Cost-Effective Kelp Drying Methods for Remote Alaskan Communities

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- *With input from kelp processors, researchers, and equipment manufacturers*

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This report summarizes the findings of the completed AFDF Joint Innovation Project aimed at identifying sustainable and scalable kelp drying solutions for remote coastal communities in Alaska. As seaweed and kelp are most commonly sold in dried form, the development of cost-effective drying systems near farm sites is critical to addressing the challenges of high perishability, long transportation distances, and steep operational costs. This project sought to provide information on practical drying methods tailored to the needs of rural communities, with a focus on energy costs, labor requirements, and capital outlays.

The project investigated existing drying technologies and compiled publicly available information to support economic development in Alaska's mariculture industry. Emphasis was placed on scalable, energy-efficient systems, including containerized dryers, mechanical dewatering systems, and thermal dryers with heat pumps.

In the spring of 2024, Barnacle Foods released a report summarizing the current state of kelp drying and equipment. This follow-up report shares the testing of equipment, recommendations, challenges, and future work.

Summary of Work and Findings

Research and Collaboration

The project began with a comprehensive review of global and local kelp drying practices. Barnacle Foods collaborated with other stakeholders to identify drying systems suitable for Alaska's rural communities. Input was gathered from communities and organizations that expressed interest in mariculture.

To deepen understanding of existing systems, representatives from Barnacle Foods traveled to Maine to visit processing facilities. This visit provided valuable insights into the operation, scalability, and feasibility of various drying technologies for kelp.

Testing Mechanical Dewatering Systems

Mechanical dewatering systems, including screw presses and plate-frame presses, were considered as a pre-thermal drying step to reduce water content and improve energy efficiency. Both methods were evaluated for their ability to handle multiple kelp species, including sugar kelp and bull kelp, and their practicality in remote, small-scale operations.

While the screw press showed potential for reducing drying time and energy costs, challenges included capital expense and the need for additional infrastructure.

Mechanical dewatering testing occurred offsite at the equipment manufacturer's facilities. Multiple companies achieved a 2-5% reduction in moisture content, which equates to a 25-30% removal of water weight from a kelp sample (Gebler and Stanley, 2024). This is around half of the water loss from a freeze/thaw cycle that was achieved in the study below. This is a limited amount of dewatering considering the high capital expense. Mechanical dewatering requires additional labor to transfer kelp into a machine before the drying step. Another disadvantage is the form of the final kelp product as a screw press or other mechanical dewatering systems will pulverize the kelp, making a full frond final product impossible.

Testing of Thermal Drying Equipment

Thermal drying systems were tested to evaluate their energy efficiency, drying capacity, and suitability for small-scale operations. The systems tested included cabinet dryers, rotary dryers, and conveyor dryers (based on a dryer visited in Maine).

Cabinet Dehydrator

The cabinet dehydrator was tested at Barnacle Foods' facility in Juneau. It provided good control over drying conditions and preserved kelp quality but was labor-intensive with lower throughput. It accommodates the drying of whole, intact fronds. This system is most suitable for small-scale operations focused on quality over volume. Cabinet dehydrators are available in a wide range of sizes, from a small 160 L capacity model that was tested for this report, with about 25 square feet of drying tray area, to models that are room-sized.

- **Energy Consumption**: Moderate to low
- **Drying Efficiency**: Moderate to high
- **Labor Requirements**: High
- **Capital Cost:** Low to High

Container, or containerized, dryers are similar to cabinet dryers. They are often built out of a converted shipping container that contains racks where kelp can be loaded to dry. They can be outfitted with fans, dehumidifiers, and heat pumps to circulate warm air throughout the container. They are available in medium-scale to large-scale modular packages. Like cabinet dryers, loading and unloading container dryers is a manual process. Energy consumption can vary greatly depending on ambient temperature, humidity conditions, and the heating source.

