

Techno-Economic Analysis of Harvesting, Processing, and Transporting Seaweed

Final Report to:

**AquaFish CRSP
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Submitted by:

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Introduction

As the earth's population continues to rise, concern over the availability of resources is increasing. Hunger, health, and availability of fuels are just some of the problems the world will need to solve. Currently, traditional agriculture plays a central role in food and fuel production, but growing population limits availability of the farmland required by these crops. With these problems in mind, marine agronomy, using oceans to produce usable crops, such as seaweed, becomes an appealing option. Seaweed offers not only a source of food, but also has some useful applications in pharmaceuticals and biofuels.

With the versatility of seaweed, and the availability of space in the ocean for seaweed production, interest in this area marine agronomy is on the rise. The key steps involved with harvesting and production can be seen in figure 1 below. Seaweed is harvested using specialized equipment, dried, and densified into pellets or bales, and is transported accordingly.



Figure 1: Brief overview of the seaweed value chain.

Currently, limited amounts of information on the seaweed production process, and economic considerations with harvesting and production are available. Fudholi (2012) recently compiled techno-economic information on the drying portion of seaweed production that provided important insight for this analysis. Unfortunately, the other areas of production did not have literature available discussing the economics of the process. Understanding the costs and economics of the process is an important factor for seaweed farmers to consider prior to starting production processes. If a profitable commercial seaweed operation isn't possible, investing in the process might not be worthwhile. This analysis will help determine annualized expenses associated with a range of production processes.

Objectives

- Investigate current production-scale equipment, and appropriately price these technologies.
- Conduct a total cost assessment of a commercial seaweed operation for a variety of harvesting and production methods, over three separate scales.
- Conduct a techno-economic analysis (TEA) to investigate relations between annualized cost/kg and production size to determine if the value chain demonstrates traditional economies of scale behavior.

Methods and Materials

In this techno-economic analysis (TEA), we integrated research and recommendations from a variety of different sources, including scientific literature, governmental, educational materials, and individual company prices and specifications to determine the economic feasibility of seaweed harvest, drying, densification, and transport. In this analysis, seaweed was harvested with a seaweed mower, dried, densified into pellets or bales, and transported accordingly by truck. Specific details about the equipment selected, and harvesting methods have been included in the tables discussing each of the options. This TEA was conducted for a generic seaweed, and was not focused on a particular species.

When the annualized costs for the overall process were determined, graphs depicting total production costs (annualized cost vs. harvesting area), and economies of scale (annualized cost/kg vs. harvesting area) were constructed. Upon completion of these graphs, conclusions about the overall value chain were made.

Major Assumptions

- Seaweed has an average growth density of 30kg/m^3 at time of harvest.
- Each of the proposed harvesting boats can hold approximately 3,000 kg of material prior to unloading.
- Harvest would occur three times each year.
- Seaweed would be dried from 90% to 10% moisture content (wet basis).

Harvest

Aquatic Mowing Boat Option

Assumptions:

Labor:	\$8.00	per hour
Diesel Fuel:	\$4.00	per gallon
Fuel Efficiency:	3.5	mpg
Employees:	2	people needed during operation

Loan life, Machine life:	15	years
Interest:	5.00%	
Assumed Maintenance:	8.00%	of capital cost yearly
Assume:	20	loads each hour
Assume harvest rate of:	3000	kg/hr



Supplier: Conver


Conver C430H with T-shaped cutting unit and push frame

Capital Cost:	\$145,000.00	USD
Maintenance Costs:	\$11,600.00	annually
Capacity:	60000	kg/hr with continuous harvesting
Annualized Capital Cost:	\$13,969.63	

<http://www.conver.com/mowingboats/product/C480H>

Economies of Scale:	Hectares per harvest		
	1 ha	10 ha	100 ha
Area, m ²	10000	100000	1000000
Production, kg/yr	900000	9000000	90000000
Hours of Harvest	15	150	1500
Labor Cost	240	2400	24000
Miles per year of the Boat	18.64113	186.4113	1864.113
Operating Costs	260.97582	2609.7582	26097.582
Annual Operation Cost	12100.97582	16609.7582	61697.582
Total Annual Cost	26070.60752	30579.3899	75667.2137
Total Cost / kg / yr	0.028967342	0.00339771	0.000840747

