NARA | EXECUTIVE SUMMARY

August 2011 - March 2013 Cumulative Report

Northwest Advance Renewables Alliance

NORTHWEST ADVANCED RENEWABLES ALLIANCE

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

Executive Summary

August 2011-March 2013

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

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Strategic Analysis

BACKGROUND

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

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

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

APPROACH

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

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

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

Assumptions in this analysis and production scenario are as follows:

- Integrated Biorefinery – 770,000 BDT/yr
- Feedstock - ground slash piles – composition from NARA FS-10
- Greenfield Capital Expenditure (CapEx) Entire Facility

- Commercial Feedstock Costs of $68/BDT delivered to mill gate
- Burn Lignin and Screen Rejects

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

SUMMARY OF FINDINGS

Assuming a complete greenfield construction of an integrated biorefinery, and a 10% internal rate of return, the current cost estimate for producing biojet (IPK) from forest residuals will be 2 to 3 times the current spot market cost of petroleum jet fuel (Figure 1 and Task SM-TEA-1). With optimistic estimates for improved yields throughout the greenfield operation of the process, this value might be lowered to 1.45 times the cost of the petroleum equivalent. Whereas a greenfield operation of the current process is not projected to reach cost equivalency as is, the analysis aids NARA in focusing our work on programmatic efforts that may bring us to cost parity within our current timeframe using different strategies than our initial model. It should be noted that this initial model is a "worst case" scenario for costs and does not investigate many of the production scenarios currently under investigation.

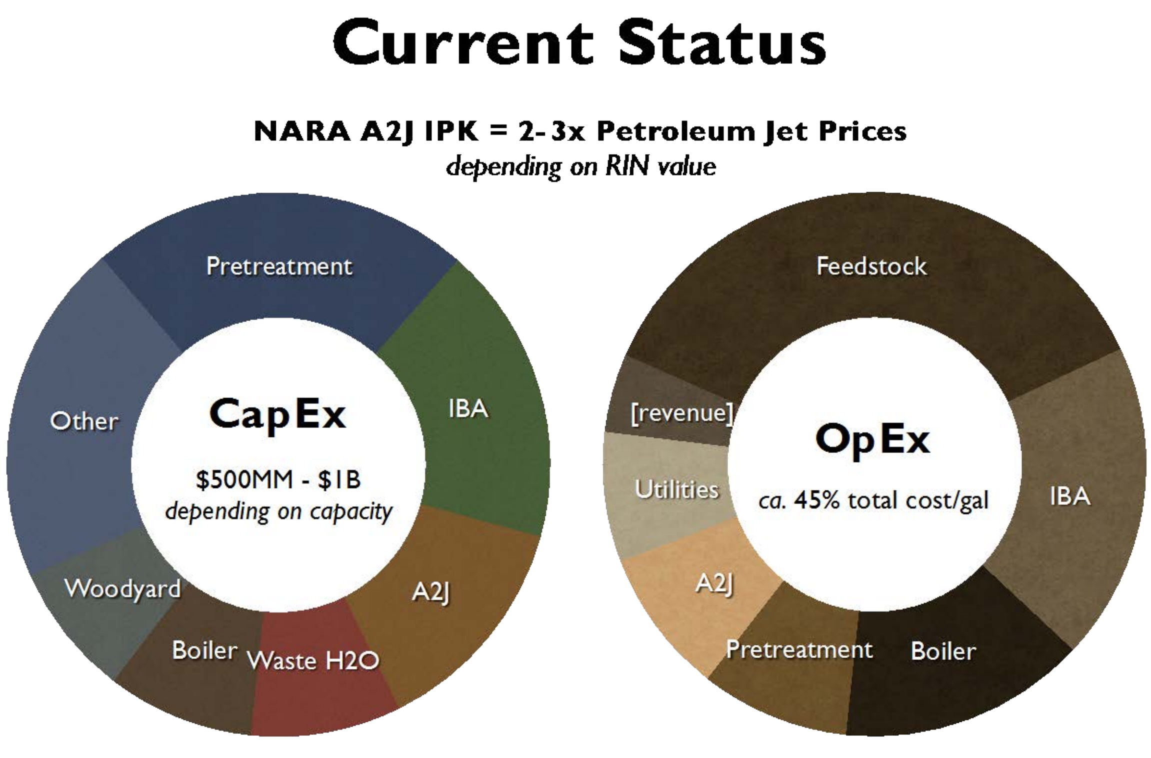

Figure 1: Summary of the current status of the techno-economic analysis for an integrated biorefinery producing biojet (IPK) using forest residuals as a feedstock and assuming a complete greenfield construction. Relative contributions of individual cost centers are provided for the capital expenditures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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

