Literature Review of Seaweed Harvest Value Chain

Final Report to:

AquaFish CRSP
Snell Hall 418
Oregon State University
Corvallis, OR 97331-1643 USA

Submitted by:

Kurt A. Rosentrater, Ph.D.

3167 NSRIC Building

Department of Agricultural and Biosystems Engineering

Iowa State University

Ames, IA 50011 USA

Ph: 515-294-4019

Email: karosent@iastate.edu

March 28, 2013

Introduction

Today, mariculture is one of the fastest growing food production sectors, with an annual growth rate of 4-11%. This rapid growth is likely due in part to the large area of "usable land" in the ocean and the high protein food that can be produced and harvested, one of which is seaweed. (Troell, 1999; CBD, 2013). In addition, seaweed is not only a source of food, but has properties that make it an option for utilization in pharmaceuticals, biofuels, and other applications. A unique advantage of this type of systems is that growing seaweed consumes excess nutrients and $CO_{2,}$ two compounds believed to have ecologically dangerous impacts (Troell, 1999). With these benefits to the marine agronomy, it is not hard to see why scientists and engineers are interested farther developing this unique industry. While on paper, harvesting seaweed seems like a simple task, there are a number of important steps in the process, which have been identified in figure 1.

Figure 1: Brief overview of the seaweed value chain.

For the purposes of this analysis, our team will investigate the harvesting, drying, densification, and transportation portions of the process. Learning a few basics of the process will help to understand the challenges and benefits associated with marine agronomy.

Harvest

There are a variety of ways that offshore seaweed can be harvested; the most widely practiced being a rope or line culture that must be harvested by hand. This practice primarily takes place in China, Indonesia and the Philippines (Diana, 2012). Small boats with teams of two people go out with their choice of hand held equipment, cut, and pull up the seaweed into a net which is then brought to shore. In a study by Kelly (2003), they found that a team of three to four people can harvest roughly 4 tonnes per hour. Harvesting by hand is thought to cause the smallest ecological destruction, but is not as efficient as machinery that is becoming more popular (E&HS, 2007).

Scoubidou

There are multiple types of mechanical harvesting, depending on the type of seaweed that is grown, where it is grown and how it needs to be harvested. One simple piece of machinery that allows young seaweed to continue growing, while collecting the mature plant is a sickle-like hook, called a scoubidou, fixed on a pole that is attached to a crane on a boat ranging from 8-12 meters in length. Boats are generally equipped with one to two scoubidou apparatus and have a carrying capacity of 10-20 tonnes of wet material. The scoubidou is lowered into the seaweed patch and twisted, causing the seaweed to become entangled in the hook. Only plants larger than 60cm stay hooked, leaving the smaller plants that are generally younger than two years to continue growing. This device is used primarily with *Laminaria digitata* in France, and can pull around 1.5-2 tonnes of wet weight per day, which each removal of 10 kg taking roughly 30 seconds (Werner, 2004). A study done in 1969 found no clear adjustment in seaweed recovery time when harvested using the scoubidou method (Perez, 1969). This method is also used in hand harvesting with the operator controlling the sickle handle by hand.

Dredge

Another type of seaweed harvesting is to use a dredge to pull across the ocean or sea bottom that has few boulders and rocks. Modern dredges are attached to a boat with a carrying capacity of 30-1850 tonnes, depending on the owner, by using a crane. The attached dredge can pull up roughly two tonnes per drag in 0.5-2 minutes at a wide range of depths, from 2-20 meters. In theory the dredge cuts the seaweed 5-20 cm from the holdfast, but they are known to pull the entire plant up instead. By using a dredging technique, the top seaweed canopy is removed, which allows bottom seaweed recruits to receive sunlight and increase in size and density (Werner, 2004).

Vertical Wet-Well

The option of using a vertical wet-well was studied by Kelly (2003). They attached a vertical wet-well with attached depth gauges to a hydraulic arm that moved the wet-well along the bottom of the ocean floor. The wet-well chopped up the seaweed and brought it up into a net on to the boat. The machine was kept from cutting to the bottom of the plant by using depth gauges that kept it 20cm from the floor. After testing in two different shore lines, they received very different results, one test with a rate of 0.2 tonnes per hour and another test with a rate of 1.125 tonnes per hour. The larger boats and machinery were found hard to bring close to shore and maneuver to cut the seaweed (Kelly, 2003).