Drying

Drying Options									
Assumptions:	Labor:	8	per hour	Loan life, Machine life	15	years			
	Electricity:	0.08	per kWh	Interest:	5.00%				
	Yearly Use:	1500	hours	Assumed Maintenance:	8.00%	of capital cost yearly			
	Employees:	2	people needed during operation						
	Power:	36.8	kW -h						
DW Belt Dryer/Conveyor Dryer/Mesh Belt Dryer:									
	Capital Cost:	\$ 20,000.00		Annualized Capital Cost:	\$1,926.85				
	Maintenance Costs:	\$ 1,600.00		Annualized Operational Cost:	\$ 18,016.00				
	Power:	55200 kW		Total Annual Cost:	\$19,942.85				
	Operating Costs:	\$ 4,416.00		Total Cost/kg/yr:	\$0.02				
	Labor Costs:	\$ 12,000.00							
	Capacity:	600 kg/h							
http://www.alibaba.com/product-gs/463879050/Mesh_belt_dryer_Seaweeds_belt_dryer.html									
Economies of Scale:									
Hectares per harvest									
		1 ha	10 ha	100 ha					
Area, m ²		10000	100000	1000000					
Production, kg/yr		900000	9000000	90000000					
Hours of Drying		1500	15000	150000					
Labor Cost		\$24,000.00	\$240,000.00	\$2,400,000.00					
Operating Costs		\$4,416.00	\$44,160.00	\$441,600.00					
Annual Operation Cost		\$30,016.00	\$287,360.00	\$2,870,400.00					
Total Annual Cost		\$31,942.85	\$291,213.69	\$2,905,083.22					
Total Cost / kg / yr		\$0.035492	\$0.032357	\$0.032279					

Densification – Baling

Baling options				Assumptions:			
Labor:	8	per hour		Loan life, Machine life:	15	years	
Electricity:	0.08	per kWh		Interest:	5.00%		
Employees:	1	people needed during operation		Assumed Maintenance:	8.00%	of capital cost yearly	

Supplier: Alibaba			Economies of Scale:			
JPA070T120 Seaweed Baler			Hectares per harvest			
			1 ha	10 ha	100 ha	
Capital Cost:	\$5,000	USD	10000	100000	1000000	
Maintenance Costs:	\$400.00	annually	90000	900000	9000000	
Power:	15	kW	200	2000	20000	
Capacity:	450	kg/hr	\$1,600.00	\$16,000.00	\$160,000.00	
Annualized Capital Cost	\$481.71		\$240.00	\$2,400.00	\$24,000.00	
			\$2,240.00	\$18,800.00	\$184,400.00	
			\$2,721.71	\$19,281.71	\$184,881.71	
			\$0.03	\$0.02	\$0.02	
			8.333	83.333	833.333	
			Days to bale (per harvest)			
			harvest every 60 weekdays			

http://www.alibaba.com/product-ps/289054537/Baling_machine_for_Seaweed_Seaweed_Baler.html

Supplier: Alibaba			Economies of Scale:			
Y82-25M Hydraulic Baler			Hectares per harvest			
			1 ha	10 ha	100 ha	
Capital Cost:	\$3,850	USD	10000	100000	1000000	
Maintenance Costs:	\$308.00	annually	90000	900000	9000000	
Power:	7.5	kW	90	900	9000	
Capacity:	1000	kg/hr	\$720.00	\$7,200.00	\$72,000.00	
Annualized Capital Cost	\$370.92		\$54.00	\$540.00	\$5,400.00	
			\$1,082.00	\$8,048.00	\$77,708.00	
			\$1,452.92	\$8,418.92	\$78,078.92	
			\$0.02	\$0.01	\$0.01	
			3.75	37.5	375	
			Days to bale (per harvest)			
			harvest every 60 weekdays			

