Methodology for Costing Production and Delivery Options for Energy Crops

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Anthony Turhollow
Bioenergy Feedstock Development Program
Oak Ridge National Laboratory

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Summary of costing methodology

1 Capital recovery (Depreciation and interest)
Calculate depreciation and interest on the value to be depreciated and calculate interest on the discounted salvage value:

$$\frac{(PP - dSV) * \frac{i(1+i)^n}{(1+i)^n - 1} + dSV * i}{h_a}$$

where n = years of life
PP = purchase price
dSV = discounted salvage value
h_a = annual hours of use
h_l = lifetime hours
I = interest (discount) rate

Note that discounted salvage value is used. Purchase price is 90% of list price. Remaining value is based on ASAE methodology revised in 1997 that is based on Cross and Perry. Remaining value at end of year n (% list price) = $100[C_1 - C_2 n^{0.5} - C_3\ ha^{0.5}]^2$, where C_1, C_2, and C_3 come from Table 4 in ASAE D497.4 JAN98 (Table 3).

2 Repairs and maintenance
Equipment is used for its entire useful lifetime to calculate repair costs and thus accumulated repairs (over h hours where h = lifetime) = total life R&M cost (as a fraction)*LP/h where LP is the list price of the machine, h = hours of accumulated use, and lifetime R&M costs come from Table 3 in ASAE D497.4 JAN98.

3 Fuel and lubrication
Average fuel use (gallons of diesel/hour) = $0.73*0.06*hp_{PTOmax}$, where hp_{PTOmax} is the maximum power takeoff (PTO) of the powered equipment in question (from ASAE S495 JAN01). Lubrication cost is 15% of fuel cost. Total fuel and lubrication costs ($/hour) = 1.15*(price of diesel)*($0.73*0.06*hp_{PTOmax}$). In 2001 the national average farm price of diesel was $1.08/gallon.

4 Insurance, housing, and taxes
Follow the AAEA methodology using 2% of the average of purchase price plus salvage value as the annual cost.

5 Labor
Assume 1.2 labor hours per machine hour, a wage rate based on all hired workers from the USDA/NASS publication Farm Labor for four regions in the Midwest (Lake, Cornbelt I, Cornbelt II, and Northern Plains), and a benefits rate of 10%.

6 Overhead
Include an overhead charge of $10/acre in 2001 dollars, where appropriate, such as growing of switchgrass, but not for corn stover as it is a by-product of the corn grain production process.

7 Interest
Assume that operating inputs are charged interest for six months based on the discount rate.

Operation of powered equipment
Incorporate the AAEA assumption that powered equipment operates 10% longer than is required to complete a field operation into our assumptions, but only for operations in the field (e.g. baling, mowing, raking).

Summary of all costs:

Nonpowered equipment

$$\frac{(PP - dSV) * \frac{i(1+i)^n}{(1+i)^n - 1} + dSV * i}{h_a} + \left(1 + \tfrac{i}{2}\right) * \frac{lifetime_repairs}{h_l} + \frac{(\frac{PP + dSV}{2}) * i}{h_a}$$

Powered equipment for field operations

$$1.1 * \frac{(PP - dSV) * \frac{i(1+i)^n}{(1+i)^n - 1} + dSV * i}{h_a} + 1.1 * (1 + \tfrac{i}{2}) * \frac{lifetime_repairs}{h_l}$$

$$+ 1.1 * (1 + \tfrac{i}{2}) * 1.15 * (0.73 * 0.06 * hp_{PTO\max}) * P_{diesel} + 1.1 * \frac{(\frac{PP + dSV}{2}) * i}{h_a}$$

$$+ 1.2 * (1 + benefits_rate) * wage_rate$$

Powered equipment for nonfield operations

$$\frac{(PP - dSV) * \frac{i(1+i)^n}{(1+i)^n - 1} + dSV * i}{h_a} + (1 + \tfrac{i}{2}) * \frac{lifetime_repairs}{h_l} + (1 + \tfrac{i}{2}) * 1.15 *$$

$$(0.73 * 0.06 * hp_{PTO\max}) * P_{diesel} + \frac{(\frac{PP + dSV}{2}) * i}{h_a} + 1.2 * (1 + benefits_rate) * wage_rate$$

Costing methodology

The following costs have to be recovered in cropping and transport operations:

1 Capital recovery (Depreciation and interest)
2 Repairs and maintenance
3 Fuel and lubrication
4 Insurance, housing, and taxes
5 Labor
6 Overhead.
7 Interest

All costing is done in constant dollars. Prices paid for production items in the U.S. Department of Agriculture's Agricultural Prices is used to adjust prices to the chosen base year.