Mowing Boat

Finally, there are mechanical harvesters that come premade, without the operator having to install other machinery such as a crane. Conver, based in the Netherlands, makes equipment that can be used for seaweed harvesting, without changes. The Conver C430H is a mid-range mowing boat, that paired with a T-front cutting tool and push frame could cut seaweed and then push it towards any net. At a width of 1.5m, this mowing boat is a small boat when compared to the above options and would maneuver much easier and allow the operator to get nearer shore, allowing for more seaweed harvested per hour (Conver, 2013).

Drying

Research has been performed at the Universiti Kebangsaan Malaysia using solar drying methods for seaweed. One study focuses on the "techno-economic analysis of a solar drying system for seaweed" because there are "few dryers that meet the technical, economical, and socio-economical requirements" that are in place (Fudholi, 2012b). Using a solar assisted forced convention drying system, the seaweed started with an initial moisture content of 90% (wet basis) and was dried to a moisture content of 10% (dry basis), which took approximately 15 hours at a solar radiation of approximately 500 W/m^2 and air flow rate of 0.0536 kg/s (Fudholi, 2012b). Fudholi found more energy can be absorbed by the collector solar array of the dryer if the intensity of the solar radiation increases (Fudholi, 2012b). In another study performed at the Universiti Kebangsaan Malaysia using the forced convection drying system, seaweed was dried from 94.6% moisture content (wet basis) to 10% moisture content (dry basis) using a solar radiation of 600 W/m^2 and an air flow rate of 0.0613 kg/s, which took approximately 7 hours (Fudholi, 2011a). The initial mass of the seaweed was 120 grams, and the final mass of the seaweed after drying was 11 grams, which resulted in 109 grams of water loss (Fudholi, 2011a). In conclusion, Fudholi was able to determine the moisture ratio using the Page model equation $MR = \exp(-1.6054t^{0.566})$, which was 96.7% accurate (Fudholi, 2011a).

The Universiti Kebangsaan Malaysia also performed research using a Low Temperature and Humidity Chamber Test to determine the optimum temperature and relative humidity for drying seaweed (Fudholi, 2011b). Fudholi compared three temperatures (40, 50, and 60^oC) to three relative humidity levels (10, 25, and 40%) using a constant air velocity of 1 m/s, while recording the weight every 5 minutes (Fudholi, 2011b). In conclusion, drying at 60^oC at a relative humidity of 10% produces the best quality of seaweed, using the Page model equation [$MR = \exp(-2.23474t^{1.1247})$], which was 99.3% accurate (Fudholi, 2011b). Using the same experimental protocol, the drying curve mathematical model was determined for brown seaweed (Eucheuma cottonii), which is also the Page's model (Fudholi, 2012a). In conclusion, both the temperature and the relative humidity of the drying air affect the drying time of seaweed (Fudholi, 2011b).

At the Chinese University of Hong Kong, Chan performed a study comparing how the means of drying affects the nutritional composition of seaweed (*Sargassum hemiphyllum*) (Chan, 1997). Sun-drying, oven-drying, and freeze-drying were compared based on moisture analysis, crude protein analysis, amino acid composition analysis, fatty acid composition analysis, dietary fiber analysis, determination of ash, determination of mineral elements, and vitamin C analysis using a statistical analysis (Chan, 1997). Chan found that the freeze-dried seaweed retained the nutritional composition because it contained the highest content of total amino acids, total polyunsaturated fatty acids, and total vitamin C content (Chan, 1997).

Henan Quiangyuan Machinery Co., Ltd is a manufacturer of machinery located in China (Alibaba, 2013). The company produces a high quality seaweed vacuum dryer starting at $10,000; the counter-flow dryer is efficient, easy to operate and maintain, and aesthetically pleasing (Alibaba, 2013). Another vacuum dryer is produced by WD, which is based out of Jiangsu, China (Alibaba, 2013). The WD dryer starts at $2,000, and saves energy, produces sanitary and low noise working conditions, and produces easy and uniform temperature controls (Alibaba, 2013). Changjin, a manufacturing company based in China, produces a conveyor dryer for seaweed staring at $1,000 (Alibaba, 2013). The conveyor belt dryer produces a continuous process, which is efficient (Alibaba, 2013). After drying the seaweed, remove any rubbish material and cover the seaweed with salt crystals to preserve it up to 2 years for consumer use (FAO, 1990).

