An Abstract of the Project of

Stephanie Ichien for the degree of Master of Science in Marine Resource Management presented on December 10, 2010.

Title: The Energetic Implications Of Seafood Processing Waste and Fishmeal/Fishoil By-Products

Abstract approved:

____

Michael Harte

The seafood industry in Alaska produces about 4.4 billion pounds of fish every year and approximately 2.2 billion pounds of fish waste. Product recovery rates in the seafood industry have increased in the last decade, but still a large portion of all harvested fish is unused and often discharged into coastal and oceanic waters. With a move toward ecosystem-based fisheries management and the minimization of environmental impacts, several agencies and organizations are working to better utilize by-product development to enhance efficiency in the industry. However, research suggests that the discharge of fish waste may have some beneficial ecological impacts by providing a readily available source of protein to scavenging predators, such as seabirds. This project investigates the production of fishmeal/fishoil by-product from fish waste and the energetic implications involved with the allocation of energy between marine ecosystem and the economic system. We apply a series of analysis tools to assess these tradeoffs using energy as a means to frame the positive and negative impacts of seafood waste in a case study of the Alaska Pollock Fishery.

The Energetic Implications Of Fisheries Processing Waste And Potential Fishmeal/Fishoil By-Products

By Stephanie Ichien

A PROJECT

Submitted to

Oregon State University

In partial fulfillment
of the requirements
for the degree of

Master of Science

Presented December 10, 2010

ACKNOWLEDGEMENTS

I would like to express my sincerest gratitude to all the people who made the completion of this project possible. Your patience, guidance, support and encouragement have been invaluable.

My committee, with Michael Harte and Hillary Egna in particular provided me the guidance and structure necessary to complete this project, but their mentorship will far extend the reach of this experience in helping me to pursue my career. My friends and colleagues in the MRM program helped to keep me on task and motivated through this process, including Robert Allan, Lori Hartline, Hunter Berns, Jeremy Childress, Neal McIntosh, Evan Bing Sawyer, and Lisa Reifke. My family and friends have always supported me through all my pursuits with their unwavering love and encouragement; I could not have done this without them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table **Page**

1.0 Introduction

1.1 Research Objective

This project presents an applied framework for evaluating energetic tradeoffs in making waste management decisions in the fish processing industry of Alaska, using the Alaskan pollock fishery as a case study. The results of this research can guide decisions about investments in new products, processing technology, and even regulatory requirements in the fisheries sector. This project looks to expand the boundaries of traditional resource analysis in order to better understand the interrelationships within and between ecological and economic systems. It specifically investigates the tradeoffs involved with reallocating the energy in processing waste from the various aquatic ecosystems at the point of discharge to human systems in the form of a fishmeal/fishoil by-product.

The specific questions this research aims to answer are:

1. What are the energetic tradeoffs of fishmeal/fish oil fuel production?
2. What are the potential bioenergetic implications of these tradeoffs?

1.2 Background

During the Bristol Bay Summer Sockeye run in 2008, I worked at the Icicle Seafoods Inc. Salmon Cannery in Egegik Alaska as the Quality Assurance (QA) Intern. Upon completion of the season-long internship, I came away from the experience in Bristol Bay with a profound recognition of the amount of fish being discharged back into the river and an uncertainty about what that meant. Given the amount of energy, money, time going into salmon conservation on the West Coast, I immediately saw this discharge as a massive waste of a valuable resource. However, through several conversations with various individuals from the plant, I became aware of some of the costs required in processing this waste as well as the possible benefits of the waste to the natural systems.

I had arrived in Egegik on June 16, 2009 and had a brief orientation with the QA Manager, Kelly Bell. I began work the following morning in cold storage, where totes of whole salmon are processed for shipping as frozen fillets or headed and gutted (H&G) frozen fish. I worked in cold storage overseeing fillet grading, taking QA samples every 30 minutes for both the fillet line and the H&G line, and taking QA samples in case up (where finished products were boxed for shipping).