Supplier: Alibaba			Economies of Scale:				
EPM-80			Hectares per harvest				101 ha, 2 machines
			1 ha	10 ha	100 ha		
Capital Cost:	\$15,000	USD	10000	100000	1000000	1000000	
Maintenance Costs:	\$1,200.00	annually	90000	900000	9000000	9000000	
Power:	37	kW	25.71428571	257.1428571	2571.428571	2571.428571	
Capacity:	3,500	kg/hr	\$205.71	\$2,057.14	\$20,571.43	\$41,142.86	
Annualized Capital Cost	\$1,445.13		\$76.11	\$761.14	\$7,611.43	\$15,222.86	
			\$1,481.83	\$4,018.29	\$29,382.86	\$58,765.71	
			\$2,926.96	\$5,463.42	\$30,827.99	\$61,655.98	
			\$0.03	\$0.01	\$0.00	\$0.01	
			1.071428571	10.71428571	107.1428571	53.57142857	
			Days to bale (per harvest)				
			harvest every 60 weekdays				

http://www.alibaba.com/product-ps/630549370/automatic_baler_for_waste_paper.html?s=p




Densification - Pelleting

Pelleting Options



Assumptions:

Labor:	\$8.00	per hour
Electricity:	\$0.08	per kWh
Employees:	1	people needed during operation

Loan life, Machine life:	15	years
Interest:	5.00%	
Assumed Maintenance:	8.00%	of capital cost yearly

			Economies of Scale:				
			Hectares per harvest				
			1 ha	10 ha	100 ha		
	Supplier: Pellet Pros						
	Model PP 800						
	Capital Cost:	\$7,995 USD					
	Maintenance Costs:	\$639.60 annually					
	Power:	30 HP					
	Capacity:	400 kg/hr					
	Annualized Capital Cost	\$770.26					
	http://www.pelletpros.com/id68.html						
				Economies of Scale:			
				Hectares per harvest			
			1 ha	10 ha	100 ha		
Area, m ²			10000	100000	1000000		
Production, dry kg/yr			90000	900000	9000000		
Hours of Operation			225	2250	22500		
Labor Cost			\$1,800.00	\$18,000.00	\$180,000.00		
Operating Costs			\$402.68	\$4,026.78	\$40,267.79		
Annual Operation Cost			\$2,842.28	\$22,666.38	\$220,907.39		
Total Annual Cost			\$3,612.53	\$23,436.64	\$221,677.65		
Total Cost / kg / yr			\$0.040139	\$0.026041	\$0.024631		
Days to pellet (per harvest)			9.38	93.75	937.50		
harvest every 60 weekdays							
	Supplier: Alibaba						
	Model SZLH250						
	Capital Cost:	\$1,500					
	Maintenance Costs:	\$120.00 annually					
	Power:	22 kW					
	Capacity:	1,000 kg/hr					
	Annualized Capital Cost	\$144.51					
	http://www.alibaba.com/product-gs/626521126/Combination_of_livestock_and_aqua_feed.html						
				Economies of Scale:			
				Hectares per harvest			
			1 ha	10 ha	100 ha		
Area, m ²			10000	100000	1000000		
Production, dry kg/yr			90000	900000	9000000		
Hours of Operation			90	900	9000		
Labor Cost			\$720.00	\$7,200.00	\$72,000.00		
Operating Costs			\$158.40	\$1,584.00	\$15,840.00		
Annual Operation Cost			\$998.40	\$8,904.00	\$87,960.00		
Total Annual Cost			\$1,142.91	\$9,048.51	\$88,104.51		
Total Cost / kg / yr			\$0.012699	\$0.010054	\$0.009789		
Days to pellet (per harvest)			3.75	37.50	375.00		
harvest every 60 weekdays							
	Supplier: Andritz						
	Model 32W-700						
	Capital Cost:	\$23,000					
	Maintenance Costs:	\$1,840.00 annually					
	Power:	522 kW					
	Capacity:	15,875 kg/hr					
	Annualized Capital Cost	\$2,215.87					
	http://dev.andritzsproutbauer.com/v-belt.asp						
				Economies of Scale:			
				Hectares per harvest			
			1 ha	10 ha	100 ha		
Area, m ²			10000	100000	1000000		
Production, dry kg/yr			90000	900000	9000000		
Hours of Operation			5.669291339	56.69291339	566.9291339		
Labor Cost			\$45.35	\$453.54	\$4,535.43		
Operating Costs			\$236.75	\$2,367.50	\$23,674.96		
Annual Operation Cost			\$2,122.10	\$4,661.04	\$30,050.39		
Total Annual Cost			\$4,337.98	\$6,876.91	\$32,266.27		
Total Cost / kg / yr			\$0.048200	\$0.007641	\$0.003585		
Days to pellet (per harvest)			0.24	2.36	23.62		
harvest every 60 weekdays							

