A Biomass Production Cost Calculator: A Decision Tool for Farmers and Investors

(Richard A. Shuren, Gwen Busby, Brian J. Stanton - 2018)

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INTRODUCTION

The Advanced Hardwood Biofuels (AHB) project, led by the University of Washington, is an effort sponsored by the USDA-NIFA under the Agriculture and Food Research Initiative (AFRI) to demonstrate the potential for development of a regional biofuels industry in the Pacific Northwest, using woody biomass from hybrid poplar as the feedstock for conversion to drop-in aviation and transportation fuels. Four poplar demonstration farms are a keystone of this project.

Feedstock of suitable quality and quantity is crucial for refineries to operate efficiently and effectively to produce fuels. A feedstock grower's thorough understanding of the economics and logistics of growing hybrid poplar is an important consideration when deciding to produce biomass feedstock as a profitable crop.

A biomass production cost calculator (BPCC) was created to incorporate the current level of knowledge surrounding all aspects of the production of hybrid poplar biomass into one document. It includes comprehensive lists of farming activities and tasks, equipment costs, fuel consumption, chemical costs and labor costs. Estimates of biomass yield, plus harvesting and transportation costs are combined with anticipated delivered price-per-ton at the refinery to determine the internal rate of return (IRR) to the grower.

This paper focusses on the Willamette Valley of Oregon and the upper panhandle of Idaho where two of the four AHB demonstration farms were established in 2012 and have completed their first two production cycles (Figure 1).[1]

Figure 1. Location of AFRI hybrid poplar demonstration farms.

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[1] The other two demonstration farms located in California and Washington where established one year after the establishment of the Oregon and Idaho farms and their evaluation has not yet been completed. A comprehensive report of all four farms will be filed in 2018.

BACKGROUND

Past research and simulation models using *Populus* in either a pulp wood plantation scenario (Gallagher, 2006) or for biomass production (Strauss, 1989; Steiner, 2010) have shown that there are many hurdles to make the transition from research and development through demonstration phases and into full-scale operation. Near-simultaneous development of the refinery facility and the feedstock production infrastructure is necessary to smoothly launch the industry beyond the demonstration phase into full-scale biofuels production from biomass operations (Steiner, 2010). Much coordination and collaboration between growers, refiners, policy makers and regulators is necessary to avoid pitfalls that could disrupt or possibly deal a death-blow to a proposed biofuels project.

When modelling pulpwood production for the entire United States, simulations indicate that up to 40% of the estimated 9.8 to 14.5 million bone dry metric tons annual demand for hardwood fiber by the pulp and paper industry could be provided by short rotation poplar plantations that would occupy less than one percent of current agricultural crop land or current forest lands nationwide (Alig, 2000). The Pacific Northwest was highlighted as one of several areas where poplar woody crops could be successful (Schneider, 2001).

However, these same models point towards the need for either cost reductions in the production of poplar biomass or significant increases in yields to bring down the delivered cost per ton to the conversion facility. Harvesting and transportation is identified as a significant portion to the overall delivered fiber or biomass price, with recommendations for additional research to improve harvesting efficiency (Gallagher, 2006). Offsetting this is the statement that biomass-based fuels fare proportionately more favorably as petroleum prices increase.

METHODS

The establishment, crop care and harvesting of hybrid poplar biomass at the AHB demonstration farms in Jefferson, Oregon in the Willamette Valley and Hayden, Idaho in the upper panhandle formed the basis for the activities and costs found in the BPCC (Table 1). These two demonstration farms were established in 2012 and have gone through five growing seasons and two harvests, with activities, costs and yields recorded and tracked throughout.

Table 1. Description of two demonstration farms

Location	Total Hectares	Number of Clones	General Site Description
Jefferson, OR	34.4	11	Willamette Valley
Hayden, ID	25.9	7	Upper Panhandle

The BPCC is a set of linked Microsoft Excel worksheets designed to inform a grower of the potential to produce biomass feedstock specific to their region and location. The model begins with selection of a Location and Land type (either leased or purchased). Once selected, land values are drawn from a table specific for each site that came from the U.S. Department of Agriculture (UDSA) website (http://quickstats.nass.usda.gov/). The next step is to define the Schedule (crop production cycle). The schedule is the number of years for the establishment cycle, plus the number of years for each subsequent coppice cycle multiplied by the number of coppice cycles. The rotation length is arbitrarily set to be no more than 20 years, with the establishment cycle and coppice cycles capped at three years and the number of coppice cycles limited to six.