Fish was brought into the plant by the dock crew, who sorted the fish coming directly from fishermen or from tenders. Offloads took place only at high tide due to the shallow nature of the riverbanks. During an offload, fish is pumped from holding tanks on the delivering boats onto a sorting belt on the dock. As fish move across the sorting belt, the dock crew sorts out the highest quality sockeye to be processed in cold storage, the lower quality for the cannery, and unwanted species for waste (i.e. starry flounder, chum salmon, pink salmon, and decomposing sockeye salmon). I became the fulltime dock QA, inspecting the quality of the salmon entering the plant. As fish moved across the sorting belt, I took a five fish sample every 30 minutes to inspect the quality of the fish coming into the plant. This included recording fish temperatures, smell, texture, and general appearances. Between samples, I helped to sort fish for cold storage and the cannery.

Processing techniques differed depending on the final destination of the product. Salmon processed for fillets were hand cut, with the intention of producing an aesthetically acceptable product in shape and size. Any portion of the fish unacceptable for the final product is discarded; for example, the trimmings of larger fish are discarded in order to turn out a product that fits the packaging and meets consumer demand. Fish on the H&G line and in the cannery are processed with a mechanical header and more of the whole fish remains intact in the final product. While aesthetics is still important on the H&G line, due to the nature of the product, little is discarded. In the cannery, aesthetics is not as big an issue as in cold storage and so processors can utilize more of the fish in the final product. In my experience, the fillet produced the most amount of fish waste during processing. Waste being pumped out of the processing facility runs through a grinder and is discharged into the river as slurry of carcasses, heads, viscera, skin and unwanted fish in compliance with EPA waste discharge regulations.

I came away from this experience with a much broader view of the fishing industry and a better understanding of the Bristol Bay Salmon fishery. The aspect of the seafood processing industry that affected me the most was the amount of fish being sent back as waste into the Egegik River for the birds. This influenced my choice of topics for my Master's research.

1.3 The Issue

The seafood industry in Alaska produces about 4.4 billion pounds of fish every year and approximately 2.2 billion pounds of fish waste (Alaska Energy Authority, 2009). The recovery rate for fish products has increased with innovative processing technologies and new markets, but still a portion of each processed fish is unused and discharged into coastal and oceanic waters(Wilen, 2003). By-product development is one of the issues addressed by the Alaska Office of Fisheries Development, exploring a range of alternative uses for fisheries waste including fishmeal and fishoil fuel development. While the apparent benefits of converting fish waste into fishmeal and fishoil by-products may appear obvious, the energetic costs of this reallocation of available energy between the marine ecosystem and the economic system are less apparent. The discharge of fish waste into the marine environment creates the potential for both positive and negative impacts. We use a suite of analysis tools to assess these energetic tradeoffs in a case study of the Alaska Pollock Fishery. This project looks at the energy content of fisheries waste and the energetic tradeoffs of converting the waste into a secondary by-product. Looking specifically at the walleye pollock (*Theragra chalcogramma*) processors in Alaska, the primary purpose of the project is to identify the parameters and dimensions of the energetic impacts of dealing with this type of waste.

Fishing is an extractive industry, dependent on the harvest of fish from aquatic systems and a reallocation of energy from the natural environment to the socioeconomic system. The discharge of fish waste back into coastal and oceanic waters can be seen as a return of some of this energy back into the ecological system, and is not necessarily completely wasted. Using the basic principles of thermodynamics, a simple analysis can demonstrate where energy is being used inefficiently and possible avenues for capturing that energy for its highest potential. The first law of thermodynamics, a statement of the conservation of energy, says that "energy can neither be created nor destroyed but can be transformed from one form to another" (Singh, 2001). The net energy extracted from fish in any form will inherently be less than what we start with in a whole fish. This analysis is centered on the comparison of these net energies and the potential for conversion to forms of energy of higher quality. Accounting for the major energy inputs and outputs, we can begin to create an image of the energy stocks and flows of this particular system and identify the energetic tradeoffs and points of inefficiency (Figure 1).

