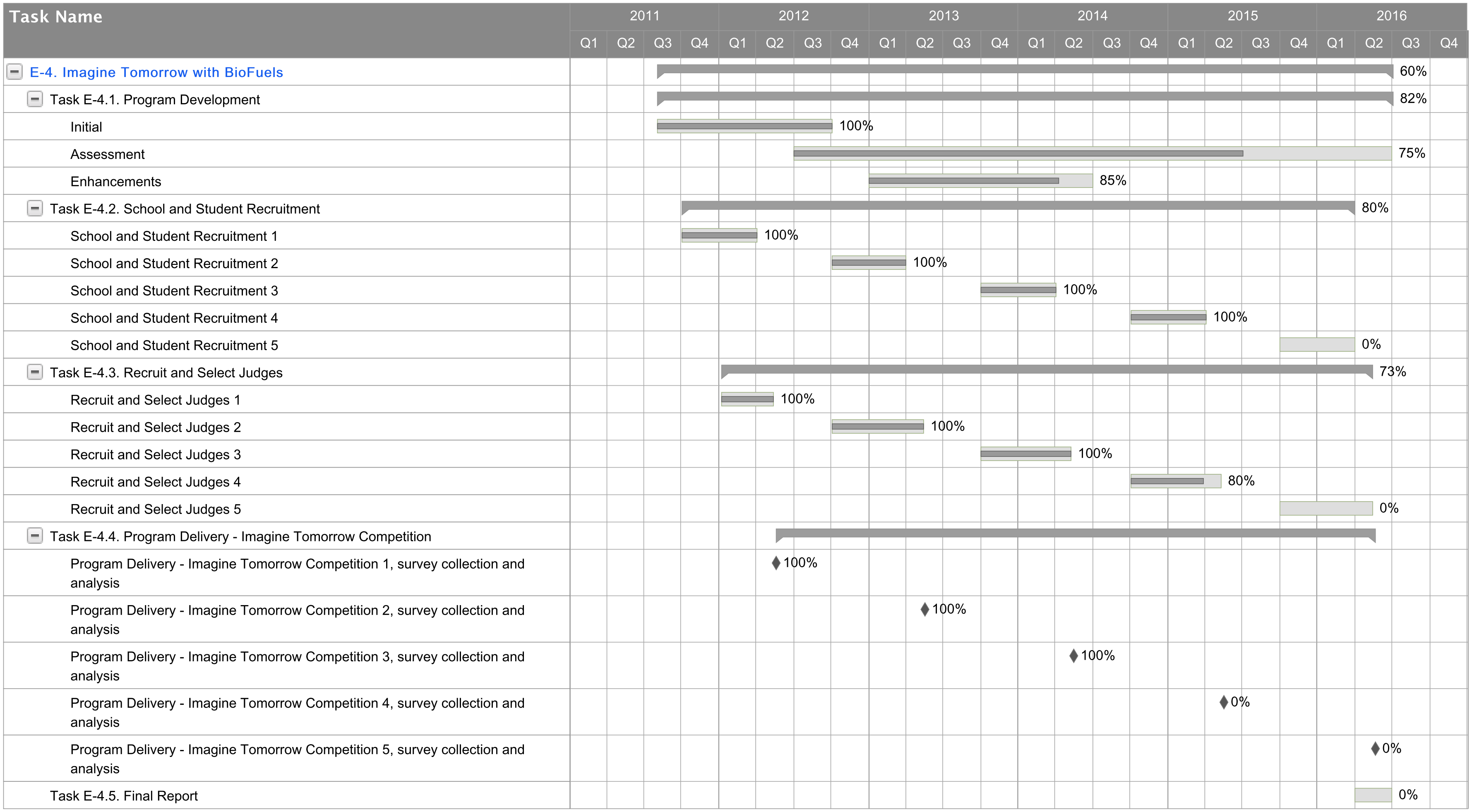
	Task Name
35	Primary Curriculum Materials
36	Web delivery and social marketing
37	Curriculum websites and marketing materials
38	Teacher training development
39	Teacher training program materials
40	Primary Teacher Training Program Materials
41	Teacher training delivery
42	Peer Educator Program
43	⊟ Program and teacher evaluations
44	Program and teacher evaluations 1
45	Program and teacher evaluations 2
46	Program and teacher evaluations 3
47	Program and teacher evaluations 4
48	E-2.4. Final Report