Activities, equipment needs and costs, labor needs and costs and cultural inputs are arrayed in a comprehensive table for each site. This table includes site preparation and establishment activities, crop care, harvesting and transportation inputs. For each activity, there is the ability to specify how many times the activity takes place, the percentage of the field treated by the activity, as well as specific types of equipment and hours of operation. If the activity is a manual labor task, the worksheet accepts inputs for the crew size and number of hours to complete the task. Table 2 shows a portion of the input table for the Hayden, Idaho demonstration farm.

Table 2. Input table for the Hayden demonstration farm.

AHB Site	Hayden Idaho	Upper panhandle farmland 100 acre model	Items in blue can be modified by user.			
CYCLE			Number of Entries	Portion of Field Treated	Type of Equipment	Operator
ESTABLISHMENT						
	Site Preparation	Activity				
		Mowing				
		Spraying	1	1.00	3-Wheel ag sprayer	1
		Tillage	2	1.00	Large tractor	1
		Ripping				
		Row Marking	1	1.00	Large tractor	1
		Pre-emergent herbicide	1	1.00	Small tractor and sprayer	1
		Soil Sampling				
	Planting					
		Transport Cuttings to field	1	1.00	Semi-tractor trailer	1
		Cuttings	145000	1.00		
		Storage	1		Cooler/van	1
		Planting	1	1.00		
	Crop Care; Year (1)					
		Herbicide - dormant	1	0.25		
		Irrigation (ac. in. per season)	8	1.00		
		Fertilization				
		Mowing	1	0.75	Small tractor	1
		Tillage				
		Hoeing	2	0.70		
		Pest control (1)	1	1.00		
		Pest control (2)				
		Herbicide - post-emergent				

Selections highlighted in blue can be modified by the user, so that any listed activity may be added, removed or changed to meet the specific needs of a potential grower (Table 2). Many of the items, such as Type of Equipment have selectable drop-down menus for picking specific items. The left side of the table lists the Cycle (Establishment, Coppice 1, Coppice 2, etc.) and the period in which the activity takes place (Crop Care; Year (1), etc.). This continues down the table for the Establishment Cycle plus six repeated Coppice Cycles. Each Coppice Cycle can have independent inputs for fine tuning the activities and costs, but for the purposes of this paper, successive coppice cycles have identical inputs, as specific data beyond the first coppice cycle have yet to be developed to warrant modification of the inputs. Adjacent to each Activity are columns for the Number of Entries and Portion of the Field Treated. For example, in Table 2 during Crop Care; Year (1), it is anticipated that weed control by hoeing will be necessary two times, but only across 70% of the field during each entry.

Table 3 compares activities between the Jefferson and Hayden demonstration farms from Establishment through Coppice Cycle 1. The types and frequency of activities shown in the lists were compiled based upon AHB's management of the demonstration farms as well as input from GreenWood's operation managers, local farmers and extension staff. It is noteworthy that there are substantial differences in tillage, hoeing and herbicide use for weed control between the two sites. Also, note that the Hayden demonstration farm was irrigated using a wheel-line sprinkler system during the first year, then converted to drip irrigation in subsequent years. The target irrigation rates are shown in Table 3.

Table 3. Comparison of Activities and Number of Entries for the Jefferson and Hayden demonstration farms.