Densification

Densification of seaweed is a process that includes quite a bit of variation on the part of the companies buying and selling their product. Seaweed is an internationally prominent product that is gaining popularity in a variety of markets, and as such manufacturers are adjusting their processes to reflect these changing customer demands. Seaweed is harvested using a variety of cultivating methods and is usually dried before the farmer sells it to a processing company. During drying moisture content is reduced to approximately 25%-35% moisture content wet basis, removing water and allowing for lower shipping costs, increased efficiency on behalf of the buyers, and a higher quality material. Two common densification methods include baling, and pelleting.

Baling

Baling is the most common method of densification available to processing companies. Typically farmers will sell dried seaweed to local companies that densify the material in bales that can easily be loaded onto truck and boats to be shipped to customers (McHugh, 2006). Advantages of bales include that they are easily transferred and only require one machine--a baler--to produce. A disadvantage associated with baling is that because of the remaining moisture in the biomass, the potential remains for the seaweed to begin to spoil in the centers of the large bales.

Biomass is crushed into bales using a bailing press or seaweed baler that uses high pressures to densify the seaweed into a tightly-packed shape that is easily transferred. In the pacific islands, farmers ship loose, dried seaweed to companies where the biomass is compacted and shipped in the bags to their customers (McHugh, 2006). Spoilage of biomass in bales can be reduced by using mechanically drying the seaweed to a lower moisture content before forming the bales. While bales are one of the most widely used form of densification, current work is being done to improve the pelletizing of seaweed.

Pellets

Seaweed is being used in pellets for animal feed principally as a binding agent but also as an additional source of protein and vitamins. Adding seaweed to feed at levels of 3% mass has been shown to noticeably improve the hardness of the pellet (Seaweed, 2012). Seaweed is usually included at low levels in livestock diets (a maximum of 15% is currently approved in chickens), but can also be included at high levels as herbivore fish feed (Instant Ocean, 2012). Producing seaweed pellets is most prominent in the aquaculture feeds and livestock feeds industries but is also used with organically grown livestock and promoted in low doses for every type of livestock by organic farmers (Bod Ayre, 2013). In order to pelletize biomass, raw materials are first dried to between 12%-15% moisture content wet basis (Mani et al., 2006). Additives and binding agents (occasionally seaweed) are added at this point and the biomass goes through an extrusion process where steam and heat are added before they're formed into finished pellet shapes. Characteristics involved in the pelletizing process include initial moisture content, ratios of included components, and compression the biomass undergoes throughout the process. More research is necessary to determine the best conditions for seaweed pellet production.

The best method for densification of seaweed ultimately depends on how the biomass is used by the buyer. Currently seaweed is principally processed into agars, alginates, and carrageenans that are used in a variety of industries (Integrated Multi-Trophic Aquaculture, 2012). Production of agars includes soaking whole, cleaned seaweed in heated water to extract the jelly-like agar (McHughes, 2003). Alginates are usually developed through a process that uses seaweed flour to produce an important product used as a thickening agent in a variety of markets (Kimica, 2009). Carrageenans are also harvested from macroalgae by boiling raw seaweed (McHughes, 2003). Macroalgae can also be processed in converters that use heat and catalysts to break down the biomass into a mixture similar to crude oil that can be further refined to create biofuels (Aquaflow, 2013). Finally, when using macroalgae in livestock diets it is most easily used in pellet or ground meal form.

Addressing how biomass is to be used determines which densification method would be most appropriate for each supplier.

Transportation

Transportation is an important player in the harvesting and production process and greatly influences the efficiency of the overall system. Unfortunately, the amount of published scientific literature discussing seaweed harvesting is very minimal, and transportation practices are rarely mentioned within these sources.