Transportation – Pellets

Commerical Pellet Option #1 Roadway																																								
Assumptions:	Labor:	\$8.00	per hour	Loan life, Machine life	15 years																																			
	Fuel:	\$4.00	per gallon	Interest:	5.00%																																			
	Employees:	1	people needed during operation	Assumed Maitenance:	8.00%																																			
	Assume the truck gets	15	mpg		of capital cost yearly																																			
Total Vertical Wet Well Chopper Pump Option																																								
Capital Cost:	\$125,266.00	USD	Annualized Capital Cost	\$12,068.41																																				
Maitenance Costs:	\$10,021.28	annually	Annual Operation Costs	\$10,315.73																																				
Fuel Required	73.53	L	Total Annual Cost	\$22,384.14																																				
Operating Costs:	\$294.12	each year	Total Cost / kg / yr	\$0.89536575920																																				
Labor Costs:	\$0.33	each year																																						
Capacity:	20000.00	kg/load																																						
Production:	25000.00	kg/year																																						
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;">  <p>Supplier: Wilson Trailer Commander DWH-500C Double Wall Aluminum Hopper</p> <table border="0"> <tr> <td>Capital Cost:</td> <td>\$32,900.00</td> <td>USD</td> <td>Annualized Capital Cost</td> <td>\$3,169.66</td> </tr> <tr> <td>Maitenance Costs:</td> <td>\$2,632.00</td> <td>annually</td> <td>Annual Operation Costs</td> <td>\$2,632.00</td> </tr> <tr> <td></td> <td></td> <td></td> <td>Total Annual Cost</td> <td>\$5,801.66</td> </tr> </table> <p>Capacity: 20000.00 kg/load Production: 250.00 kg/year</p> <p>http://www.wilsontrailer.com/trailers/commander/index.php</p> </div> <div style="width: 45%; text-align: right;"> <p>*Assume pellets loaded straight into truck Trips Req 0.0125</p> </div> </div>						Capital Cost:	\$32,900.00	USD	Annualized Capital Cost	\$3,169.66	Maitenance Costs:	\$2,632.00	annually	Annual Operation Costs	\$2,632.00				Total Annual Cost	\$5,801.66																				
Capital Cost:	\$32,900.00	USD	Annualized Capital Cost	\$3,169.66																																				
Maitenance Costs:	\$2,632.00	annually	Annual Operation Costs	\$2,632.00																																				
			Total Annual Cost	\$5,801.66																																				
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;">  <p>Supplier: International 2011 International 7600 SFA 6x4 2010 Tractor</p> <table border="0"> <tr> <td>Capital Cost:</td> <td>\$92,366.00</td> <td>USD</td> <td>Annualized Capital Cost</td> <td>\$8,898.75</td> </tr> <tr> <td>Maitenance Costs:</td> <td>\$7,389.28</td> <td>annually</td> <td>Annual Operation Costs</td> <td>\$7,977.85</td> </tr> <tr> <td>Fuel consumed:</td> <td>3.40</td> <td>km/L</td> <td>Total Annual Cost</td> <td>\$16,876.60</td> </tr> <tr> <td>Fuel Required</td> <td>74</td> <td>L/Year</td> <td></td> <td></td> </tr> <tr> <td>Labor Costs:</td> <td>\$0.33</td> <td>each year</td> <td></td> <td></td> </tr> <tr> <td>Capacity:</td> <td>0</td> <td>kg/hr</td> <td></td> <td></td> </tr> <tr> <td>Production:</td> <td>#REF!</td> <td>kg/year</td> <td></td> <td></td> </tr> </table> <p>http://www.internationaltrucks.com/trucks/inventory/truck/detail/2011-7600-SFA-6X4-2010-9974</p> </div> <div style="width: 45%;"></div> </div>						Capital Cost:	\$92,366.00	USD	Annualized Capital Cost	\$8,898.75	Maitenance Costs:	\$7,389.28	annually	Annual Operation Costs	\$7,977.85	Fuel consumed:	3.40	km/L	Total Annual Cost	\$16,876.60	Fuel Required	74	L/Year			Labor Costs:	\$0.33	each year			Capacity:	0	kg/hr			Production:	#REF!	kg/year		
Capital Cost:	\$92,366.00	USD	Annualized Capital Cost	\$8,898.75																																				
Maitenance Costs:	\$7,389.28	annually	Annual Operation Costs	\$7,977.85																																				
Fuel consumed:	3.40	km/L	Total Annual Cost	\$16,876.60																																				
Fuel Required	74	L/Year																																						
Labor Costs:	\$0.33	each year																																						
Capacity:	0	kg/hr																																						
Production:	#REF!	kg/year																																						