			Jefferson, Oregon		Hayden, Idaho	
CYCLE			Number of Entries	Portion of Field Treated	Number of Entries	Portion of Field Treated
ESTABLISHMENT						
	Site Preparation	Activity				
		Mowing				
		Spraying	1.5	1.00	1	1.00
		Tillage	2	1.00	2	1.00
		Ripping				
		Row Marking	1	1.00	1	1.00
		Pre-emergent herbicide			1	1.00
		Soil Sampling				
	Planting					
		Transport Cuttings to field	1	1.00	1	1.00
		Cuttings	145000	1.00	145000	1.00
		Storage	1	1.00	1	1.00
		Planting	1	1.00	1	1.00
	Crop Care; Year (1)					
		Herbicide - dormant	1	0.25	1	0.25
		Irrigation (ac. in. per season)			8	1.00
		Fertilization				
		Mowing			1	0.75
		Tillage				
		Hoeing	1	0.05	2	0.70
		Pest control (1)			1	1.00
		Pest control (2)				
		Herbicide - post-emergent	1	0.15		
	Crop Care; Year (2)					
		Irrigation (ac. in. per season)			14	1.00
		Fertilization				
		Mowing	2	0.70		
		Tillage			1	1.00
		Hoeing				
		Pest control (1)			1	1.00
		Pest control (2)				
		Herbicide - post-emergent	1	0.30	2	0.75
		Interplant	1	0.05	1	0.05
	Harvesting; Year (2)					
		Cutting	1	1.00	1	1.00
		Off-loading	1	1.00	1	1.00
		Support Vehicle	1	1.00	1	1.00

Table 3 (continued). Comparison of Activities and Number of Entries for the Jefferson and Hayden demonstration farms.

			Jefferson, Oregon		Hayden, Idaho	
CYCLE			Number of Entries	Portion of Field Treated	Number of Entries	Portion of Field Treated
COPPICE 1						
	Crop Care; Year (1)					
		Post-harvest clean-up	1	0.15	1	0.15
		Herbicide - dormant	1	1.00	1	1.00
		Irrigation (ac. In. / season)			14	1.00
		Fertilization				
		Mowing				
		Tillage				
		Hoeing				
		Pest control (1)			2	1.00
		Pest control (2)				
		Herbicide - post-emergent	1	0.10	2	0.75
	Crop Care; Year (2)					
		Herbicide - dormant	1	0.50	1	0.50
		Irrigation (ac. in. per season)			16	1.00
		Fertilization				
		Mowing	1	0.70		
		Tillage				
		Hoeing			2	0.25
		Pest control (1)			2	1.00
		Pest control (2)				
		Herbicide - post-emergent	1	0.05	2	0.25
	Crop Care; Year (3)					
		Herbicide - dormant	1	0.50		
		Irrigation (ac. in. per season)			18	1.00
		Fertilization				
		Mowing	1	0.70		
		Tillage				
		Hoeing			2	0.25
		Pest control (1)			2	1.00
		Pest control (2)				
		Herbicide - post-emergent	1	0.05	2	0.25
	Harvesting; Year (3)					
		Cutting	1	1.00	1	1.00
		Off-loading	1	1.00	1	1.00
		Support Vehicle	1	1.00	1	1.00

Assumptions about the cost of equipment operation, labor rates, fuel prices, biomass yields by year and coppice cycle and land prices are found in the Assumptions tab of the BPCC. Yields are based on actual inventories of the demonstration farms and local yield tables. They represent current best estimates concerning the performance of the top-performing hybrid poplar clones at each site. Yields are expressed as bone dry metric tons per hectare per year (BDMT ha^{-1} yr^{-1}), also known as the mean annual increment (MAI), to facilitate calculation of harvest yields for differing coppice cycle lengths. There is also a Yield Range Selector allowing the user to specify a specific site as high or low yield relative to the average yield for the region. Changes to yields can be entered in the tables as percent increases or decreases from average that are applied when Low or High yields are selected using the modifier.

Fuel prices were taken from the U.S. Energy Information Administration web site (www.eia.gov/petroleum) and entered in the Assumptions. Fuel consumption is calculated based on the horsepower rating of the equipment item using formulas from the State of Virginia Cooperative Extension Publication 442-073, 2014 (Grizzo, 2014). On-farm fuel consumption for a series of 15 herbaceous and woody crops for energy production showed that hybrid poplar ranked 11th lowest when growing and delivering biomass to a processing facility (Carmago, 2013).

Activities involving labor crews, such as backpack spraying or manual weed control are entered in the columns showing the crew size and the estimated number of crew-hours to complete the activity. The model calculates total labor cost assuming there is one supervisor and the remainder of the crew is made up with laborers. Labor rates for both the supervisor and laborer are entered in the Assumptions.