Exported on April 24, 2015 4:17:13 PM PDT

Page 2 of 2

Education_Haselbach

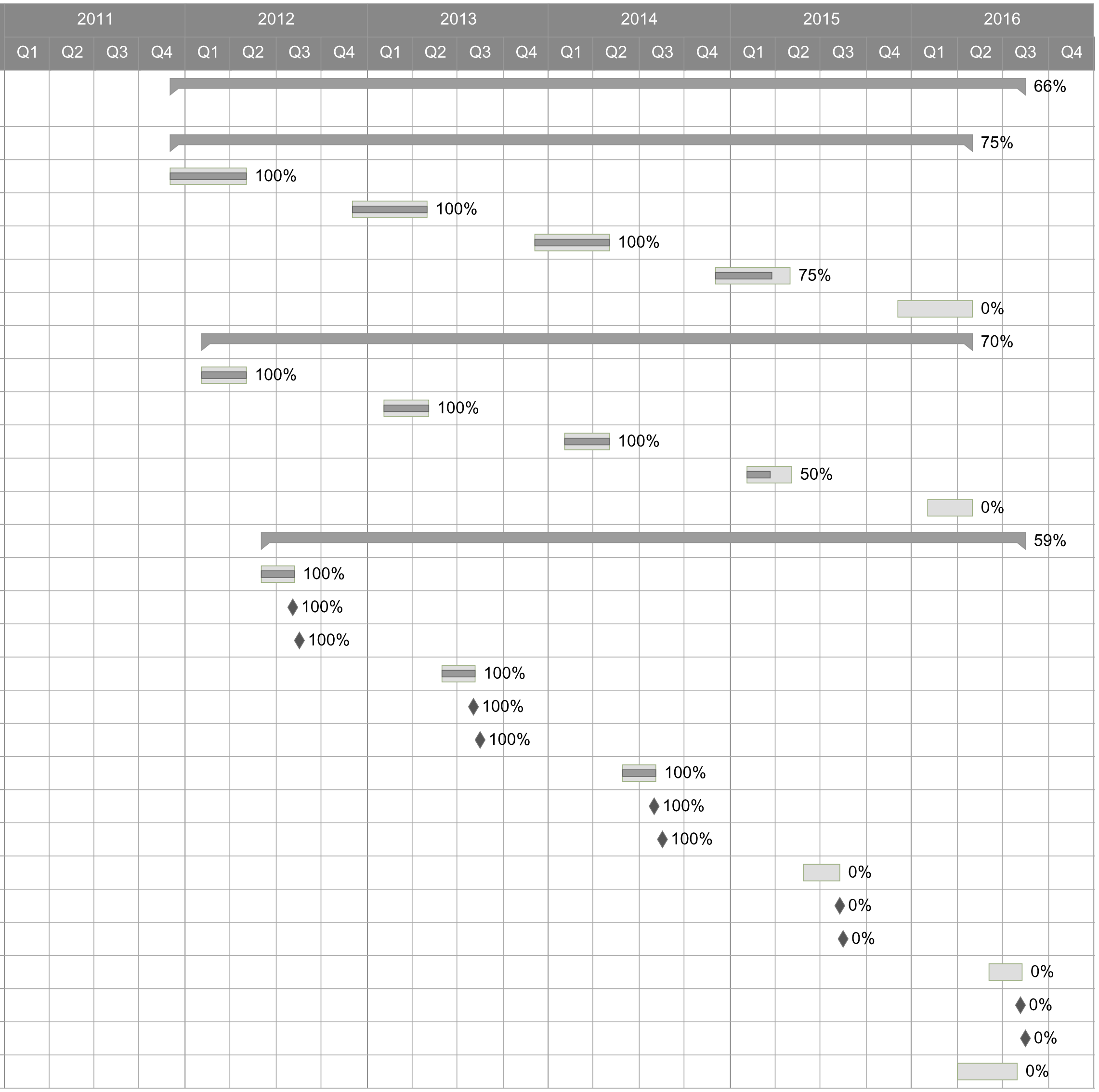


	Task Name	
1	E-4. Imagine Tomorrow with BioFuels	60%
2	Task E-4.1. Program Development	82%
3	Initial	100%
4	Assessment	75%
5	Enhancements	85%
6	Task E-4.2. School and Student Recruitment	80%
7	School and Student Recruitment 1	100%
8	School and Student Recruitment 2	100%
9	School and Student Recruitment 3	100%
10	School and Student Recruitment 4	100%
11	School and Student Recruitment 5	0%
12	Task E-4.3. Recruit and Select Judges	73%
13	Recruit and Select Judges 1	100%
14	Recruit and Select Judges 2	100%
15	Recruit and Select Judges 3	100%
16	Recruit and Select Judges 4	80%
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	100%
21	Program Delivery - Imagine Tomorrow Competition 3, survey collection and analysis	100%
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%

Exported on April 13, 2015 10:40:20 AM PDT

Education_Pressley