Rotary Dryers

Rotary dryers were tested to provide insights into their potential for larger-scale operations. Rotary dryers were used to dry kelp, however, the equipment used was not designed specifically for kelp drying but repurposed. Although functional, these dryers were very inefficient so they do not provide relevant data related to energy consumption or drying time. However, they do serve to prove the concept that rotary dryers can be used for kelp. Results are encouraging enough that rotary dryers should continue to be investigated and developed.

By turning the kelp while drying, rotary dryers can dry quickly. However, the testing revealed that this turning also causes material loss during the drying process. Additionally, high energy consumption, larger footprints, and high upfront costs make them less suitable for small-scale operations. During drying, the kelp is tumbled, which causes it to break apart to such a degree that this method is only suitable for final products that are flaked or powdered and not when an intact frond is desired. Labor for loading and unloading is less than that required for cabinet dryers and could be further reduced by using conveyors.

Currently, work is being done in Alaska and Europe to develop a rotary dryer that uses a heat pump as the heating source. We look forward to seeing the results once this unit is activated.

- **Energy Consumption**: Moderate to High
- **Drying Efficiency**: Moderate to high (with material loss)

- **Labor Requirements**: Moderate
- **Capital Cost:** Moderate to High

Conveyor Dryers

Conveyor dryers were not directly tested but information was gathered during a visit to a processing facility in Maine. These dryers have high throughput and low labor requirements, making them ideal for larger operations. However, these dryers have large footprints (~12'x50' minimum), high energy demand, and high upfront costs making them more suited for industrial-scale applications.

- **Energy Consumption**: High
- **Drying Efficiency**: High
- **Labor Requirements**: Low
- **Capital Cost:** Very High

Cabinet Dryer Research

Introduction

As mentioned above, kelp as a farmed product in rural Alaskan communities provides a number of challenges to processing and shipping. It is highly perishable (Wirenfeldt et al. 2022), there are vast distances between farms accessible only by boat or float plane, and shipping costs can be very high. For these reasons, along with market demand, drying farmed kelp is the most effective way for farmers to process and get their product to market. However, high energy costs, low access to labor, and limited access to capital for industrial-scale processing equipment are all barriers to cost-efficient kelp drying. For this reason, we tested a small-scale cabinet dryer that is low-cost and readily available. The cabinet dryer can be easily scaled up for larger harvests and as operations grow.

The main focus of this test was on the water activity (a_w) of the kelp. A_w is an important measure for food safety and shelf stability of food products. A_w is the measurement of available water for the growth of bacteria, yeasts, and molds by measuring the ratio of vapor pressure to that of pure water. A_w of 0.85 or lower inhibits the growth of most bacteria and therefore foods with a_w below 0.85 are considered low-a_w foods (Beuchat et al., 2013). However, there are species of spoilage molds and yeasts that can grow between a_w 0.60 - 0.70 (Beuchat et al., 2013). For short-term storage, drying to a_w below 0.85 may be sufficient to prevent spoilage of fresh kelp, while for long-term storage, drying to below a_w 0.60 is recommended. Additionally, for texture-related reasons in food production, a_w of below 0.60 can be desirable.

Methods

We tested a 160-liter cabinet dehydrator with stack trays. The kelp used in this study was bull kelp, *Nereocystis luetkeana,* harvested in June of 2024 in Lisianski Strait near Pelican, AK as well as farmed bull kelp grown at Sea Quester Farm outside of Juneau, AK, also harvested in

June, 2024. The kelp was frozen for six months at -10 ℉ and then thawed under refrigeration before conducting this drying trial. The kelp sample was weighed, all 20 ± 0.5 lb, and then drained for 30 minutes in a harvest wash basket. The freeze and thaw cycle causes cell walls to burst and water to become unbound, resulting in drip loss of water and some nutrients (Sund et al. 2024). After draining, between 7.6 and 8.5 lb of material remained, a loss of about 60% by weight from the freeze/thaw cycle.

The drained kelp was then placed into the tray dehydrator. Some of the kelp was carefully laid out in discrete layers on the trays while other kelp was spread around in random arrangements. The dehydrator was set to 160 ℉ and then water activity measurements were taken regularly. An Aqualab PAWKIT Water Activity Meter was used to measure water activity in the samples. Electrical usage was also measured, using a Suraielec Energy Watt Meter.