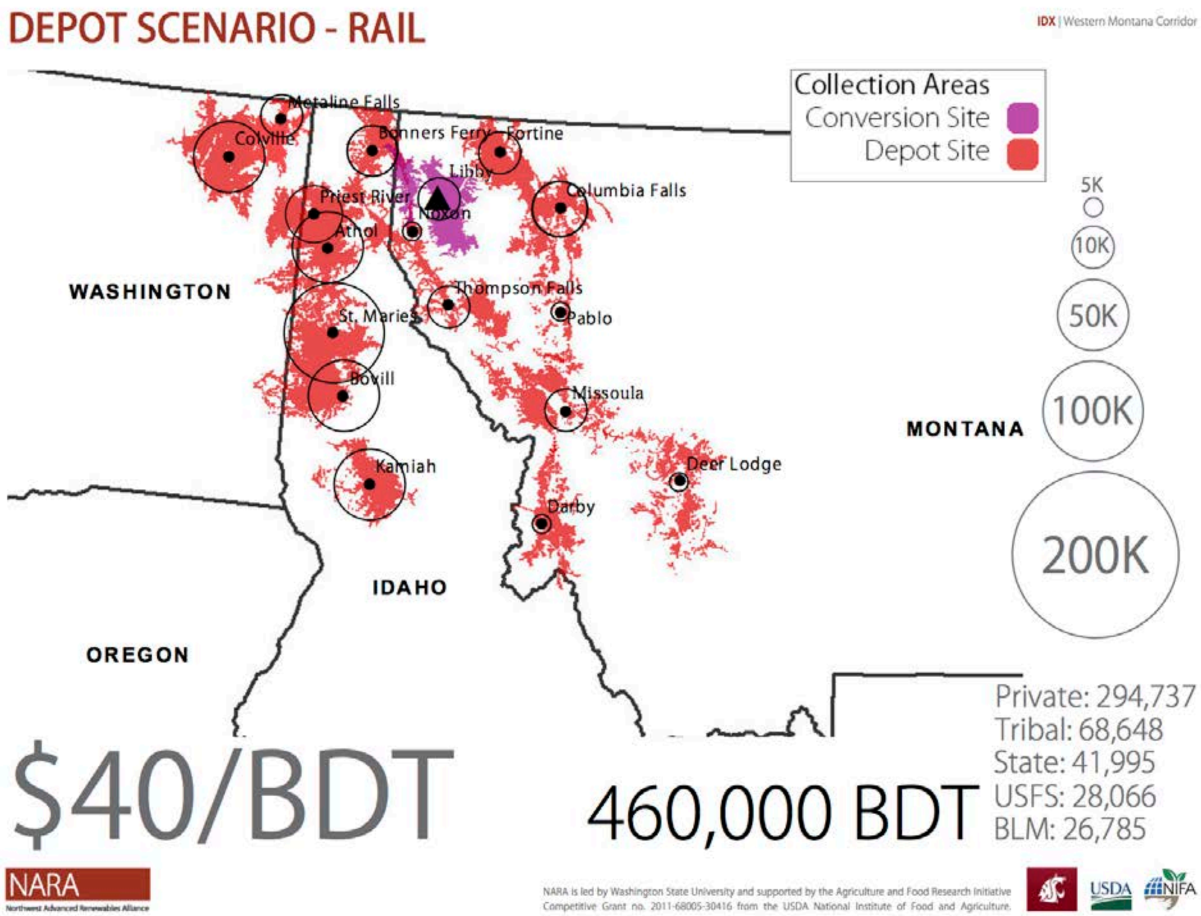

Figure 2: Example depot model for feedstock sourcing at $40/BDT transportation costs in the Western Montana Corridor. Depot sites were located at existing or shuttered primary wood processing facilities with rail sidings and transportation routes into a hypothetical conversion site in Libby, MT. Direct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

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

The mechanisms by which the EPA intends to enforce the RFS mandates are Renewable Identification Numbers (RINs). RINs are unique 38-character numbers assigned to each gallon of renewable fuel and issued to biofuels producers or importers at the point of production or importation (Yacobucci 2012).

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

STRATEGIC FUTURE DIRECTIONS

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

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

- Continue supporting pretreatment technologies that have the potential for economic viability at small scale. Wet oxidation is one such technology, but others should be sought and explored.
- Continue to monitor, reexamine, and when possible, leverage dynamic U.S. biofuels RFS, RIN, and other related policies to better understand opportunities for NARA stakeholders.