Harvesting is assumed to be done by a single-pass machine that cuts and chips the biomass stems, blowing them into an adjacent off-loading vehicle such as a truck or tractor-wagon. The off-loading vehicle then transports material to the field edge where is it reloaded into trucks for transport to the biorefinery. Harvest costs represent our current estimates for the operation of a single-pass New Holland 9080 forage harvester with a 130 FB coppice header. Operating hours are based on actual harvests of both establishment cycle and coppice cycle biomass material at each location. However, weather and equipment breakdown issues plagued the three-year coppice harvest at both Jefferson and Hayden leading to less than the entire sites being harvested and therefore limited data on which to estimate harvesting efficiency. It is anticipated that with improvements to the 130 FB head, optimization of material handling by off-take systems and better field operating conditions, harvesting costs could be significantly reduced over the costs reported in Table 4.

For the results shown below, harvest is assumed to take place after dormancy, so biomass does not contain leaves. The Hayden demonstration farm was irrigated the first season using wheel-line sprinklers, then converted to drip irrigation the following year. Although the water carried no cost to the project, the cost of pumping water for the Hayden site is estimated at \$6.00 per acre inch[2]. Transportation cost for both sites is estimated to be \$0.08 green ton^{-1} $kilometer^{-1}$ with a travel distance of 64 kilometers to the refinery. To calculate the real internal rate of return (IRR), the consumer price index was set at 2.3%. This was taken from the Bureau of Labor Statistics website (USDL, 2017). For converting green biomass to bone dry weight, the moisture content is assumed to be 58%.

RESULTS

Current best estimates of activities, crop care costs, harvesting costs and yields are arrayed in Table 4. With these inputs, breakeven delivered price for biomass (0% real IRR) shown in Table 5 ranged from \$83.01/BDMT (Jefferson site, purchased land), to \$107.95/BDMT (Hayden site, leased land).

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[2] The Hayden demonstration farm is located on property of the Hayden Area Regional Sewer Board and as such was intended to serve as a simulation of effluent water disposal, thus providing an environmental benefit in addition to growing the biomass. No effluent was applied to the trees during the project, however, due to specific ground water restrictions regarding the actual demonstration farm acres.

Table 4. Inputs used to calculate delivered biomass price.

	Hayden	Jefferson
	$USD/ha	
Land Lease	$ 130.91	$ 187.72
Land Purchase	$ 3,260.40	$ 4,693.00
Site Preparation	$ 303.29	$ 130.02
Planting [1]	$ 673.03	$ 647.63
Crop Care		
Establishment Cycle	$ 963.32	$ 347.25
Coppice Cycle	$ 1,627.68	$ 430.98
Harvesting [2]		
Establishment Cycle	$ 804.73	$ 804.73
Coppice Cycle	$ 1,482.01	$ 1,482.01
Site Restoration	$ 1,482.01	$ 1,482.01
Yield	*BDMT/ha*	
Establishment Cycle	8.6	12.3
Coppice Cycle	42.8	38.5

1/ Includes cost of cuttings, refrigerated storage, transport to the field and labor to plant the cuttings.
2/ Anticipated improvements to the harvesting machine and head, coupled with increased efficiency of the off-take systems could significantly reduce harvesting costs.

Table 5. Delivered biomass price ($USD) per bone dry metric ton (BDMT) for two sites, under two land scenarios

Biomass Price to achieve:	Jefferson		Hayden	
	Land Lease	Land Purchase	Land Lease	Land Purchase
0% real IRR [1]	$ 94.01	$ 83.01	$ 107.95	$ 102.44
2% real IRR	$ 97.47	$ 94.35	$ 113.14	$ 112.72
4% real IRR	$ 101.35	$ 106.71	$ 118.94	$ 124.09
6% real IRR	$ 105.61	$ 120.12	$ 125.27	$ 136.48
8% real IRR	$ 110.26	$ 134.74	$ 132.20	$ 149.99
10% real IRR	$ 115.27	$ 150.49	$ 139.68	$ 162.74