Table 1. Price paid by farmers for production items, 1990-92=100

Year	Index
2001	120
2000	116
1999	111
1998	113
1997	119
1996	115
1995	108
1994	106
1993	104
1992	101
1991	100
1990	99
1989	95
1988	90

Source: USDA/NASS, Agricultural prices, summary (various issues)

The American Society of Agricultural Engineers (ASAE 2001) and the American Agricultural Economics Association (AAEA 2000) have slightly different methods of calculating costs.

1 Capital recovery (Depreciation and interest)

The ASAE lists two different methods, 1) calculate depreciation and interest separately and 2) calculate depreciation and interest on the value to be depreciated and calculate interest on the salvage value [6.2.2 and 6.2.4 in ASAE S495 JAN01 (ASAE 2001)]. This second method is what the AAEA uses. Note that list price (LP) is different from purchase price (PP). Purchase price is used to calculate capital recovery costs. The AAEA indicates that a rough number used is that the difference between purchase price and list price is 15% [p. 6-8[1] AAEA (2000)]. In their example (p. 14-11[1]), the AAEA assumed that the purchase price was 10% more than the list price (or purchase price is 90.9% of list price). I assume that purchase price is 90% of list price.

Let n = years of life
PP = purchase price
dSV = discounted salvage value
h_a = annual hours
h_l = lifetime hours
I = interest (discount) rate

1) Calculate interest and depreciation separately

(PP-dSV)/hl + (PP + dSV)*i/(2*ha)

2) calculate depreciation and interest on the value to be depreciated and calculate interest on the salvage value

$$\frac{(PP - dSV) * \frac{i(1+i)^n}{(1+i)^n - 1} + dSV * i}{h_a}$$

Let us look at an example of how the two methodologies give slightly different answers.

Let n = 12 years, h_a = 1000 hours, h_l = 12,000 hours, PP = $90,000, SV = $20,000, i = 0.06. Because the salvage value is received in the future, it should be discounted [see p. 14-17[1], AAEA (2000)]. The discounted salvage value (dSV) is $20,000/(1.06)^{12}$ = 9,939.

method 1: $9.13/hour
method 2: $9.55/hour.

If the salvage value is not discounted the answers are:

method 1: $9.67/hour
method 2: $10.15/hour.

My suggestion is that we use the second method and with the discounted salvage value.

Salvage value (remaining value) must be computed to determine interest and depreciation. The AAEA (pp. 6-7 to 6-11[1]) shows a number of methods to determine salvage value and estimates salvage value using either the Cross and Perry (1995, 1996) (first choice) or the old ASAE method [p. 14-17[1] AAEA (2000)]. The AAEA states that where there is a good match in the machine types to those listed in the Cross and Perry, these are used. Where there is not a good match with the Cross and Perry categories, the old ASAE equations are used. Interestingly, AAEA states that mixing the two sets of equations is probably not a good idea, but they do it anyway in their examples [p. 14-17[1] AAEA (2000)].

For many years ASAE used the data in the Table 2 to estimate remaining value.

Table 2. Pre 1997 equations used by the ASAE to calculate remaining values

Equipment class	Remaining value (% list price) as end of year n
Tractors	$68(0.920)^n$
Combines, cotton pickers, self-propelled windrowers	$64(0.885)^n$
Balers, forage harvesters, blowers, self-propelled sprayers	$56(0.885)^n$
All other field machines	$60(0.885)^n$

Source: ASAE (2001)

The ASAE revised these equations in 1997 and used Cross and Perry (1995, 1996) as one source for their data [ASAE D497.4 JAN98 Table 4 (ASAE 2001)]. Cross and Perry and ASAE have the same categories. The revised coefficients used in the following ASAE equation:

remaining value at end of year n (% list price) = $100[C_1 - C_2 n^{0.5} - C_3\, ha^{0.5}]^2$

are below (Table 3).