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NARA Phase-Gate Model

Description of Phase and Gate

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

Objectives for NARA Phase and Gate

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

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

Implementation and Results from Phase and Gate

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

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

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

The Phase and Gate process continues to evolve and become ever more deeply implemented within the NARA project. We are currently in the process of developing gate frameworks to facilitate comparison of technologies and support additional down select decisions.

Lessons Learned

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

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

PHASE 1: FEASIBILITY ASSESSMENT	
Forest Residue Samples	Feedstock types & inventories for NARA regions complete
Cost Curves	Selection of target supply regions & feedstock types
Conversion Methods; Pretreatment Samples	Pretreatment process yields usable, cost effective sugars & lignin from target feedstock type
Pretreatment Samples	One pretreatment process selected - input from aviation fuels & co-products teams (G)
Conversion Methods	Cost effective production of IPK from IBA from target pretreated feedstock
	Cost effective production of IBA from target pretreated feedstock
Coproduct Samples & Products; Separated Lignin	Lab production of co-products from pretreatment lignin
Value Proposition	Proof of concept application testing of co-products at lab scale
Fuels & Co-products LCA	Slash to fuels LCA model framework complete
Overall Economic Feasibility	Primary leverage points identified from techno-economic analysis
Cost Curves	Feedstock supply scenario model complete
Value Proposition	Market data and EEP input for selection of priority co-products
East/West Pilot Supply Chains; Stakeholder Coalitions	Communities receptive to bio-refineries identified & downselected based on feedstock supply
Educated Workforce; Energy Literacy Matrix	General educatioin on bio-refineries & bio-preferred products for production & end use communities

PHASE 2: FEASIBILITY VALIDATION	
Feedstock Spec	Feedstock specification for target regions to gate & to pretreatment
OPEX; Harvest Transport Methods	Harvest, logistics, & transport leverage points
Cost Curves	Detailed supply cost curves for target regions
OPEX; Pretreatment Samples	Optimized pretreatment process at pilot scale on specification feedstock
Conversion Methods	Optimized IBA production & separation on pretreated specification feedstock
	Optimized IPK production from IBA
	Co-products process design for pilot scale complete
Coproduct Samples & Products; Separated Lignin	Pilot production of co-products from pretreatment lignin
Value Proposition	Testing & confirmation of co-products from customers at lab scale
Fuels & Co-products LCA	LCA complete for slash to fuels, plus co-products
Overall Economic Feasibility	Regionally specific techno-economic analysis complete, including intermediate product scenarios
Carbon Inventory	Carbon inventory complete
Regional Supply Chains; Cost Curves	Feedstock supply model input to feedstock risk & regional cost curves
Value Proposition	Value proposition developed for priority co-products
East/West Pilot Supply Chains; Regional Asset Databases	Target sites selected based on feedstocks, logistics, assets, & community support
Educated Workforce; East/West Pilot Supply Chains	Specific education on bio-fuels and co-products in target regional communities