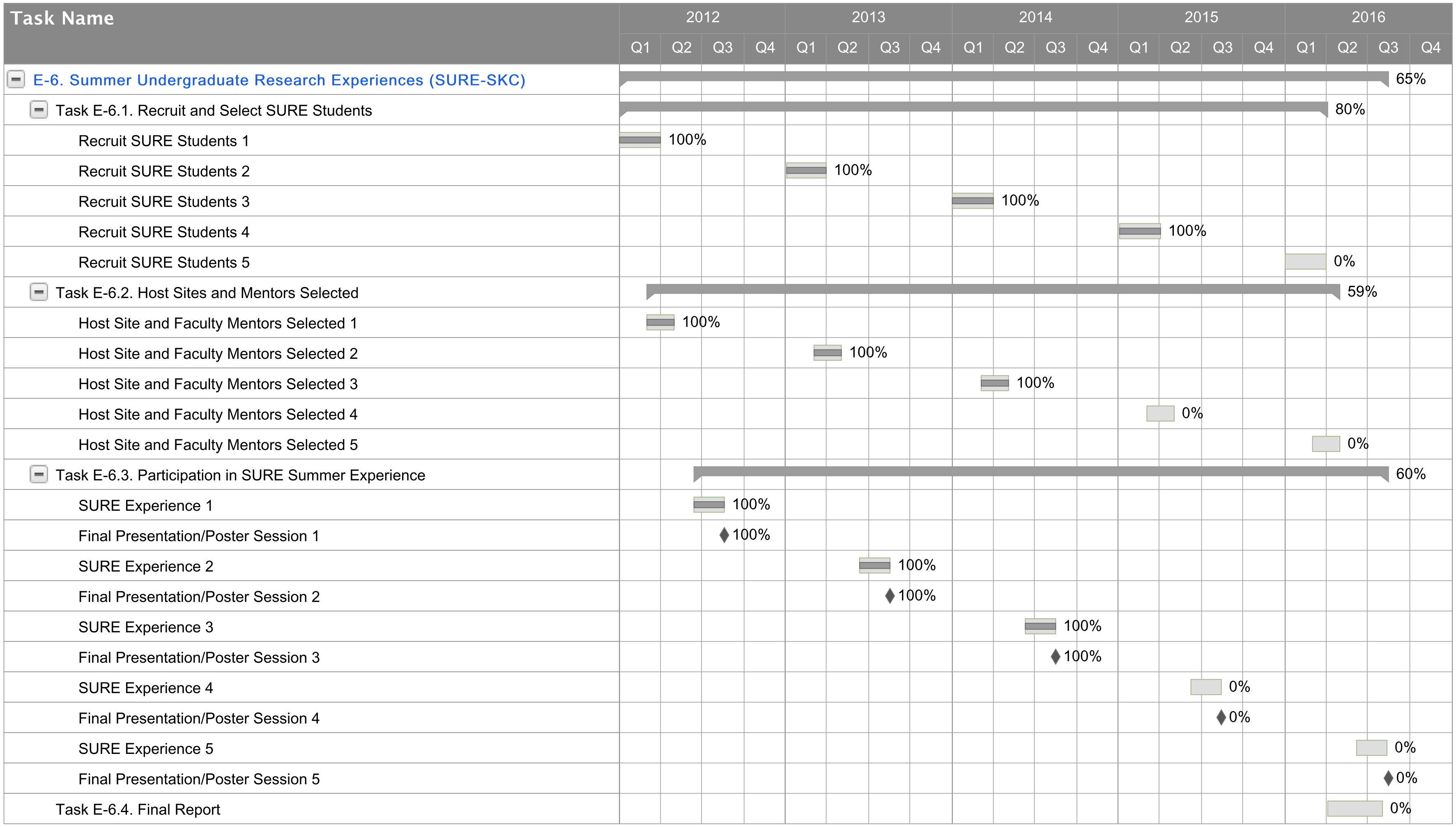
	Task Name
1	E-5. Summer Undergraduate Research Experiences (BF-SURE)
2	Task E-5.1. Recruit and Select SURE Students
3	Recruit SURE Students 1
4	Recruit SURE Students 2
5	Recruit SURE Students 3
6	Recruit SURE Students 4
7	Recruit SURE Students 5
8	Task E-5.2. Recruitment of Faculty Mentors
9	Recruitment of Faculty Mentors 1
10	Recruitment of Faculty Mentors 2
11	Recruitment of Faculty Mentors 3
12	Recruitment of Faculty Mentors 4
13	Recruitment of Faculty Mentors 5
14	Task E-5.3. SURE Experience
15	Task E-5.3.1. SURE Experience 1
16	Poster Session
17	Posters Posted on Web
18	Task E-5.3.2. SURE Experience 2
19	Poster Session
20	Posters Posted on Web
21	Task E-5.3.3. SURE Experience 3
22	Poster Session
23	Posters Posted on Web
24	Task E-5.3.4. SURE Experience 4
25	Poster Session
26	Posters Posted on Web
27	Task E-5.3.5. SURE Experience 5
28	Poster Session
29	Posters Posted on Web
30	Task E-5.4. Final Report