An initial test was run to confirm the capabilities of the dryer and electrical consumption meter. Two trials were run to compare the time it took for kelp fronds of various thicknesses to dry. In the first trial, the kelp dried much faster than anticipated. This was corrected in the second trial with more frequent water activity (a_w) measurements.

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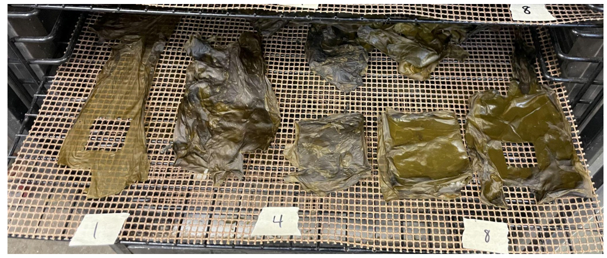

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Figures: 1. Kelp arranged on trays in the dehydrator. The number represents the number of stacked frond layers; unnumbered trays have clumps of kelp not carefully arranged. **2.** Fronds retained some pliability below 0.6 a_w when layered. **3.** Pawkit Water Activity meter testing kelp frond samples. **4.** Kelp fronds at various stages of a_w, with the single and four-layer fronds being below a_w 0.60 but the eight-layer frond still being above a_w 0.8.

Results

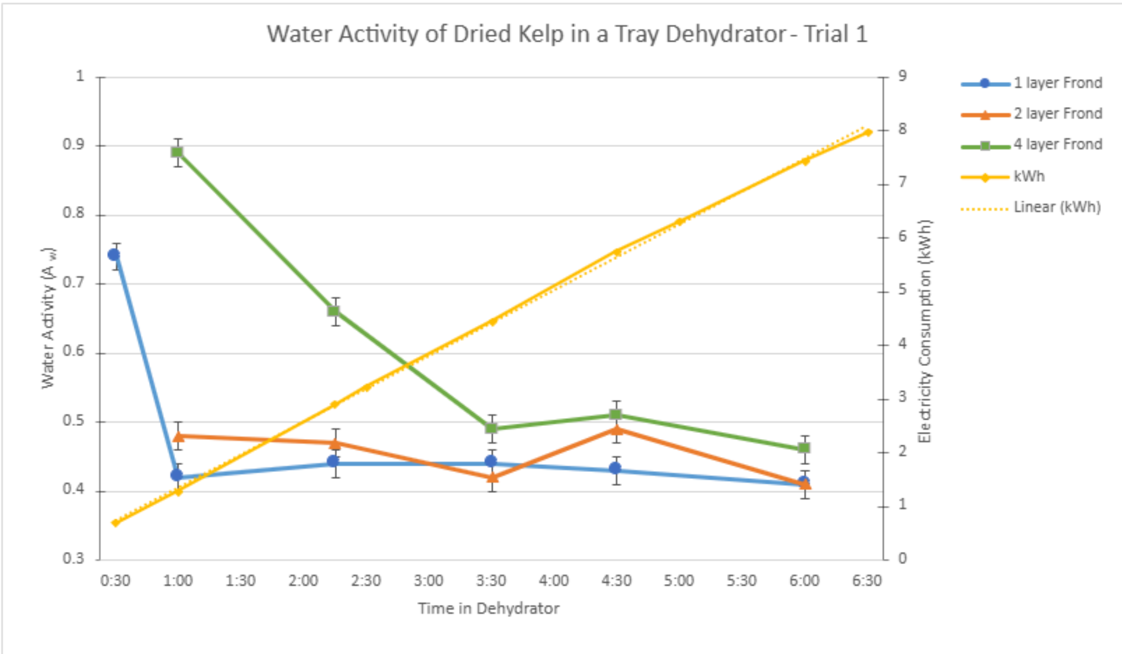
Energy Consumption:

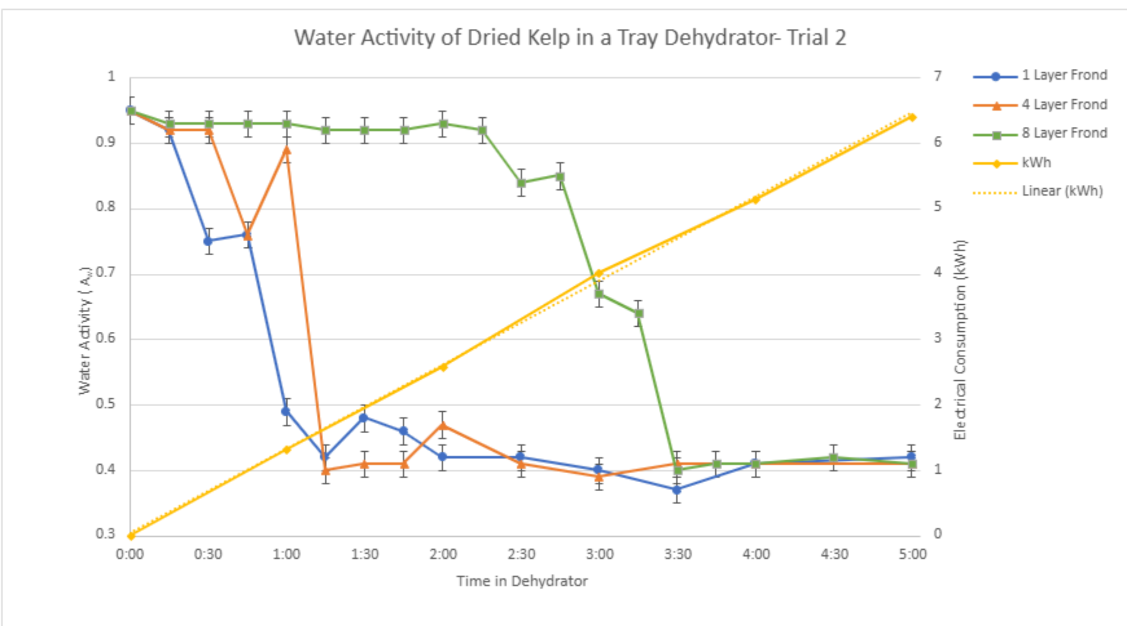
Across the three trials, the tray dehydrator used an average of 24.2 kWh to dry all of the loaded kelp. This computes to an average of 26.69 kWh per lb of dry kelp or 2.97 kWh per lb of wet kelp. To sufficiently dry the carefully laid out fronds, though, the tray dehydrator used 5.12 kWh. There was some slight variation due to the dehydrator door opening more frequently to measure the water activity but the effect was negligible. At $0.1178 per kWh in Juneau, AK, it costs under $0.50 to dry 7 lb of wet kelp to under 0.7 a_w, resulting in approximately 1 lb of dried kelp. The dryer ended up running for 22 hours for both trials to ensure all the kelp loaded into the dryer was sufficiently dried and that cost ended up between $3.25 - $3.50 per pound of dried kelp.

Water Activity:

In the first trial, fronds were stacked in a single layer, a double layer, and a quadruple layer. The fronds had an initial a_w of 0.95. After 30 minutes, the single layer had a_w of 0.74. After 1 hour, the single and double-layer samples had a_w below 0.5 and the four-layer sample was at 0.89 a_w. The four-layer sample was at 0.66 a_w at 2.25 hours and all the samples were below 0.5 after 3.5 hours in the dehydrator. The a_w was also measured of a random sample of kelp that had not been laid out carefully and after 2 and 3.5 hours the a_w was 0.92.

In the second trial, there were samples of fronds in a single-layer, four-layer, and eight-layer. Both the single-layer and the four-layer frond samples were dried to a_w below 0.50 after 1.25 hours. The eight-layer frond sample reached a_w below 0.85 after 2.5 hours, below 0.70 after 3 hours, and below 0.60 after 3.5 hours. From 3.5 hours and onwards, the three samples maintained a_w of around 0.40. Regarding texture, an important consideration for food production, at a_w of 0.70-0.80 the samples maintained some flexibility but as the a_w is lowered, the samples become more brittle. Depending on the final product goal, this can be desirable or not.