Table 3. Coefficients for the ASAE remaining value equations (Table 4 in ASAE D497.4 JAN98)

Equipment type	C_1	C_2	C_3
30-79 hp tractors	0.9809	0.0934	0.0058
80-150 hp tractors	0.9421	0.0997	0.0008
150+ hp tractors	0.9756	0.1187	0.0019
Mowers	0.7557	0.0672	-
Balers	0.8521	0.1014	-
Combines	1.1318	0.1645	0.0079
Swathers and all other harvest equipment	0.7911	0.0913	-
Plows	0.7382	0.0510	-
Disks and all other tillage equipment	0.8906	0.1095	-
Planters	0.8826	0.0778	-
Manure spreaders and other miscellaneous equipment	0.9427	0.1111	-
Skid-steer loaders and all other vehicles	0.7858	0.0629	0.0033

Source : ASAE (2001)

Note that only powered equipment has a coefficient (C3) on hours of annual use. In the revised ASAE equations, remaining values are calculated for windrowers, forage harvesters using the swathers and all other harvest equipment category, telescopic handlers using the skid-steer loaders and all other vehicles category, and wagons using the manure spreaders and all other miscellaneous equipment category. The AAEA recommends using the revised remaining value from ASAE [p. 6-10[1] AAEA (2000)]. Where equipment is missing one would need to use the pre 1997 ASAE equations.

For some example values, for a tractor that has a life of n = 12 years and h_a = 1000 hours the old and the new salvage value formulas give the following as a fraction of list price:

30-79 hp old: 0.25001 revised: 0.22462
80-150 hp old: 0.25001 revised: 0.32653
150+ hp old: 0.25001 revised: 0.25347.

For a round baler with life of n = 2.5 years and h_a = 600 hours the old and the new salvage value formulas give the following as a fraction of list price:

old: 0.41262 revised: 0.47855.

My suggestion is that we use the revised ASAE (Cross and Perry based) method for

determining salvage value and where equipment types are not listed in the revised method, use the old (pre-1997) ASAE method.

Remaining values for buildings is difficult to estimate and a common method used is simply to estimate a long life and minimal salvage value [p. 6-11[1] AAEA (2000)]. For collecting corn stover this is not a major issue. For the cubing operation this is important for the equipment (dryer, cuber, conveyers) and buildings. I have assumed that the building have a 20-year life with no salvage value and the equipment has a 15-year life with a 10% (undiscounted) salvage value at the end of their useful lives.

2 Repairs and maintenance

ASAE uses the following for estimating repair and maintenance costs:

accumulated repairs (over h hours) = $RF1*LP(h/1000)^{RF2}$,

where LP is the list price of the machine, h = hours of accumulated use, and RF1 and RF2 come from Table 3 in ASAE D497.4 JAN98, Agricultural machinery management data (the original source of the data) or Table 5.2 in AAEA (2000). (These two tables, 3 and 5.2 are identical.) When h = the hours of useful life, then accumulated repairs equal lifetime repairs from tables 3 and 5.2 mentioned above. I assume that equipment is used for its useful lifetime. All RF1 and RF2 do is spread repair costs over time, spreading more cost to later in a machine's life. With this assumption the formula simplifies to:

accumulated repairs (over h hours where h = lifetime) = total life R&M cost (as a fraction)*LP/h,

where LP is list price, and total life R&M costs and estimated life in hours come from tables 3 and 5.2 mentioned above.

The AAEA either recommends using this formula and averaging repair and maintenance costs over time [i.e. average repair costs/hour = accumulated repairs (over h hours)/h = $RF1*LP(h/1000)^{RF2}/h$] or a more complex procedure [p. 5-30[1] AAEA (2000)].