1/ Internal Rate of Return, including anticipated taxes

Interestingly, for each site, purchased land produces lower delivered cost per BDT until interest rates reach about 2.5% for Hayden and about 3.0% for Jefferson, when the leased land option shows lower delivered cost than the purchased land option (Figure 2). This is due to the slope of the lines and results from underlying differences in the cost structure of each land acquisition method. For instance, with land purchase, it is assumed that the land is purchased in the first year, then sold the final year of the investment. The lease option has quarterly payments built in throughout the life of the investment. This difference in the timing and the magnitude of the payment structure accounts for the different slope of the lease versus purchase lines shown in Figure 2. As an example, a biomass price of $110/BMDT delivered to the refinery from the Jefferson site would return about 4.5% under the purchase option, but nearly 8% under the lease option. This difference is due to the embedded leverage of the lease option that requires smaller periodic payments rather than a large early payment to acquire the land. In each case, the grower receives the same cash flow benefit of producing the biomass crop, but the lease option has lower payments up front that benefit the cash flow analysis resulting in a higher IRR.

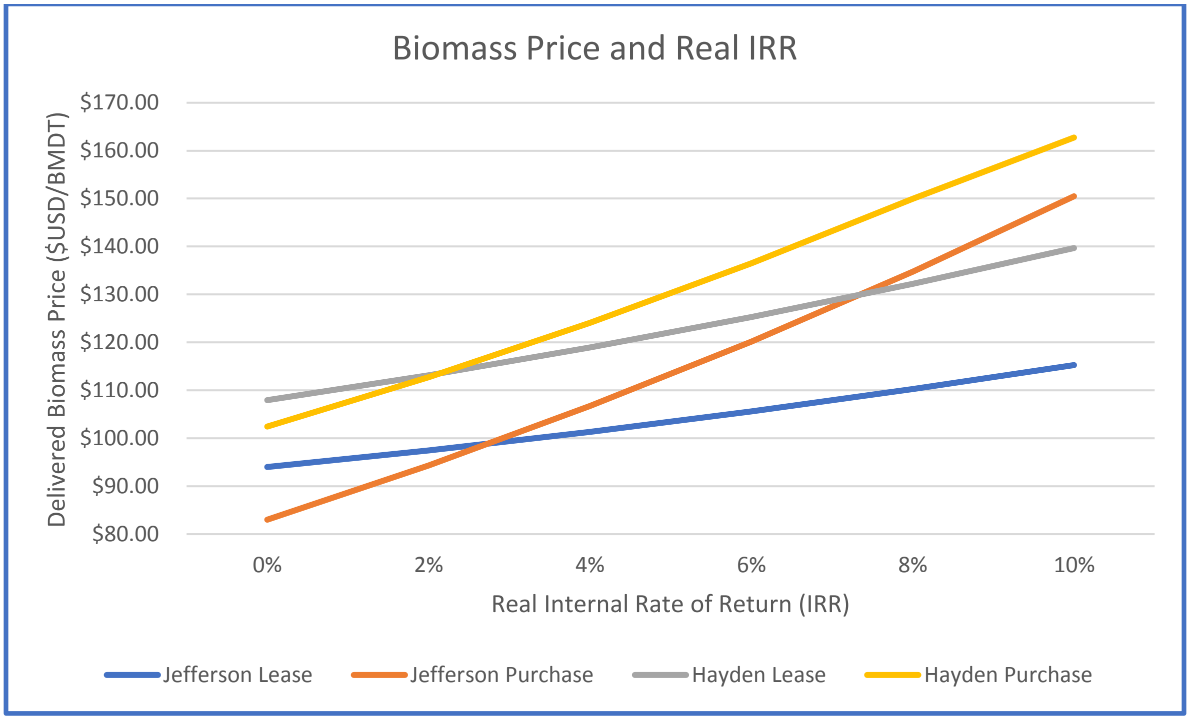

Figure 2. Delivered price of biomass (US dollars/BDMT) as a function of the real Internal Rate of Return (IRR) for two planting locations and two land scenarios.

A typical benchmark real IRR for greenfield development of a biomass project is 5.25% (Chudy, R., publication pending in Biomass and Bioenergy). Using this rate and the inputs from Table 4, delivered biomass prices range from a low of $103.96/BDMT (Jefferson site, leased land) to a high of $122.83/BDMT (Hayden site, leased land).