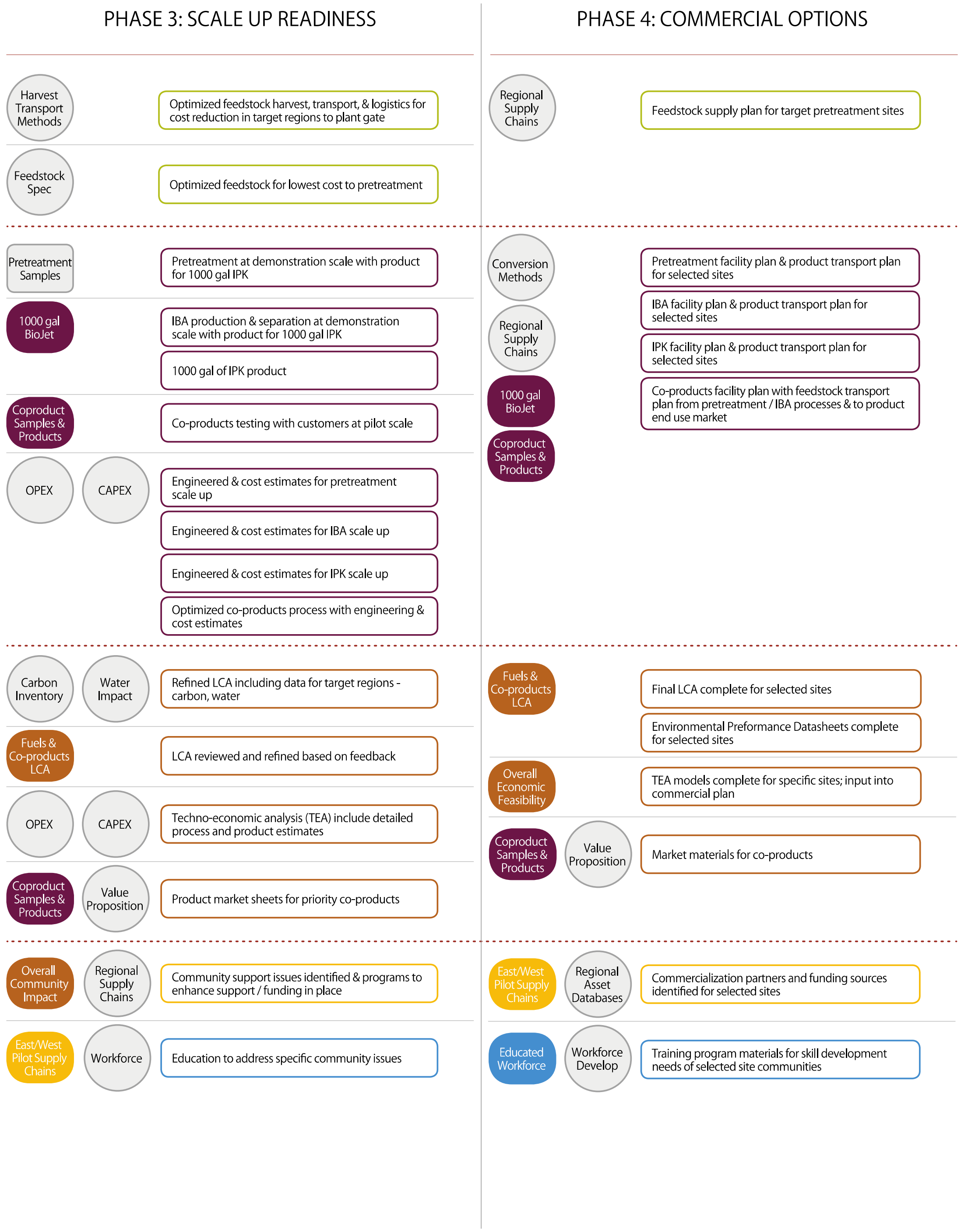

Figure 1: Schematic of NARA Phase and Gate process. Ovals indicate outcomes, elongated rectangles indicate outputs and circles indicate deliverables. Colors align with NARA programs: blue-Education, purple-Conversion, brown-Systems Metrics, gold-Outreach.