Transportation between harvesting and processing

Philipsen (2010) discussed some of the techniques currently used in the harvesting of brown sea weed. Two types of seaweed farms are in use today. In near shore farming, seaweed grows relatively close to shore, and a variety of successful planting systems are in use. An area being investigated farther is the development of off shore farming; this would allow larger farms and increased seaweed production, but involved more transportation. Harvesting practices off shore farming are limited due in part to the few number of off shore farms. While each of these two strategies are viable farming options, that transportation mechanisms used in each of the processes could differ dramatically. Philipsen shared that in a near shore farming operations a skiff, or small boat, transports seaweed from the harvesting rig to shore where it is processed (dried and densified), often times on skiff will make multiple trips from the harvesting unit to the shore (Philipsen, 2010). In other situations the harvesting rig itself will transport seaweed from the location it is farmed to the shore. As farming moves farther offshore, produces would likely be deterred from using small skiffs, looking to transport more seaweed per trip to the processing facility. This would result in a move to larger barges or cargo ships in order to keep costs low, while minimizing the number of trips from shore to farm that are necessary.

Often times, a single drying/densifying operation is located near the coastline. Seaweed can be dropped off directly at the facility, or dropped off at the coast and transported via truck or train to its final destination. A facility with both drying and densification processes would be the most idea situation, but this may not always be feasible. Again, the dried seaweed could be transported vial truck or rail to the location where densification occurs at.

Transportation to final production site

Transportation out of the pre-processing phase is really where the scientific literature comes to an end. I suggest that the transport of seaweed based biomass is quite similar to other biomass materials. Sokhansanj discussed different techniques could be used for different densification practices. For round and square bales of corn stover several self-loading trailers are currently in use. After loading the bales onto these trailers, bales could be transported to the plant that finalizes processing. This equipment loads bales quickly, requiring only 10-20 minutes, and will move 17 total bales (Sokahansanj, 2002).

Several sites also suggested that pelleting the material would also be possible; however no sites went in depth on transport of the pelleted biomass. I would assume that the pelleted material could be transported in a similar style as grains, using semi-trucks. The pellets could be transported bagged, or unbagged. These transport conditions would likely be determined by the final fate of the product.

While seaweed planting/tending to seaweed growth requirements, is outside of the area this study is focusing on, I believe it is something to keep in mind as evaluating the feasibility of either the near shore or off shore farming mechanism. After seaweed is planted divers are required to dive periodically to ensure that the seaweed is attaching as necessary. Transportation in each of these different situations could play a role in the overall efficiently of the system as a whole.

Conclusion

Seaweed harvesting holds great potential in the food, biofuel, and pharmaceutical arena. With near limitless ocean area for crop production, many of the land shortage challenges of typical farming are erased. A successful operation must fully consider the ideas associated with harvesting, drying, densification, and transportation presented in scientific literature, along with the type of waters they are planning to work on, be it offshore, close to shore, or a pond setting. The type of shore can greatly alter what type of machinery, boats, and transportation which should be used.

References

Alibaba. 2013. Seaweed Dryer. Available at: http://www.alibaba.com/showroom/seaweed-dryer.html. Accessed 25 March 2013.

Aquaflow. 2013. Technology. Available at: http://www.aquaflowgroup.com/technology. Accessed 10 March 2013.

Bod Ayre Seaweed Products. 2013. Animal feed seaweed granules. Available at: www.seaweedproducts.co.uk. Accessed 25 March 2013.

Buck, B. H., and C. M. Buchholz. 2004. The offshore-ring: A new system design for the open ocean aquaculture of macroalgae. *Journal of Applied Phycology* 16: 355-368.

CBD. 2013. Mariculture. Convention on Biological Diversity. Available at: www.cbd.int/marine/mariculture.shtml. Accessed 25 March 2013.

Chan, J. C.-C., Peter C.-K. Cheung, Put O. Ang, Jr. 1997. comparative studies on the effect of three drying methods on the nutritional composition of seaweed *Sargassum hemiphyllum (Turn.) C*. Ag. *Journal of Agricultural and Food Chemistry* 45(8): 3056-3059.

Conver. 2013. Aquatic Machines – Mowing Boats. Available at: www.conver.com/mowingboats. Accessed 15 March 2013.

Cowling, Mike, Alex Adrian. 2012. Climate: The case for marine bioenergy in Europe & the Crown Estate's response in the US. *Seaweeds to Biofuel Symposium*.

Diana, J.S., M.E. Capron, J. Forster, N.A. Sims, C.A. Goudey, C. Yarish, and K. Hopkins. 2012. Can marine agronomy help to restore the oceans and sustain humanity? *Scientific American: (in review).*

E&HS. 2007. Environmentally Sustainable Seaweed Harvesting in Northern Ireland. Belfast, Ireland.: Environment & Heritage Service.