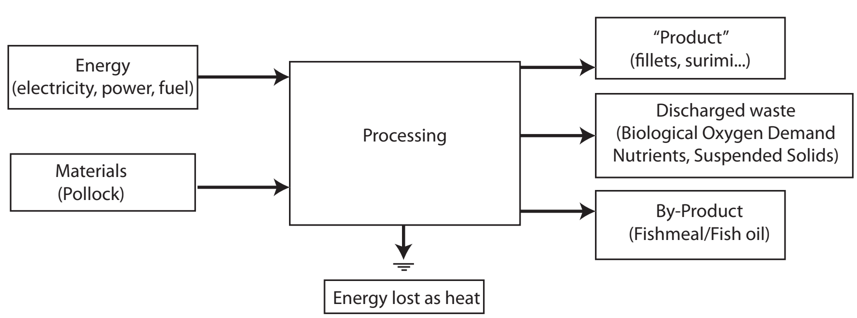


Figure 1. Based on the first law of thermodynamics, this figure is a simple map of inputs and outputs and provides a general schematic for the net energy analysis.

This analysis looks specifically at the alternative uses in fishmeal and fish oil by-product processing due to the relative commonality of their production in the Alaska pollock fishery. Fishmeal is a product that can be used as a fertilizer or an animal feed in agriculture and aquaculture. Fish oil is a co-product of fishmeal and can be used in similar ways. Fishoil can also be converted into a biofuel that can be used to supplement the fuel used on-site for generators and engines. Since many of Alaska's processing plants are in remote parts of the state, they are required in large part to run generators for electricity. On-site supply of fuel could be a money saver no matter how small the supply. With these by-products, there is a direct reallocation of energy. In terms of fishmeal, the reallocation of energy is defined in the feed conversion ratio (FCR) in agriculture and aquaculture and in the case of fish oil fuel, the simple conversion of energy to power ratio. However, in producing fishmeal and fish oil, the fish waste being used is no longer re-entering the aquatic ecosystem. It is necessary to understand the flows of mass and energy that go between the ecological and the aquatic system with respect to fisheries in order to have a comprehensive understanding of this part of the system and the system on whole in order to maintain a balance on both ends.

Though this research primarily draws on information and data from the Alaska pollock fishery, the concepts are ones that can be applied to any fishery for improving waste management techniques. The application of net energy analyses is a unique way to evaluate natural resource issues and their relative environmental processes for a more ecosystem-based view of the issue. In the final recommendations of the US interagency ocean policy task force, the US Council of Environmental Quality demonstrates a strong push toward ecosystem-based management, integrating ecological, social, and economic goals, and recognizes both that humans and healthy ecosystems are essential to human welfare (US Council on Environmental Quality, 2010). Energy, as the basis for all types of systems is an ideal window through which we can investigate the interrelationships associated with ecosystem-based management in fisheries. The results can provide insight to improve the efficiency of seafood production and processing and potentially supply information to stakeholders about alternative management practices.

1.4 THE CASE STUDY

The Alaska pollock fishery is the largest single species fishery in the world (Morell, 2009), making data on this fishery relatively more available and more comprehensive compared to many other fisheries. The volume of the fishery allows industry to explore innovative techniques for new methods of waste management. Already there are processors in the Alaska pollock industry using a pollock oil fuel onsite in their generators (Steigers, 2002). These characteristics of the fishery make it a logical choice as a case study for this project.

Due to the time and constraints on resources, there are several assumptions that were made in order for this project to be possible. There are several directions in which future investigations will significantly improve the robustness of the results. This project should serve as a starting point for discussion and further investigation.

2.0 LITERATURE REVIEW:

This project relies on the information and data available in the peer reviewed and grey literature. The following sections describes this literature.