Transportation – Pellets (continued)

Economies of Scale:	Hectares per harvest		
	1 ha	10 ha	100 ha
Area, m ²	10000	100000	1000000
Production, kg/yr	90000	900000	9000000
Hours of Transportation	200	200	200
Number of Loads per Year	45	450	4500
Equipment Quantity	1	5	45
Labor Cost	\$1,600.00	\$7,200.00	\$72,000.00
Operating Costs	\$720,000.00	\$3,240,000.00	\$32,400,000.00
Annual Operation Cost	\$721,600.00	\$3,247,200.00	\$32,472,000.00
Total Annual Cost	\$733,668.41	\$3,301,507.86	\$33,015,078.58
Total Cost / kg / yr	\$8.151871	\$3.668342	\$3.668342

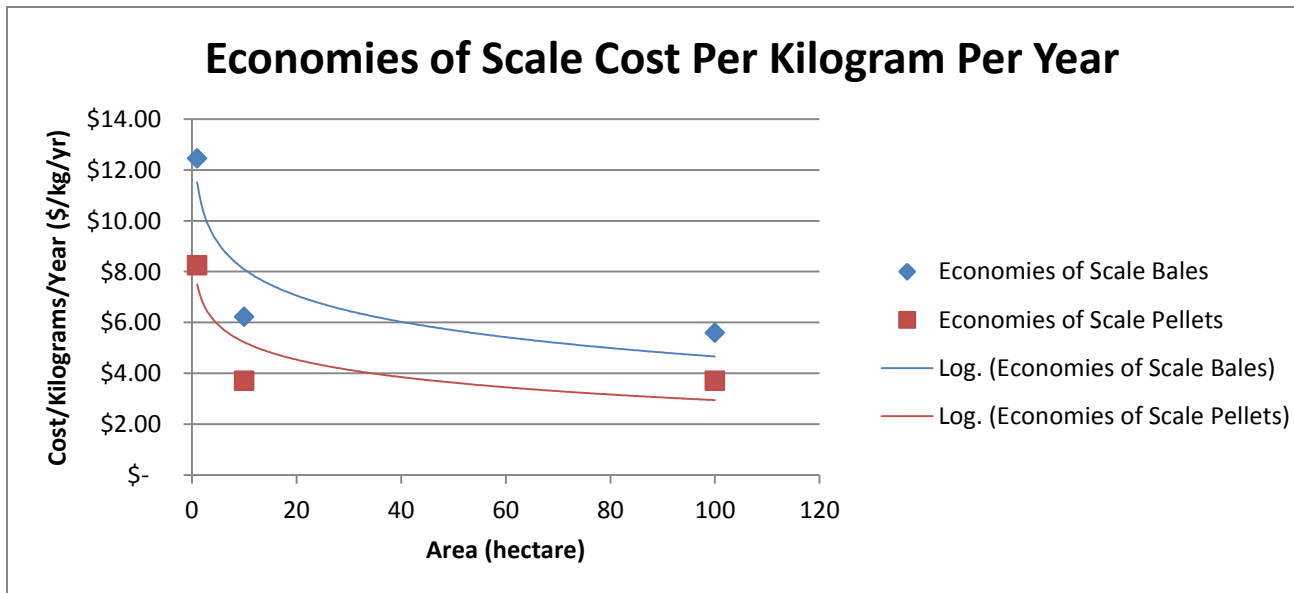