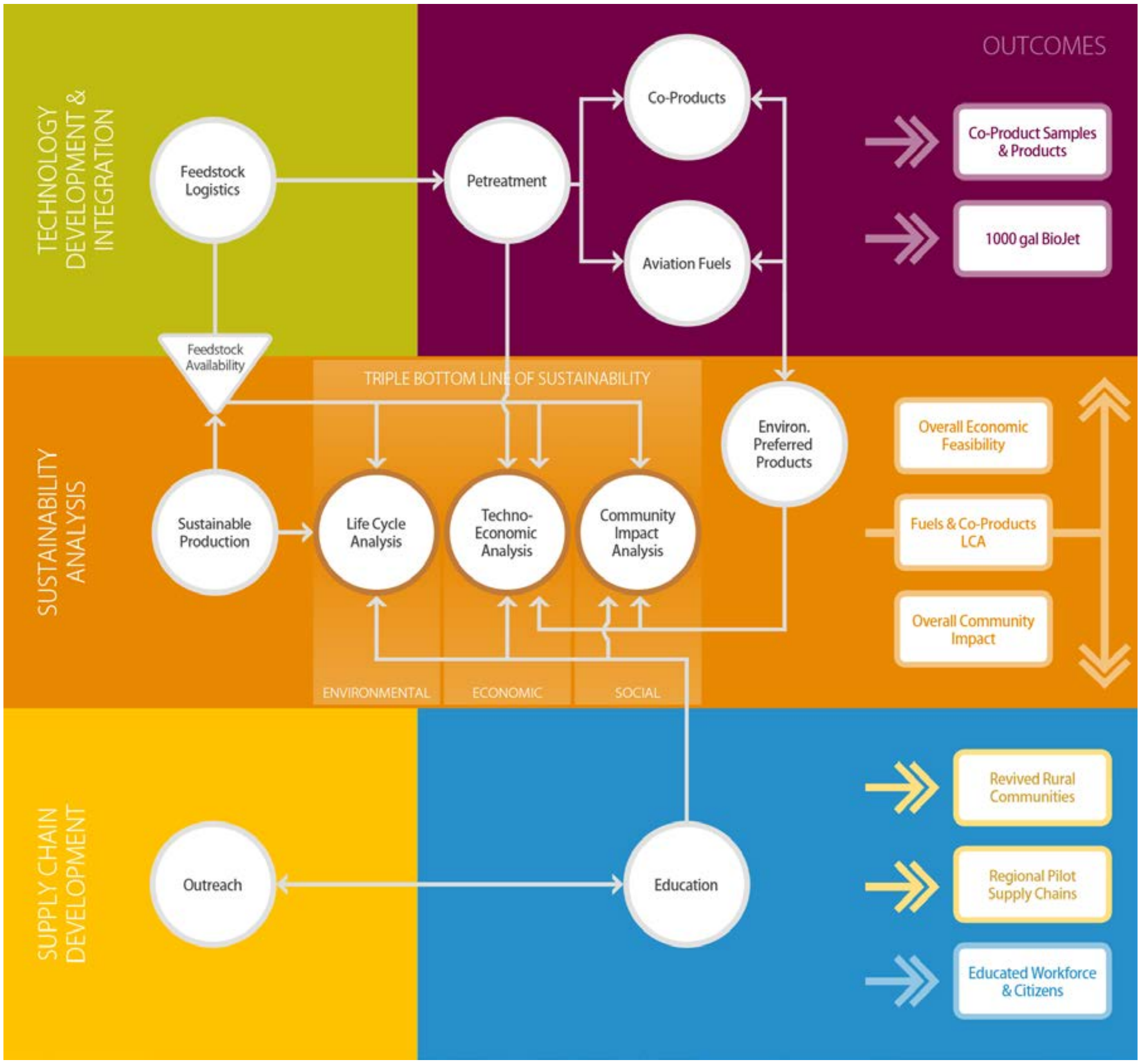

Figure 2: NARA project flow diagram with desired outcomes by project area.

Project Summary

Goal One: Sustainable Biojet

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Goal Two: Value-added Polymer and Carbon Products from Lignin:

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

Based on current estimates, for every bone-dry ton of forest residue converted to isobutanol, 1450 dry pounds of co-product residuals are produced (Tom Spinks presentation at the Idaho Small Log Conference 2013). Approximately 37% of the co-product residual is lignin (550 dry pounds) with the remainder being cooking acids, non-reacted cellulose (polysaccharides), non-fermented monomeric sugars, extractives, bark, yeast bodies, and wood ash (Table 1; Task C-CP-2 each task progress is detailed in progress reports following this summary). The most common strategy for dealing with these residual solids is to recover their fuel value to assist in powering the plant. While this strategy remains as a potential, NARA researchers are developing new lignin-based products that provide a higher value than current commercial lignin use. Creating high-value products from the lignin-rich byproduct is essential to establishing a value-chain to improve profitability of the bio-refinery.

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

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

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

Our final lignin effort is aimed at partially depolymerizing the high molecular weight and recalcitrant form of lignin that results from the enzymatic hydrolysis process. The goal of producing partially depolymerized lignin (DPL) is to create building blocks for engineering high value polymers. In route to this approach, naturally occurring lignomers were evaluated for their use in epoxy. Eugenol was converted to an epoxy with excellent physical and mechanical properties; however, because the technology to convert lignins to eugenol is not currently economical or efficient this task was concluded. Two depolymerization protocols have been evaluated on NARA hydrolysis lignin and Kraft lignin: mild hydrogenolysis and base-catalyzed depolymerization. The partially depolymerized lignin was evaluated as a curing agent for epoxies. A third protocol, phenolation liquefaction, has been applied to hydrolysis lignin with the intent to generate lignin-based polyurethanes and phenolics. (C-CP-3)

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

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

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

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

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

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

Goal Three: Rural Economic Development:

Enhance and sustain rural economic development

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

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

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

To provide more specific information regarding the influence of harvesting forest residuals on sites, soil, and water, the **Sustainable Production Team** evaluates the influence of biomass harvesting scenarios, develops potential forest management prescriptions, assesses forest residual availability from harvest of highly managed stands, and the impact of industry feedstock requirements on overall supply chain dynamics. In whole, this team provides a host of primary data to improve and verify a variety of predicted impacts from this new industry.

The **Environmentally Preferred Products Team** evaluates the social viability of the industry. This analysis of social sustainability investigates stakeholder needs and perceptions, community social assets, market opportunities for biojet and co-products, and governmental regulations and incentives for renewable products.