Example: let h_l = 12,000 hours, LP = $90,000, Total life R&M = 100% of list price, RF1 = 0.007, RF2 = 2.0

Average repair cost per hour = $0.007*\$90,000*(12,000/1000)^2/(12,000 \text{ hours})$
= $7.56/hour

Using the simplified formula, average repair costs per hour = 1.0*90,000/12,000 = $7.50/hour. The answers would both be $7.50/hour if RF1 were more precisely specified as 0.006944. If one wants to assume that the machine will be used less than the lifetime hours, then one needs to use the formula with RF1 and RF2.

I assume that equipment is used for its entire estimated life to calculate repair costs and thus accumulated repairs (over h hours where h = lifetime) = total life R&M cost (as a fraction)*LP/h where LP is the list price of the machine, and h = hours of estimated life and

lifetime R&M costs come from Table 3 in ASAE D497.4 JAN98.

3 Fuel and lubrication

The ASAE has two methods for computing fuel consumption. In ASAE S495 JAN01:

average fuel use (gallons of diesel/hour) = $0.73*0.06*hp_{PTOmax}$, where hp_{PTOmax} is the maximum power takeoff (PTO) of the powered equipment in question.

It is stated that this is an estimate for tractors. In ASAE D497.4 JAN98:

fuel use (gallons of diesel/hp-hour) = $0.52X + 0.77 - 0.04(738X+173)^{0.5}$

where X is the faction of the maximum PTO used for a particular operation. It is stated that this is an estimate for tractors and combines. If one assumes that X averages 0.5 then the two methods give similar answers. The ASAE (2001) states that if one wants to determine the average fuel consumption over a range of loads and over a period of time, one should use the first equation, from ASAE S495 JAN01. We use the first equation.

The amount of lubricating oil used can be estimated using equations from ASAE. However, this is not necessary. The ASAE estimates that lubrication costs, including the oil and filter, is 15% of fuel costs.

Total fuel and lubrication costs ($/hour) = 1.15*(price of diesel)*($0.73*0.06*hp_{PTOmax}$). In 2001 the national average farm price of diesel was $1.08/gallon. This price is for onfarm use.

4 Insurance, housing, and taxes

The AAEA refers to this as taxes, insurance, and shelter (TIS). If actual data are not available the ASAE suggests using the following: taxes 1.00%, housing 0.75%, and insurance 0.25%, for a total of 2% of purchase price as the annual cost of insurance, housing, and taxes. In their examples the AAEA uses 2% of the average of purchase price plus salvage value. Note that these two numbers will be different. For a machine with no salvage value the ASAE methodology gives annual costs twice as high the AAEA methodology. One would expect that insurance (presumably this is property insurance) and taxes (presumably this is property tax) would go down as equipment is depreciated. However, one would not expect housing costs to decrease as a machine ages. The appropriate methodology is probably somewhere in between these two methodologies.

I suggest that we follow the AAEA methodology using 2% of the average of purchase price plus salvage value.

5 Labor

Farm labor rates can be obtained from a publication by the National Agricultural Statistics Service of the U.S. Department of Agriculture, Farm Labor which is published quarterly (USDA/NASS). They list a number of farm labor rates: field, livestock, field and

livestock, and all hired workers for 18 regions of the United States. I have decided to use the wage rate for all hired workers in four regions making up the Midwest. Data for 2000 to 2002 for farm wage rates are shown in the Table below for the Midwest of the United States.

Table 4. Wage rates for all hired workers in the Midwest

	2002				
Region	January	April	July	October	Average
Lake	9.91	9.88	8.33		9.37
Cornbelt I	9.75	9.23	9.13		9.37
Cornbelt II	9.74	9.34	9.20		9.43
Northern Plains	9.00	9.22	8.72		8.98
Average	9.60	9.42	8.85		9.29
	2001				
Lake	9.53	9.57	8.38	9.21	9.17
Cornbelt I	10.10	8.62	8.66	9.53	9.23
Cornbelt II	9.05	8.80	8.10	8.78	8.68
Northern Plains	9.11	8.89	8.24	8.68	8.73
Average	9.45	8.97	8.35	9.05	8.95
	2000				
Lake	8.83	8.55	8.45	9.05	8.72
Cornbelt I	9.32	8.69	8.23	8.39	8.66
Cornbelt II	8.13	8.08	8.39	7.90	8.12
Northern Plains	8.34	7.80	7.64	8.41	8.05
Average	8.66	8.28	8.18	8.44	8.39

Sources: USDA/NASS, Farm labor (various issues)

In their examples the AAEA includes no benefits for farm workers except in their example of a California cotton-almond farm in the San Joaquin Valley. For the farm in the San Joaquin Valley they use a 34% benefits rate. Our work, for most part, does not deal with California. I would expect a farmer to only pay required Social Security and Medicare taxes (7.65%), state unemployment taxes, and any other required taxes. For our purposes I use a fringe benefits figure of 10%. Based on the 2001 data for the four region of the Midwest, the average wage rate was $8.95/hour.