FAO. 1990. Harvesting and selling seaweed. In *Handbook on Eucheuma Seaweed Cultivation in Fiji.* Rome, Italy.: Food and Agriculture Organization of the United Nations. Available at: www.fao.org/documents. Accessed 25 March 2013.

Feeney, M. W. 1999. Regulating seaweed harvesting in Maine: the public and private interests in an emerging marine resource industry. *Ocean and Coastal Law Journal* 7(2): 329-352.

Fudholi, A., M. H. Ruslan, L. C. Haw, S. M. Othman, A. Zaharim, K. Sopian, (2012a). mathematical modelling of brown seaweed drying curves. In *Proc. 6th WSEAS International Conf. on Computer Engineering and Applications*, 207-211. Cambridge, Mass.: World Scientific and Engineering Academy and Society.

Fudholi, A., M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim, K. Sopian, (2011a). Design and testing of solar dryer for drying kinetics of seaweed in Malaysia. In *Proc. 4th WSEAS International Conf. on Energy and Development – Environment - Biomedicine* 119-124. Corfu Island, Greece.: World Scientific and Engineering Academy and Society.

Fudholi, A., M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim, K. Sopian. (2011b). the effects of drying air temperature and humidity on the drying kinetics of seaweed. In *Proc. 4th WSEAS International Conf. on*

Energy and Development – Environment - Biomedicine , 129-133. Corfu Island, Greece.: World Scientific and Engineering Academy and Society.

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, Ecosystesm and Sustainable Development* , 89-95. Angers, France.: World Scientific and Engineering Academy and Society.

Instant Ocean. 2012. Herbivore fish food pellets. Available at: www.instantocean.com. Accessed 08 March 2013.

Integrated Multi-Trophic Aquaculture. 2012. Seaweeds – a part of everyday life. Available at: www.youtube.com. Accessed 10 March 2013.

Iowa State University: Extension and Outreach. 2012. Seaweed in Poultry Diets. Available at: www.extension.org. Accessed 08 March 2013.

Kelly, L., L. Collier, M. J. Costello, M. Diver. 2001. Impact Assessment of hand and mechanical harvesting of *Ascophyllum nodosum* on regeneration and biodiversity. *Marine Resources* 19: 1-51.

Kimica. 2009. Manufacturing process of aliginic acid. Tokyo, Japan. Available at: www.kimica-alginate.com. Accessed 10 Mar. 2013.

Mani, S., L. Tabil, S. Sokhansanj. 2006. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. *Biomass and Bioenergy* 30(7) 648-54.

McHugh, D. J. 2003. A guide to the seaweed industry. FAO Fisheries Technical Paper 441. Rome, Italy. Available at: www.fao.org/documents. Accessed 10 March 2013.

McHugh, D. J. 2006. The seaweed industry in the Pacific Islands. ACIAR-61. Canberra, Australia.: Australian Centre for International Agricultural Research.

Perez, R. 1696. Croissance de Laminaria digitata (L.) Lamouroux etudiee sur trois annees consectutives. *Proceedings of the Internationals Seaweed Symposium* 6: 329-344.

Phillippsen, A. 2010. Energy input, carbon intensity, and cost for ethanol produced from brown seaweed. MS thesis. Saanich, British Columbia, Canada.: University of Victoria, Department of Mechanical Engineering.

Sokhansanj, S., A. Turhollow, J. Cushman, J. Cundiff. 2002. Engineering aspects of collecting corn stover for bioenergy. *Biomass and Bioenergy* 23(5): 347-355.

Troell, M., P. Ronnback, C. Halling, N. Kautsky, A. Buschmann. 1999. Mariculture, Ecological Engineering in Aquaculture: Use of Seaweeds for Removal of Nutrients from Intensive Mariculture. *Journal of Applied Phycology* 11: 89-97.

Werner, A., S. Kraan. 2004. Review of the potential mechanization of kelp harvesting in Ireland. *Marine Environment and Health Series* 17: 1-52.

Acknowledgements

Special thanks to the Value-Added Bioprocessing Research Group students who conducted the work on this project, including Jordan Foley, Mandy Homan, Bailley Richardson, and Holly Wrage.