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

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

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

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

Significant internal outputs to date are:

- A preliminary Social Accounting Matrix for the Inland Empire region has been completed.
- NARA has developed a significant partnership with Potlatch Corporation which is currently pursuing an Affiliate Member status. As part of this partnership, Potlatch has donated a dataset of a major biomass and pulpwood thinning trial for use in the LCA analysis.
- A collaborative relationship with researchers at the University of Idaho was established that enables access to the IMPLAN economic data (UI work supported under NIFA; grant # 2010-04759) needed to facilitate the community impact assessment for the Inland Empire region.
- The preliminary results of the LCA emissions comparison of aircraft burning biojet or fossil fuel suggest that the overall global warming potential of the NARA bio-jet fuel, measured in kilograms of CO2 emissions, is just 38.4% that of fossil fuel-based jet fuel (Table 5; SM-LCA-1). In addition, the ozone depletion potential of the NARA bio-jet fuel is approximately 12% that of fossil fuel-based jet fuel while the fossil fuel depletion potential is 39.1% of fossil-based jet fuel. In other words, our preliminary analysis suggests that there is a 61.6% reduction in the global warming potential, an 88.1% reduction in the ozone depletion potential and a 60.7% reduction in fossil fuel

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

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

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

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

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

Significant internal outputs to date are:

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

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

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

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

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

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

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

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

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

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

Outcomes/Impacts:

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

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

Goal Four: Supply Chain Coalitions

Envision and delineate pilot supply chains within the NARA region

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

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

1. Identifying and engaging key stakeholders and incorporating them into the planning process
2. Cataloging regional supply chain assets, analyzing the logistical and economic relationship among these assets, and providing recommendations and strategies on how best to employ them
3. Communicating researched-based strategies to stakeholders and facilitating business development where feasible

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

The Outreach Team assisted in developing surveys and identified over 300 stakeholders to participate in a stakeholder survey coordinated by the NARA EPP Team (Goal 3; Task SM-EPP-1). Additional surveys to assess stakeholder and youth understanding of biofuels were developed and distributed by the University of Idaho Extension (Figures 1-5; Task O-5; each task progress is detailed in progress reports following this summary).

Ruckelshaus Center/DGSS staff interviewed stakeholders to obtain their input on the formation and management of a NARA Advisory Board (Task O-7).

NARA Outreach team members developed a list of 24 communities/bioregions to be considered as a “NARA Community” and collaborated with the NARA EPP and Education Teams to develop a methodology for pilot supply chain selection. The Outreach Team played a significant role in identifying and coordinating stakeholders within the Western Montana Corridor (WMC) to participate in supply chain development. With the supply chain analysis in the WMC maturing, efforts to organize stakeholders on the west side of the Cascades in Oregon and Washington have come into focus (Task O-4).

To envision regional supply chain assets for providing recommendations and strategies on their utility, the Education Team assists the outreach efforts by forming collaborations between students, NARA mentors and stakeholders to provide the analysis. NARA researchers and university students participate in a year long integrated design course called Bioregional Integrated Design Experience (IDX). In this collaborative course, multidisciplinary student teams analyze biofuels supply chain scenarios in partnership with regional stakeholders. This group developed two regional atlases, one that focused on the Clearwater Basin in Idaho and another that focused on the WMC. Each atlas consists of two parts: a profile that outlines regional assets (natural, physical, human, economic, policy and incentives) and an analysis that provides recommendations for capitalizing on existing infrastructure, site, and natural resources. In developing the atlases, extensive participation and review was provided by members of the NARA Outreach Team, particularly by the Bureau of Business and Economic Research (BBER) at the University of Montana, as well as regional stakeholders. For the WMC, the Forest Products Retention Roundtable of the Montana Forest Restoration Committee served as the focal stakeholder group interacting with NARA (Task E-3, O-3).

A similar collaboration of students, NARA mentors, and stakeholders is employed with the regional tribal stakeholders. NARA is working with tribal foresters on biomass and cost of transport assessments that integrate with landscape management goals for the Confederated Salish and Kootenai Tribe (CSKT) reservation (Task E-1; report is listed under goal 5).

Forest residues constitute a majority of the wood biomass supply considered for producing biojet. Another source of wood residue feedstock is construction and demolition debris (C&D) portion of municipal solid waste (MSW). A preliminary assessment was performed that provides available wood waste quantities and identifies MSW and municipal recycling facilities (MRFs) for each state in the NARA region. A more detailed assessment is provided for the WMC. To determine quantities in regions where solid waste sites and inventory are not recorded, a model approach has been developed (Task E-7).

To communicate the researched-based strategies to stakeholders and facilitate business development where feasible, the Outreach Team played a significant role in orchestrating the NARA annual meeting held in Fall 2012 that attracted over 50 stakeholders and provided a forum for NARA members to exchange information. The Outreach Team maintains a database of regional stakeholders used to disseminate relevant NARA information verbally and electronically (Task O-5). Originally GreenWood Resources was tasked to work with stakeholders to develop hardwood resources, but that project was redirected to explore softwood plantation development (Task O-8).