It is a common assumption in crop budgeting that more labor time is required than machine time in the field. The AAEA assumes that 1.2 labor hours are required for each machine hour. This is the assumption that we have been using and will continue to use.

Assume 1.2 labor hours per machine power, a wage rate based on all hired workers and the USDA/NASS publication Farm Labor for four regions in the Midwest (Lake, Cornbelt I, Cornbelt II, and Northern Plains) plus a 10% benefits rate.

6 Overhead

In the past I have not included overhead in our cost calculations. Overhead includes such items as: office expense; fuel, lube, and utilities (not previously included in the machinery cost estimates); maintenance and repairs on buildings & improvements and machinery & equipment (not previously included in the machinery cost estimates); and farm insurance (not previously included in the machinery cost estimates) [Schedule 14.8 in AAEA (2000)]. The AAEA includes overhead which varies by crop. In 1992 dollars (and converted to 2001 dollars using prices paid by farmers for production items, in 1992 = 101 and in 2001 = 120) the AAEA used the following in their examples:

	1992 dollars	2001 dollars
corn:	$ 9.73/acre	$11.56/acre
soybeans	$10.68/acre	$12.69/acre
alfalfa	$ 4.54/acre	$ 5.39/acre.

In the their examples the AAEA does not explain how they come up with how much overhead to allocate to each farm activity (crop and animal).

My suggestion is that we should include an overhead charge of $10/acre in 2001 dollars, where appropriate, such as growing of switchgrass, but not for corn stover as it is a by-product of the corn grain production process.

7 Interest

The AAEA charges interest on operating expenses (e.g. fertilizers, fuel) and states that there is general agreement that interest should be charged on farm operations. However, there is no single agreed upon method of calculating interest charges, and the AAEA lists three alternatives. I choose their second alternative and assume that operating inputs are charged interest for six months based on the discount rate. For corn stover the operating inputs are fuel and lubrication, repairs, and twine for baling. Based on my assumptions baling incurs about a $0.30 to $0.40 interest on operating expense charge, or less than 1% of the delivered cost (including grinding) to the conversion facility.

Operation of powered equipment

The AAEA assumes that powered equipment operates 10% longer than the time required for field operations. (Powered equipment includes tractors, self-propelled windrowers, self-propelled forage harvesters, and combines.) I have not been using this assumption, nor is this one of the assumptions the ASAE makes. What this assumption means is that is 0.20 hours is required to complete a field operation such as raking an acre, then the tractor had to run 0.22 hours, but the rake was only operated 0.20 hours. It seems reasonable to assume that the power equipment operates some additional time above that required by the unpowered equipment. But is 10% reasonable?

Right now we look at field equipment and assume a typical field efficiency that ASAE

has estimated for each equipment type. How is field efficiency defined? Hunt (1995) elucidates a concept that he calls time efficiency. There are 10 elements that involve labor:

1) Machine preparation time at the farmstead (could be any place away from the field)
2) Travel time to and from field
3) Machine preparation time in the field both before and after field operations
4) Theoretical field time (i.e. time actually spent in optimally performing the intended field operation)
5) Turning time and time to cross nonproductive areas (e.g. grassed waterways)
6) Loading and unloading time
7) Machine adjustment time
8) Maintenance time in field
9) Repair time
10) Operator's personal time.

Field efficiency is defined as item 4) divided by the sum of items 4) to 9). Thus items 1, 2, 3, and 10 are excluded in calculating field efficiency. Is the equipment running an extra 10% of the time for times 1, 2, 3, and 10 above the time required for field operations?