Exported on April 24, 2015 2:59:00 PM PDT

Page 1 of 1

Education_Leighton

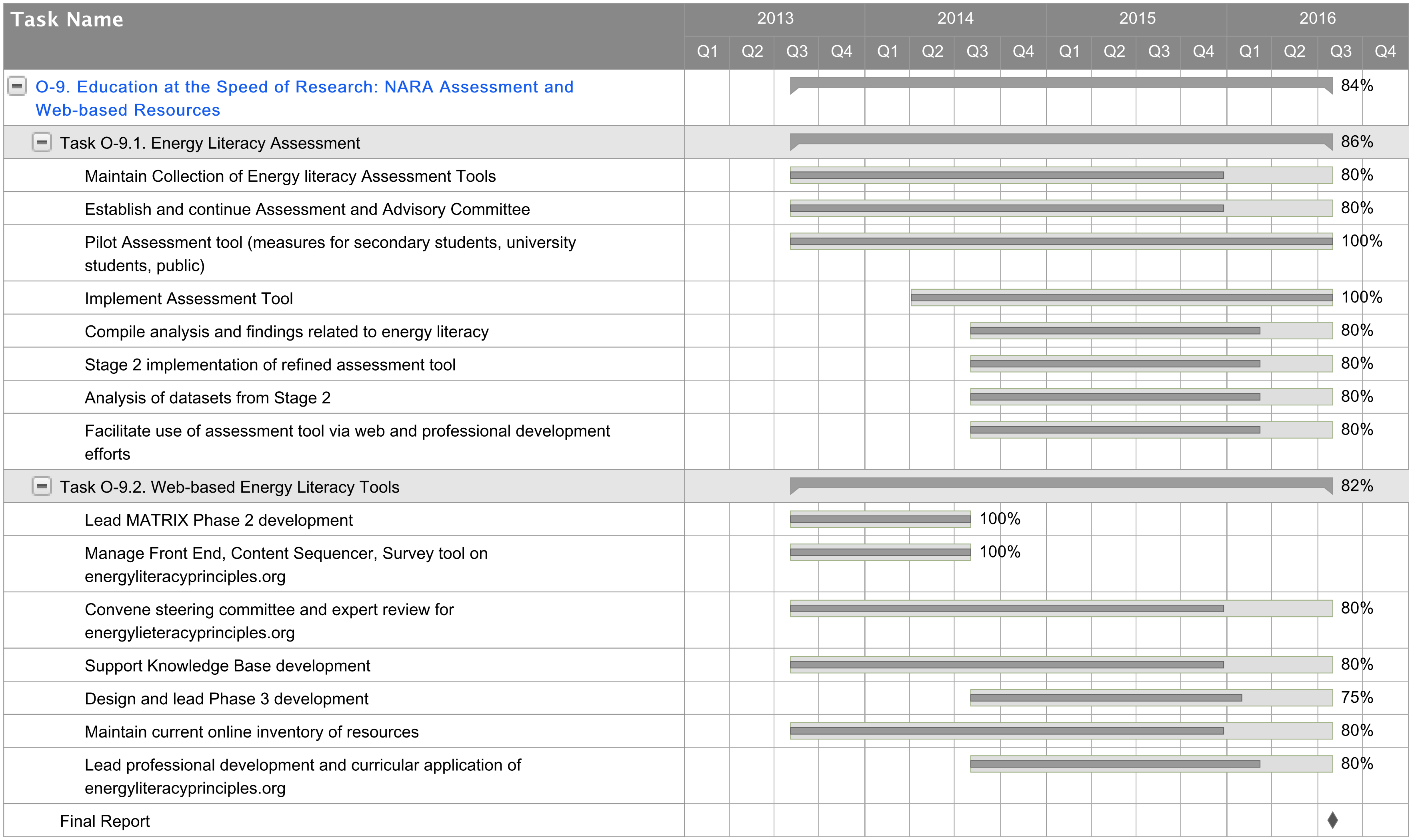


	Task Name	
1	E-6. Summer Undergraduate Research Experiences (SURE-SKC)	65%
2	Task E-6.1. Recruit and Select SURE Students	80%
3	Recruit SURE Students 1	100%
4	Recruit SURE Students 2	100%
5	Recruit SURE Students 3	100%
6	Recruit SURE Students 4	100%
7	Recruit SURE Students 5	0%
8	Task E-6.2. Host Sites and Mentors Selected	59%
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	100%
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	60%
15	SURE Experience 1	100%
16	Final Presentation/Poster Session 1	100%
17	SURE Experience 2	100%
18	Final Presentation/Poster Session 2	100%
19	SURE Experience 3	100%
20	Final Presentation/Poster Session 3	100%
21	SURE Experience 4	0%
22	Final Presentation/Poster Session 4	0%
23	SURE Experience 5	0%
24	Final Presentation/Poster Session 5	0%
25	Task E-6.4. Final Report	0%

Exported on January 12, 2015 4:04:16 PM PST

Page 1 of 1

Outreach_Hougham



	Task Name	
1	O-9. Education at the Speed of Research: NARA Assessment and Web-based Resources	84%
2	Task O-9.1. Energy Literacy Assessment	86%
3	Maintain Collection of Energy literacy Assessment Tools	80%
4	Establish and continue Assessment and Advisory Committee	80%
5	Pilot Assessment tool (measures for secondary students, university students, public)	100%
6	Implement Assessment Tool	100%
7	Compile analysis and findings related to energy literacy	80%
8	Stage 2 implementation of refined assessment tool	80%
9	Analysis of datasets from Stage 2	80%
10	Facilitate use of assessment tool via web and professional development efforts	80%
11	Task O-9.2. Web-based Energy Literacy Tools	82%
12	Lead MATRIX Phase 2 development	100%
13	Manage Front End, Content Sequencer, Survey tool on energyliteracyprinciples.org	100%
14	Convene steering committee and expert review for energylieteracyprinciples.org	80%
15	Support Knowledge Base development	80%
16	Design and lead Phase 3 development	75%
17	Maintain current online inventory of resources	80%
18	Lead professional development and curricular application of energyliteracyprinciples.org	80%
19	Final Report	◆

Exported on April 23, 2015 12:09:49 PM PDT

Page 1 of 1