Figures 5-6: Graphs show the water activity (a_w) over time of kelp in a tray dehydrator. The more thinly arranged fronds dried significantly faster than the fronds in thicker stacks. The graphs also show consistent electrical consumption throughout drying of around 1.25 kWh. Error bars show the standard error of Pawkit Water Activity Meter, ±0.02.

Discussion
The cabinet tray dryer is a useful tool for measuring kelp drying as it can be a viable off-the-shelf option for kelp farmers to begin drying. The widespread availability, low cost, and scalability are all useful positives. However, an important consideration of dryer efficiency is the labor cost associated with drying. The labor cost for tray dryers is high. For the initial test, it took approximately 0.3 hours to load 8.4 lb of kelp into the cabinet dryer. It then took 0.1 hours to empty the dryer. Then there was an additional ~0.25 hours of setup and cleaning, plus the 0.5 hours of inactive draining time. In total, it was approximately 0.75 hours of labor to result in 1 lb of dried kelp using the cabinet dryer.

For the two trials where time was taken to carefully arrange fronds on the dryer trays, the set-up time was approximately .1 hour longer than the initial test. A 50% increase in time spent arranging led to a roughly 50% decrease in time that the kelp needs to spend in the dryer. This is a calculation that an individual kelp farmer or processor would need to make depending on labor availability and whether an increase in overall drying time is worth less active time, if there is more harvesting left to be done, for example.

Freshly harvested sugar kelp is likely to require less labor to lay out carefully in single fronds on a dryer tray. Based on the results of this trial, with scaling up tray drying it would seem worthwhile to spend the time carefully arranging kelp for maximum drying efficiency and it may require full-time kelp drying labor. All this being said, the time required to load and unload cabinet dryers can be expected to be reduced in commercial operations.

The other benefit of shortening the drying time at the expense of active labor time is the decrease in electrical consumption. Commercial electricity in Juneau is around $0.11 per kWh, cheaper than the national average. However, in other locations in Alaska, electricity is significantly more expensive. In Kodiak and Homer, electricity rates are above $0.17 per kWh, Gustavus around $0.35 kWh, and smaller villages in Southeast Alaska, like Kake, Hoonah, and Angoon, can be over $0.50 per kWh. Smaller villages are more likely to be powered by diesel generators instead of hydropower plants. If a rural farmer is not able to utilize a small-scale renewable energy source like wind or solar, the electricity costs will be high and therefore focusing on minimizing electrical consumption per pound of kelp becomes more valuable to sustaining a business.

Another consideration when deciding the initial processing is who the end user is. In the case of kelp for human consumption where a food manufacturer may do a second drying process, it would be worthwhile for the kelp farmer to dry only to $a_w < 0.85$. The shelf life will be reduced compared to $a_w < 0.60$ but it could be a long enough shelf life for shipping to the secondary processor. Further research is required on the shelf stability of kelp dried to various water activities and how storage is impacted by a range of ambient temperatures and humidities.

This study was conducted using frozen and thawed bull kelp fronds. The majority of kelp farmers in Alaska currently grow sugar kelp (*Saccharina latissima*). There are some differences in the physiology of these two kelp species. Though further research is required, average sugar kelp fronds may have slightly thicker fronds but also appear to have a slightly lower water content of approximately 90% (Blikra et al., 2024) compared to bull kelp. Therefore, there is a chance that the drying time could be significantly different for sugar kelp. Additionally, fresh kelp will not have lost the same percentage of water through the freeze/thaw cycle. However, while drying various types of kelp in a rotary drum air dryer at Barnacle Foods, no significant difference in drying time was found with drying both fresh and previously frozen bull kelp and sugar kelp.