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

- NARA Outreach team members developed a list of 24 communities/bioregions to be considered as a “NARA Community” and collaborated with the NARA EPP and Education Teams to develop a methodology for pilot supply chain selection (Task O-1).

- Key regional stakeholders have been identified and are in communication with NARA (Task O-1).

- The two regional atlases serve as a tangible reference and roadmap for NARA members and stakeholders (Task E-3).

- Quantitative data on construction and demolition wood waste have been obtained and fill a critical gap in understanding the regional supply of woody biomass available as feedstock. A sum of 647,000 tons of recycled wood waste has been accounted for by MRFs within the NARA region to date (Task E-7).

Outcomes/Impacts:

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

- Establishing the WMC supply chain motivated stakeholders within the region to organize and promote development of supply chain infrastructure for a wood residue to biojet industry. The WMC Atlas provides stakeholders with biofuels supply chain scenarios that will enable the region to identify potential economic development opportunities. The WMC Atlas is an important resource to increase stakeholder's energy literacy, specifically related to using woody biomass to create liquid biofuels (Task O-1, E-3).

Goal Five: Bioenergy Literacy

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

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

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

Programs targeted to **K-12 students and teachers** provide curriculum development and educational programs. The NARA Education Team developed ten energy and biofuels related lesson plans for middle and high school students. These lesson plans were field-tested with students and educators at the University of Idaho's McCall Outdoor Science School (MOSS) and through webinars sponsored by Facing the Future (FtF). Once field-testing is complete, FtF will offer the lesson plans to educators worldwide through web-based delivery (Task E-2; each task progress is detailed in progress reports following this summary).

NARA has partnered with the annual Imagine Tomorrow Renewable Energy challenge for 9th-12th graders at Washington State University. In 2012, NARA's involvement expanded the competition to attract student teams from Oregon, Idaho and Montana as well as Washington, and to include a new "biofuels" competition category. As a result, 433 students participated in 2012 as compared to 363 students in 2011, and the number of biofuels projects increased from 3 to 14 teams over the same time period. An assessment team has been established to evaluate the effects of Imagine Tomorrow on students' STEM career choices and energy literacy. In 2012, this team conducted a preliminary student survey with a 35% response rate and results suggests that participation is having positive effects on students' STEM career related attitudes and interests (Task E-4).

MOSS provided workshops to educate K-12 teachers on bioenergy lesson plans. In addition, MOSS graduate students mentored teachers in preparing students to participate in the Imagine Tomorrow Competition. Assessments that measured teacher literacy and experience followed the workshops. To provide educational resources to K-12 teachers, a web-based bioenergy matrix (http://energyliteracyprinciples.org) was developed that allows teachers to locate bioenergy related resources (lesson plans, images, reference materials) based on energy literacy concepts outlined by the U.S. Department of Energy (Task E-2).

Programs targeted to **undergraduate and graduate students** provide research opportunities that contribute directly to NARA project outcomes. The Summer Undergraduate Research Experience in Biofuels (BF-SURE) is a summer (10 week) research experiences for undergraduate students that provides laboratory, fieldwork, and research skills in the broad area of biofuels and bio-products research. In 2012, eleven students applied and eight were selected and teamed with NARA principal investigators to conduct research and showcase their projects at a poster symposium sponsored by Washington State University. Demographics of 2012 applicants were 36% women, 64% men; and 18% Hispanic, 9% Native American, 9% Asian, and 64% Caucasian (Task E-5).

The IDX course involved undergraduate and graduate students representing a variety of disciplines including engineering, environmental studies, chemistry, community planning, architecture, landscape architecture, construction management and law, to develop the Clearwater Basin and Western Montana Corridor atlases described in the Goal 4 segment of this report. (Task E-5)

Graduate students associated with the University of Washington, Salish Kootenai College and IDX comprise a NARA Tribal Team who are working with tribal foresters on biomass and cost of transport assessments that integrate with landscape management goals for the Confederated Salish and Kootenai Tribe (CSKT) reservation (Task T-E1, T-E6).

Lastly, as of March 31, 2013, NARA funds have supported 43 graduate students working on tasks assigned to the NARA project.