Discussion

Biorefinery operations require a steady, secure source of feedstock for efficient operation. Dedicated hybrid poplar biomass plantations can be such a source of feedstock. However, to remain cost competitive in current markets where petroleum is trading just below $50 per barrel (http://www.nasdaq.com/markets/crude-oil.aspx) is a significant challenge. Biofuel producers have indicated their weighted average delivered biomass price from all sources should be no more than $77.16/BDMT (Shuren, et al. 2016). The Department of Energy 2016 Billion Ton Report indicated that $88.18/BDMT is a critical threshold for biomass pricing in order to incentivize growers to consider biomass production.

As shown in Table 5, none of the scenarios reach this $77.16/BDMT delivered price, but the Jefferson site, under the purchased land scenario at 0% real IRR does meet the $88.18/BDMT threshold of the 2016 Billion Ton Report. A different way to look at these economics is from the perspective of a blended price when poplar plantation feedstock is combined with other cellulosic sources from the same feedstock basket. Bio-refineries are likely to source multiple feedstock supplies such agricultural wastes that typically sell in the range of $33/BDMT to $55/BDMT (personal communication with Tim Lynch, Owner, AgraTrading, Chico, California). Thus, a blended price is the most realistic metric. One analysis has indicated that if poplar feedstock was priced at $107/BDMT and agricultural waste at $35/BDMT, over 50% of the refinery feedstock could be provided by hybrid poplar while still meeting this goal of $77.16/BDMT weighted average cost (Shuren, 2016). Of course, should oil prices increase, the feasibility of biofuels from cellulosic sources such as hybrid poplar becomes increasingly attractive.

A sensitivity analysis of the internal IRR for the Hayden area using leased land and the same input costs from Table 4 shows that biomass price is by far the greatest determiner of real IRR to the grower (Figure 3). Changes to land lease rates have the smallest impact on IRR. Lowering production costs and harvesting costs also has an impact on IRR, but not to the degree that an increase in biomass price at the refinery. From Figure 3, a change as small as +5% in the biomass price leads to an increase from 5.25% IRR to nearly 7% IRR to the grower.