2.1 ENERGY IN FISHERIES

Energy is a more basic unit of account than money and is a way to assess tradeoffs in natural resource problems where valuation can be difficult (McAllister, 1980). This provides a means of looking at various systems on a broader scale, incorporating both ecological and economic implications. As ecosystem based management approaches are emerging, it is becoming more important to understand the impacts of extractive uses, such as fisheries in a more comprehensive way. Fisheries remain the most energy intensive food production system in the world, burning 12.5 times more fuel than the edible protein they produce (Tyedmers, 2005). It is essential to understand where energy may be being wasted and where it can be utilized more efficiently.

Use of a bioenergetics framework provides a means for managers and researchers to evaluate the inputs and outputs of the industry, looking at mass and energy flows between fish and their environment as well as between fish and the human environment. Based on the first law of thermodynamics, bioenergetics can be defined as the mass balance relationship between the amounts of food consumed by fish and the fish's growth, the energy it expends, and the waste it produces (Brandt, 1993). An understanding of the flow of energy within and between species and their environment can have many implications on the health of populations as well as ecosystems on the whole(Dubreuil, 2009). These concepts are the same as the principles of net energy analyses and life cycle analyses in the industrial system, making energy an ideal window through which we can evaluate flows between natural systems and economic systems(Bakshi, 2002).

The world's fisheries operate on the extraction of energy from the aquatic system and a reallocation of this energy primarily into seafood. Energy is a common input and output in both systems so energetics and the basic concepts in thermodynamics can be used to exploit the synergies between methods from process systems engineering, systems ecology, and life cycle analysis in a type of joint analysis that can potentially overcome the shortcomings of the individual fields in understanding the flow of energy between natural and economic systems(Bakshi, 2002). This concept is based on the concept that growth and sustenance of both industrial and ecological processes are limited by the available energy and its conversion to useful work (Bakshi, 2002).

2.2 The Alaska Pollock Fishery

The Alaska pollock fishery is the largest single species commercial fishery in the world and the most lucrative fishery in North America, supplying whole fish products, fillets, surimi, and pollock roe (Morell, 2009) (Wu, 2009). Alaska pollock is a fast growing, short lived species distributed throughout the North Pacific with the largest concentration in the Eastern Bering Sea (Ianelli, 2009). Alaska pollock are harvested primarily with pelagic trawl gear with some of the fleet delivering to shoreside processors and others processing at-sea (Marine Stewardship Council, 2009).

The fishery has remained stable over the past 30 years with an average harvest rate of 1.18 million tons per year between 1977 and 2009 (Ianelli, 2009). However, in 2007 population numbers were down and the quota was reduced from the 1.33 million ton average to one million tons in 2008 and to 815,000 tons in 2009 (Morell, 2009). Ongoing stock declines could become a serious issue for the fishing industry and impacts on marine ecosystems could have implications for the species that rely on pollock as a food source (Morell, 2009).

In 2005, of the 805,652 tons of fish brought on board at-sea processors, 0.6% was directly discarded; 53% was discarded as offal, 14% was offal converted into fishmeal/oil, 3% into secondary products (roe, cheeks, etc.), meaning a total of 70% was not used as a primary product (Furness, 2007). In 2009 the total allowable catch was set at 815,000 tons with 35% allocated to the shore based fleets and the remaining 65% allocated to the at-sea processors(Ianelli, 2009). Therefore, approximately 285,250 tons of pollock were processed along Alaska's shore and 529,750 tons were processed at sea.

2.3 Fish Processing Waste and NPDES

The production of seafood from whole fish inevitably produces some waste during both the harvesting and processing stages, with an average recovery yield of 30-40%(Torres, 2007). The remaining 60-70% is the by-product; a mixture of edible and inedible materials remaining once the primary product is processed. While often times this by-product is ground up and discarded as waste, its qualities make it suitable for a variety of secondary products in four primary groupings: 1) plant fertilizers, 2) livestock/fish feeds, 3) value-added foods, and 4) specialty products(Torres, 2007). With innovative technologies emerging and new markets developing, our ability to produce secondary products from fish by-products can increase dramatically in the next decade. Increasing our utilization of wild caught fish reduces the amount of wasted resource, increases industry wide profits, reduces disposal costs, and can help to reduce the environmental impacts of processing facilities.