To promote **stakeholder professional development**, web-based mechanisms are established to receive and disseminate information to stakeholders. These mechanisms include a knowledge base repository, a monthly E-newsletter with over 230 subscribers as of March 2013 and a presence in social media. NARA maintains a stakeholder mailing list of over 120 individuals who receive updates to NARA's progress. The NARA project is also linked to various websites hosted by extension groups within the Outreach Team. NARA has co-hosted three symposia/conferences in 2011 and 2012 and has had representative speakers at over 40 conferences worldwide. Eight "NARA one-pagers" have been produced, disseminated to audiences, and posted on the NARA website (Goal 4; Task O-1).

To raise **public energy literacy**, 35 news articles have been published about NARA. The NARA project, in connection with WSU, is featured on a display at the Future of Flight Aviation Center and Boeing Tour, Mukilteo, Washington and was featured at the 2012 Smithsonian Folklife Festival at the Washington Mall. The Future of Flight Aviation Center and Boeing Tour attracts over 225,000 regional, national, and international visitors annually. An additional 75,000 people visit the facility to participate in special events, such activities surrounding delivery of Boeing aircraft, receptions, and school activities. The Smithsonian Folklife Festival attracts over one million visitors each year. To inform policy makers about NARA, the NARA Outreach Team, led by the Ruckelshaus Center, assembled a list of over 1,500 policy-makers in Washington, Oregon, Idaho, Montana and Northern California (Goal 4; Task O-7).

Policy-makers receive quarterly reports of NARA's progress that direct these stakeholders to the NARA web assets. NARA maintains a website which experienced 20,539 individual visits with 83,270 page views from September 2011 to March 2013. Visitations were from all 50 US states and from 114 countries. The term "NARA" in Google now ranks nararenewables.org third. Analytics provided by Alexa indicate that the nararenewable.org web traffic was ranked 2,059,772 worldwide in May, 2013. Rankings for similar AFRI projects during the same time period are 23,772,075 for Advance Hardwood Biofuels Northwest and 18,970,588 for the Southern Partnership for Integrated Biomass Supply Systems (Goal 4; Task O-1).

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

- Based on measured outcomes, both the K-12 student and teacher programs have elevated the level of bioenergy literacy of participants. As a result, the three-pronged approach of direct K-12 student programming, teacher professional development, and development of the web-based Energy Literacy Principle Matrix will be continued (Task E-2).

- The collaborative investment by the K-12 group in teacher mentoring, education in energy literacy and student team support for Imagine Tomorrow has generated increased awareness and participation. Over 20 biofuel projects are entered for the 2013 competition compared to 14 in 2012. This event draws news coverage (see outputs in Task E-4) and introduces NARA to over 140 science and resource based industry leaders as judges to the event. In addition, over 400 high-school students interested in science are exposed to the NARA project. The marketing campaign for 2013 also includes the distribution of energy-based literature in new media (see outputs in Task E-4) that is expected to enhance the interest in the competition and also increase energy knowledge in those who are not able to directly participate (Task E-2, Task E-4).

- The NARA SURE program exposed students to biofuels research work. In 2013, the number of applications has tripled from the previous year and the trend should provide a pipeline for research assistance and increase the number of undergraduate students with work experience related to the NARA project. To date, a total of 38 applicants have been received and offers are currently being made to selected students (3 to date). Demographics of 2013 applicants are 61% women, 39% men; and 11% Hispanic, 3% Native American, 8% African American, 34% Asian/Pacific, and 39% Caucasian (Task E-5).

- The Knowledge Base repository contains unbiased information that covers a broad coverage of biofuels development. It is available to the general public and to date has had a total of 1710 visits from 23 states and 10 countries (Task O-1).

- Establishing a biofuel display at the Future of Flight Aviation Center and Boeing Tour has spurred discussions with Boeing's education outreach staff to include biofuel lessons to K-12 students (Task O-1).

Outcomes/Impacts:

- K-12 Teachers are more knowledgeable about biofuels, biofuels research, and energy. All participants in teacher workshops showed a statistically significant increase in content knowledge related to biofuels, water resources and climate change. K-12 Teachers apply knowledge in energy literacy to assist students successfully develop an approach to answering a problem-based energy issue. In a 9-month follow-up survey, 68% of teachers report being more likely to use a problem-based learning pedagogy after being involved in a MOSS teacher workshop. 90% of teachers report that they learned new ways of teaching. 66% percent of teachers agree or strongly agree that they have a good understanding of biofuels, that they understand key parts of the supply chain and that they have enough of an understanding to have developed an informed opinion about the feasibility of a woody biomass biofuel program in the Pacific Northwest. 45.8% of teachers say that they have been able to incorporate biofuels into their teaching (Task E-2).

- NARA's partnership with the Imagine Tomorrow competition changed this event from a statewide to a Pacific Northwest regional activity and injected biofuels research as a main focus (Task E-2).