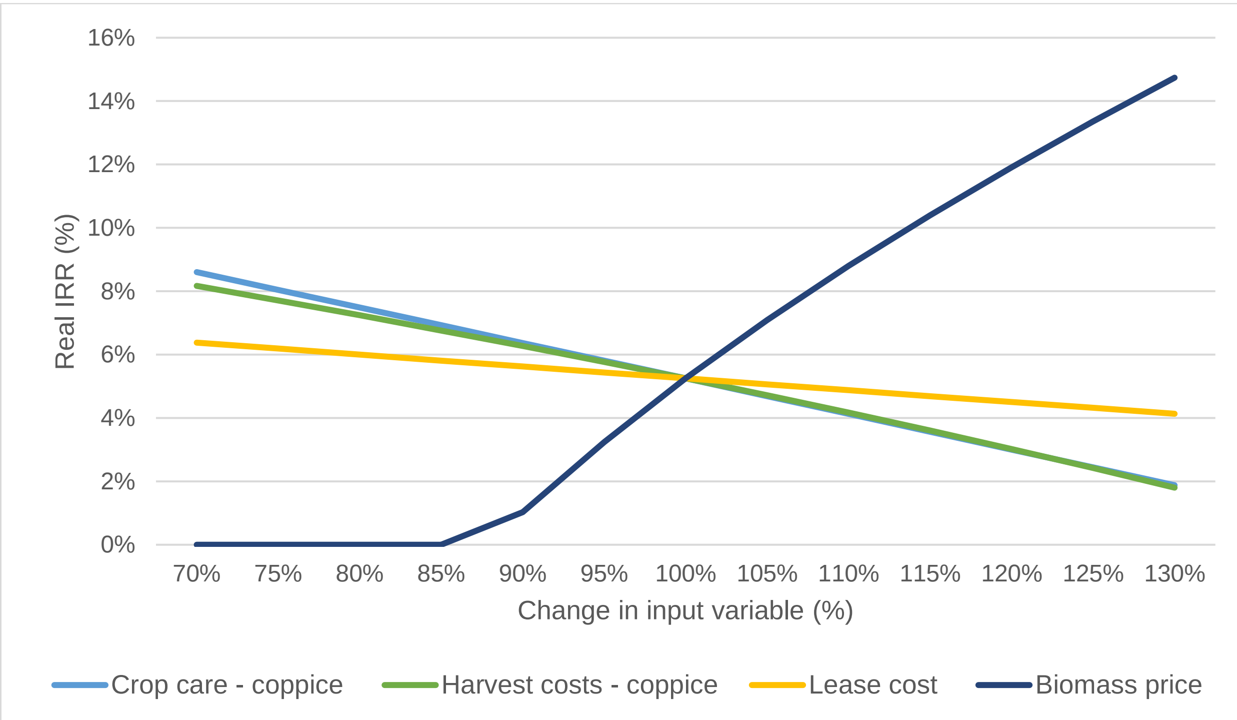

Figure 3. Change in Internal Rate of Return (IRR) as a function of change in crop care costs, harvesting costs, land lease rate and biomass price for the Hayden demonstration farm.

Research within the AHB-AFRI CAP has focused on the areas of crop production, yield increases and harvesting efficiency. Studies in planting density, intercropping with N-fixing red alder (*Alnus rubra*), and tests of improved hybrid varieties for increased yields have taken place at all four of the demonstration farms. Results from these trials will lead to increased yields, thus lowering production costs.

As previously mentioned, total operating hours and costs for the harvester in three-year coppice plantings at Jefferson and Hayden are likely higher that what could be achieved under near-ideal field conditions and operating efficiency. Research to improve harvesting systems is continuing beyond the AHB-AFRI CAP in collaboration with the State University of New York (SUNY) to further refine harvesting equipment and off-take systems using the New Holland 9080 forage harvester and coppice header combined with various collection and off-loading equipment. These efforts are designed to make hybrid poplar biomass production more cost effective and therefore more feasible for a potential grower.

A grower who wants to evaluate the opportunity to grow hybrid poplar in their area faces the question of how to determine potential yields for their situation. The BPCC uses current estimates of yield from the demonstration farms, but a grower can also look at site-specific yields using the 3PG-AHB yield simulation developed by the Sustainability Team of the AFRI-AHB project at the University of California, Davis (http://poplarmodel.org). Site specific yield predictions can be made by selecting locations from an online map. The yield output curves follow the base-case production schedule of two years for establishment followed by repeated three-year coppice cycles. By moving these yields into the BPCC and using their own site-specific best estimates of activities, intensities and costs, the grower can have a highly-localized picture of the overall production cost and returns from hybrid poplar feedstock enterprises. This would then provide key insight into the economics of switching to a biomass crop.

The BPCC worksheets are not a static set of tools, but rather a dynamic model that reflects the current state of knowledge regarding activities and costs. As such, successive updates to the model will take place as additional crop care, harvests and yield information become available. Farmers, investors or other interested users can download a copy of the BPCC from the AHB Biofuels website (http://hardwoodbiofuels.org/) for their own use in determining the feasibility of growing hybrid poplar for biofuels feedstock.

Conclusion

The BPCC is a useful tool for a potential grower to estimate the cost of production and potential returns when growing hybrid poplar biomass for feedstock to produce liquid fuels. The BPCC indicates that using current technology, available hybrid poplar varieties and existing harvesting technology a grower can produce a break even delivered price that meets the $88.17/BDMT of the 2016 Billion Ton Report at the refinery for sites that produce yields of 56 BDMT ha^{-1} or more. However, using the BPCC to calculate delivered cost and biorefinery price necessary to produce a positive internal rate of return indicates that hybrid poplar biomass as a 100% feedstock source for a biorefinery is likely not feasible, given the comparison to transportation fuels produced from today's inexpensive petroleum.

Several possibilities could point to future adoption of hybrid poplar feedstock for liquid fuels:

1. Global increases in petroleum products create a more cost-effective scenario for the use of poplar feedstock;
2. Strategies where poplar feedstock is combined with other less expensive local sources of cellulosic feedstock, such as agricultural waste to meet the requirement of the biorefinery delivered feedstock price on a weighted average basis;
3. Improvements in crop production technology using more efficient farming equipment, increased yields through the introduction of superior performing hybrid poplar varieties, improved methods for crop care and improvements in harvesting and handling efficiency all designed to reduce the cost of delivered feedstock.

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