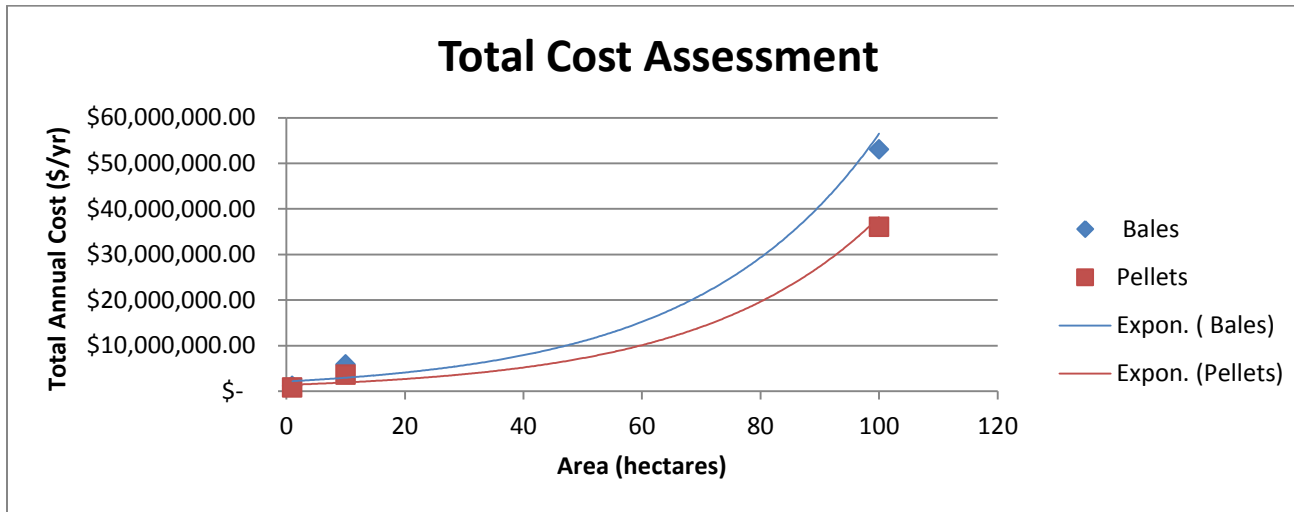
Transportation – Bales

Economies of Scale:	Hectares per harvest		
	1 ha	10 ha	100 ha
Area, m ²	10000	100000	1000000
Production, kg/yr	90000	900000	9000000
Hours of Transportation	200	200	200
Number of Loads per Year	45	450	4500
Equipment Quantity	1	5	45
Labor Cost	\$18,188.80	\$90,944.00	\$818,496.00
Operating Costs	\$1,080,000.00	\$5,400,000.00	\$48,600,000.00
Annual Operation Cost	\$1,098,188.80	\$5,490,944.00	\$49,418,496.00
Total Annual Cost	\$1,112,028.56	\$5,560,142.81	\$50,041,285.30
Total Cost / kg / yr	\$12.355873	\$6.177936	\$5.560143