What this assumption means is that the costs of capital recovery; repairs and maintenance; fuel and lube; and insurance, housing, and taxes; of powered equipment is 10% higher per acre (hectare) than I have been assuming. What is typically done in crop budgeting is to determine an hourly cost based on an hour in the field. There are a number of ways to incorporate the extra 10% time for power equipment into the budgeting process. One need to make sure that one appropriately accounts for this assumption.

Let us look at an example using a 120 hp tractor with a round baler with megatooth pickup and crop processor. Mesh wrap costs $2.76/dry ton. The equipment cost in $/hr is:

tractor	32.45
tractor (10% additional time)	34.51
round baler	28.08
megatooth pickup	1.55
crop processor	13.37

The total baler cost is $43.00/hr. Assume that we bale 5.69 dry tons of stover/hour. Costs are:

10% additional time for tractor	without 10% additional time for tractor
$16.38/dry ton	$16.02/dry ton

So baling cost increases by 2.3% with the assumption that the tractor runs an additional 10% time above that required for the field operation.

When I costed operations such as transporting bales or loose stover from the field to a storage facility, I assumed an 80% field efficiency. What this means is that I calculated the amount of take it took to load bales on the truck, drive over the road, weigh at a scale, unload, and travel back to the field and then assumed that it actually took 25% (1/0.8-1) longer to actually complete the operation. I think that for out of the field operations this adequately captures the additional 10% time that AAEA is saying that a power machine operates in the field.

I propose that we incorporate the AAEA assumption that powered equipment operates 10% longer than is required to complete a field operation into our assumptions, but only for

operations in the field (e.g. baling, mowing, raking).

A comparison of results based on the revised and old methodology

I changed the methodology in my logistics model spreadsheet for corn stover collection, packaging, transport, and storage to conform to my recommendations in this document. Also, I corrected a few minor errors, updated the model from 1997 to 2001 dollars, and updated some of the input prices. The end results of all these changes are shown in Table 5. The resulting changes are relatively minor, varying from $0.28 to $1.10/dry ton, or between 0.8% and 4.9%.

Table 5. Changes in delivered prices for a selected number of corn stover packaging options

	Methodology				
	old (1997$)	old (2001$)	revised (2001$)	difference (2001$)	difference (%)
Packaging system	Delivered to intermediate storage ($/dry ton)				
Large round bales-mesh	24.62	24.83	25.79	0.96	3.9
Large rectangular bales	22.59	22.78	23.89	1.11	4.9
Silage to compacted bales	30.01	30.26	30.79	0.53	1.7
Whole plant to compacted bales	17.31	17.46	17.74	0.28	1.6
	Delivered to conversion facility ($/dry ton)				
Large round bales-mesh, ground	38.77	39.10	40.17	1.07	2.7
Cubes-stover at 20% moisture, stover fuel	48.49	48.90	49.31	0.41	0.8

Note

[1]The AAEA revised its Commodity costs and returns estimation handbook in 2000. I have this as a PDF file and the earlier 1997 version as a printed document. The revisions appear to be minor. However, the pagination between the two versions is slightly different and I list the page numbers referred to in this document from these two versions in the following table.

Page number from 2000 PDF file	Page number from 1997 printed version
5-30	5-28
6-7 to 6-11	6-7 to 6-11
6-8	6-8

6-10	6-10
14-11	14-8
14-17	14-14

References

AAEA. 2000. Commodity costs and returns estimation handbook. American Agricultural Economics Association, Ames, IA.

ASAE. 2001. ASAE Standards 2001, 48th ed. American Society of Agricultural Engineers, St. Joseph, MI.

Cross, T.L. and G.M. Perry. 1995. Depreciation patterns for agricultural machinery, *American Journal of Agricultural Economics* 77:194-204.

Cross, T.L. and G.M. Perry. 1996. Remaining value functions for farm equipment, *Applied engineering in agriculture* 12:547-553.

Hunt, Donnell. 1995. Farm power and machinery management, 9th ed. Iowa State University Press, Ames, IA.

USDA/NASS. Various issues. Agricultural prices summary. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, D.C.

USDA/NASS. Various issues. Farm labor. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, D.C.