The Impact of High Energy Costs

High energy costs remain one of the most significant barriers to developing kelp drying operations in Alaska. Energy prices in remote areas are among the highest in the United States due to the reliance on diesel generators and limited access to cheaper or renewable energy. Most coastal communities in Alaska exclusively have electricity as a power source. In other locations, many commercial heating loads are powered by a form of gas, which is not an option here. The electrical load from heating can be large and this drives up expenses from the required electrical infrastructure as well as the electricity consumption.

During the project, energy consumption was recorded for the cabinet drying. The findings underscored that energy costs can be reduced but often in a tradeoff so that more labor is required. Additionally, knowing the end product form and use will help determine the type of drying equipment to use and the degree to which the kelp is dried - both are factors that can affect energy consumption.

Recommendations

Based on the findings of this project, the following recommendations are made:

1. **Mechanical Dewatering Systems**: Mechanical dewatering systems—such as screw presses and plate-frame filter presses—are not recommended for small-scale kelp drying operations in rural Alaskan communities. While these systems can offer some water extraction, their capital costs, low throughput, and uncertain industry demand for specific product types make them unsuitable for large-scale or community-based drying. The high investment and operational costs associated with mechanical dewatering equipment would likely outweigh the benefit of marginally faster thermal drying.
2. **Focus on Thermal Drying**: Containerized or modular cabinet options with electric heat pumps show the most promise for small-scale operations. Continued effort will be

needed to refine these systems to optimize for the drying of kelp. Multiple iterations will likely need to be employed and refined before a dryer is fully optimized. This sort of operational-scale testing will be capital intensive but the costs can be spread over multiple seasons (when revenue-generating product is being produced) and across communities and farms. A collective effort will speed the development of dryers in Alaska.

Challenges Encountered

Challenges were encountered during this project that impacted the scope of testing and the ability to procure and test all intended equipment. The most significant challenge was related to funding constraints, which limited the acquisition of specific equipment, particularly for the mechanical dewatering systems. Initially, the project aimed to test multiple mechanical dewatering machines in detail; however, due to budget limitations, no units were available to test in-house.

To mitigate this, samples of kelp were sent out to multiple manufacturers of mechanical dewatering systems for analysis. These manufacturers tested the samples in their facilities and provided data on the effectiveness of their equipment. While this approach provided valuable information on the potential of mechanical dewatering, it limited hands-on testing and prevented a more comprehensive evaluation of the equipment in real-world conditions. The data from these manufacturers were not relied upon specifically for the measurements but results were looked at from a high level and are directionally supportive.

Looking forward, additional funding would be necessary to further test a wider range of drying equipment to ensure more comprehensive solutions for Alaskan kelp farmers and processors.

Conclusion

The project successfully evaluated a variety of drying systems for their applicability to the unique conditions faced by Alaskan kelp farmers and processors in remote communities. As the mariculture industry in Alaska continues to grow, developing efficient, cost-effective drying systems will be key to increasing kelp's marketability and reducing operational costs. However, several key factors, including high energy costs, remote geographic locations, and labor constraints, must be taken into account when selecting equipment.

Emerging Industry and Need for Equipment Testing:
The kelp industry is still in its infancy in North America and Europe, and little equipment has been specifically designed or extensively tested for kelp drying. The drying processes and equipment that are used globally for drying seaweed are for large-scale operations and so are not optimized for the unique needs of Alaskan communities, including the need for small systems used where there are energy constraints.

As the industry grows, further testing, modification, and adaptation of existing technologies will be needed. Equipment may require design changes to function for kelp. This process will likely be iterative and will require making changes to meet the evolving needs of the kelp farming industry, especially as more species of kelp are cultivated and new product forms are developed. Collaborative efforts between farmers, manufacturers, and researchers will continue to be essential.

Future Needs and Focus:
Future work must continue to focus on small-scale, energy-efficient, and adaptable drying technologies that are specifically suited to the conditions in coastal Alaska. The containerized thermal dryers and electric heat pump systems demonstrated promise and should be prioritized for future deployment. These systems, while requiring investment, hold the potential to scale up drying operations and create new opportunities for kelp farmers and processors without the prohibitive costs of larger, industrial-scale equipment.

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