Transportation –Bales (continued)

Commerical Baling Option #1				
Assumptions:				
Labor:	\$8.00	per hour	Loan life, Machine life:	15 years
Electricity:	\$0.08	per kWh	Interest:	5.00%
Yearly Use:	1920	hours	Assumed Maintenance:	8.00% of capital cost yearly
Employees:	1	people needed during operation	Assume Truck travels:	40000 miles a year
			Assume Diesel costs:	4 per gallon
			Assume Diesel Efficiency:	30 mpg
			Assume Diesel costs:	1500 miles per year for bale fork and skid-steer
			Assume truck receives:	15 mpg
Total Commercial Baling				
Capital Cost:	\$143,652.00	USD	Annualized Capital Cost	\$13,839.76
Maintenance Costs:	\$11,492.16	annually	Annual Operation Costs	\$29,680.96
Labor Costs:	\$18,188.80	each year	Total Annual Cost	\$43,520.72
Supplier: International				
2011 International 7600 SFA 6x4 2010 Tractor				
	Capital Cost:	\$92,366.00	USD	Annualized Capital Cost
	Maintenance Costs:	\$7,389.28	annually	Annual Operation Costs
	Operating Costs:	\$2,400,000.00	each year	Total Annual Cost
	Labor Costs:	\$15,360.00	each year	\$2,431,648.03
Supplier: Wilson Trailer				
Commander DWH-500C Double Wall Aluminum Hopper				
	Capital Cost:	\$32,900.00	USD	Annualized Capital Cost
	Maintenance Costs:	\$2,632.00	annually	Annual Operation Costs
	Fuel Costs:	0	Liters	Total Annual Cost
	Fuel Consumption:	0	each year	\$5,801.66
	Labor Costs:	0	each year	
	Capacity:	20000.00	kg/load	
	Production:	900000.00	kg/year	
	http://www.wilsontrailer.com/trailers/commander/index.php			
Supplier: Bobcat				
S70 Skid-Steer Loader				
	Capital Cost:	\$17,791.00	USD	Annualized Capital Cost
	Maintenance Costs:	\$1,423.28	annually	Annual Operation Costs
	Operating Costs:	\$180,000.00	each year	Total Annual Cost
	Labor Costs:	\$1,228.80	each year	\$184,366.11
	Total Cost / kg / yr			#REF!
	http://procure.ohio.gov/pricelist/800155pricelist.pdf			
Supplier: Bobcat				
Bale Fork				
	Capital Cost:	\$595.00	USD	Annualized Capital Cost
	Maintenance Costs:	\$47.60	annually	Annual Operation Costs
	Power:			Total Annual Cost
	Operating Costs:	\$180,000.00	each year	\$195,464.92
	Labor Costs:	\$15,360.00	each year	
	Total Cost / kg / yr			#REF!
	http://www.bobcat.com/attachments/bale_fork			

TEA Evaluation of Scenarios



Conclusions

As expected, a larger scale of operation is more economical. The annualized cost per kilogram of seaweed was less expensive when working with a 10 hectare field opposed to working with a 1 hectare field. What this means is that traditional economies of scale apply, and a commercial seaweed operation should consider increasing production scale to higher levels in order to maximize profits. It can also be noted that the most significant changes in cost per kilogram per year occur when harvesting between zero and thirty hectares per harvest.

Further analysis is needed to evaluate costs versus benefits for harvesting a larger area, including parameters such as customer needs and market prices for the sale of specific seaweed varieties.

References

Fudholi, A., M. Y. Otman, M. H. Ruslan, M. Yahya, A. Zaharim, K. Sopian, (2012b). Techno-economic analysis of solar drying system for seaweed in Malaysia. In *Proc. 7th IASME/WSEAS International Conf. on Energy, Environment, Ecosystems and Sustainable Development*, 89-95. Angers, France. World Scientific and Engineering Academy and Society.

Acknowledgements

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