WESTERN MONTANA CORRIDOR

SUSTAINABILITY
Techno-Economic Analysis

Northwest Advanced Renewables Alliance

4.1 TECHNO-ECONOMIC ANALYSIS (TEA)

4.1.1 Approach

The NARA Executive Team directed establishment of a TEA founded on the National Renewable Energy Laboratory (NREL) analysis of producing celluloic-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 (http://nararenewables.org/2013-report/).

4.1.2 Summary of Findings

Assuming a complete greenfield construction of an integrated biorefinery, and a 20% internal rate of return, the current cost estimate for producing biojet (IPK) from forest residuals will be 2 to 3 times the current spot market cost of petroleum jet fuel (Figure 3.1.1). 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 equivalence as is, the analysis aids NARA in focusing our work on programmatic efforts that may bring us to cost parity within our current time-frame 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 4.1.1 shows a 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).

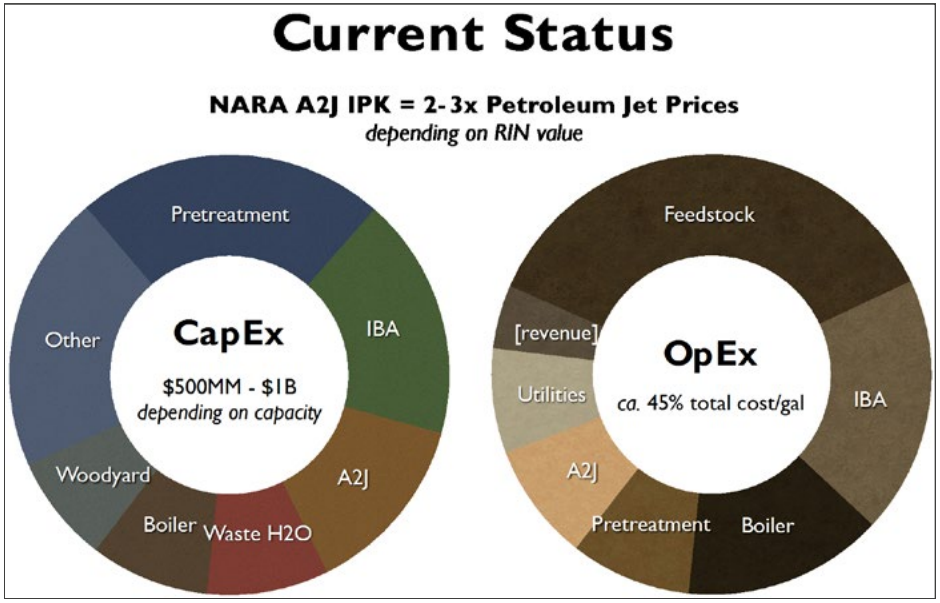

Figure 4.1.1 Current status of the techno-economic analysis

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

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

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

Reducing the capital cost of a biorefinery is necessary to reduce production costs as well as to improve the access to capital for producers. The high capital costs of biorefineries are an issue that is not exclusive to NARA (Table 4.1.1). 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 NARA's goal to establish supply chain coalitions, and it is conducted by our Outreach and Education Teams. Illustrative case studies of how to retrofit existing assets for depot sites and conversion facilities in the WMC are provided in the WMC/Volume 3: Site Selection and Supply Chain Analysis.

Table 4.1.1. shows a 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.

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.

Table 4.1.1. Summary of commercial cellulosic biofuels projects

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

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 fiber-shed, prepare that material, and ship it to conversion facilities. In a recent feedstock sourcing study of the Western Montana Corridor (Figure 4.1.2), 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.

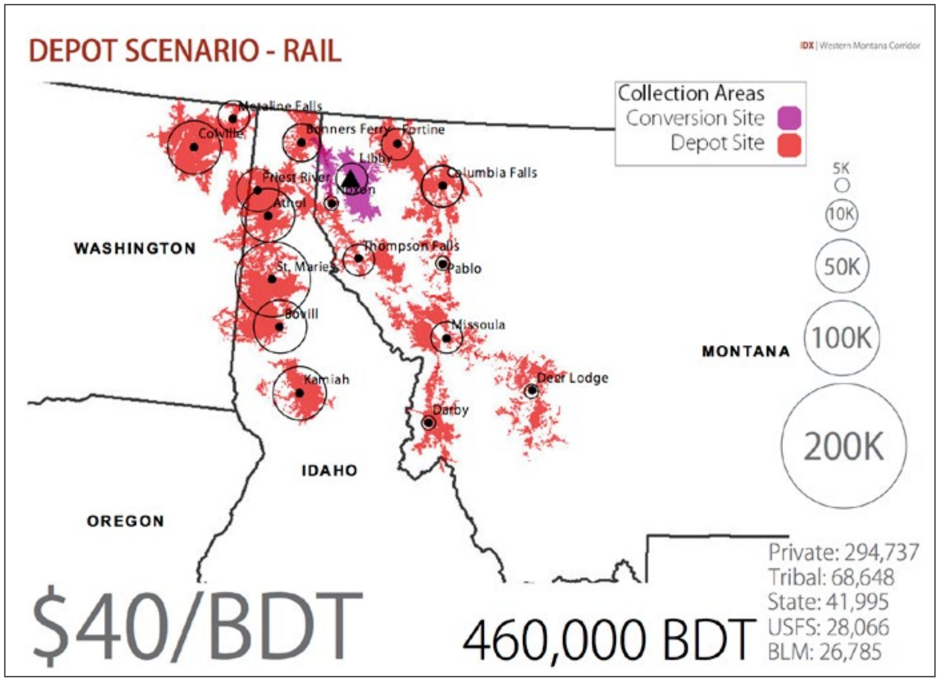

Figure 4.1.2 Example depot model for feedstock sourcing in the Western Montana Corridor

One additional approach that may be successful is to conduct more of the processing at the depot to facilitate shipping of either pretreated or saccharides 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.

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. See Appendix A for further information regarding RINs and the RFS.

4.1.3 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.

4.1.4 References

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