In considering post-production processes of the fishing industry, not only is it critical to more fully utilize this marine resource, but also to reduce impacts on marine ecosystems. Seafood processing effluents are a primary contributor to the organic input discharged into coastal waters, characterized by high concentrations of nutrients, nitrogen, suspended solids, and increased biological oxygen demands

(Theriault, 2007). The affects of processing effluents on the receiving waters vary with the characteristics of the environment at the point of discharge. Under the EPA's Clean Water Act 1972, the National Pollutant Discharge Elimination System (NPDES) permit program regulates the discharge of pollutants into waters of the United States. NPDES authorizes the State to determine discharge standards, with the intention of supporting the most beneficial use of public water of the US. Specific permits exists for offshore processors and onshore processors due to the variation in the characteristics of the receiving waters for each case.

Under NPDES in Alaska, seafood-processing waste may be discharged no closer than one nautical mile (1852 meters) from shore in waters least 120 feet (36.6 meters) in depth (USEPA). The amount of waste allowable for discharge is also determined by NPDES and is based on the volume of settleable solids discharged and the allowable size of the pile of seafood waste accumulated on the seafloor. The Alaska Department of Environmental Conservation (ADEC) permits the allowance for a one-acre zone of deposit (ZOD) area in which settleable solids may be deposited. The total amount of waste allowed is then based on the decay rate of the effluents, the average current speed, and this one-acre deposit area (Findley, 1995). In order to maintain a margin of safety, ADEC uses conservative estimations in their regulations for seafood processors and allocates them a waste load of 95% of the total allowed waste, leaving a 5% cushion between the waste allocation to processors and the total waste allowed (Findley, 1995).

Offshore processors operating more than three nautical miles from shore, including catcher/processors, motherships, and tenders must also apply for an NPDES permit in order to discharge any amount of seafood processing waste into the waters of the US. In the permit process, processors are required to estimate the maximum amount of waste produced by species on a daily and an annual basis. The poundage that is reported becomes the maximum discharge permitted by the vessel. According to

NPDES, seafood processing wastewater and wastes consists of any of the following: waste fluids, heads, guts organs, flesh, fins, bones skin, and stickwater produced by the conversion of aquatic animal to its marketable form. All discharged material must be reduced to pieces 0.5 inches or smaller and must discharge effluents into waters characterized as hydrodynamically energetic with a high capacity of dilution and dispersion.

In addition to the regulations directly related to the conditions of the discharge, processors must also obey restrictions related to the after affects of the discharge on the receiving environment. The "nuisance discharge" regulation deals with the fauna at the point of discharge stating that neither waste nor wastewaters may create an attractive nuisance by which fish or wildlife are attracted to the discharge in a manner that creates a threat to said fish and wildlife or to human health and safety. These regulations primarily deal with residues and aesthetics, requiring that all receiving waters remain free of floating debris, scum, oil, any objectionable color, odor, taste, or turbidity. Compliance with the entirety of the permit is mandatory for all processors, with a civil penalty of $37,500 per day for each violation. (The regulations listed here are a small selection of permit conditions.)

2.4 Ecological Impacts of Seafood Processing Waste

In considering impacts and alternative uses of fish processing waste, it is important to understand the characteristics of the waste. In the fish processing industry, the waste stream consists of a combination of fish heads, viscera, fins, frames, and skin. Further characterization focuses primarily on the biochemical oxygen demand (BOD), total suspended solids, nitrogen, oil and grease levels (Lalonde, 2009). There are several factors that determine the exact composition of this type of waste ranging from environmental factors such as season and ocean conditions to different processing techniques. These factors can alter the fat content of the fish, the amount of flesh left on the carcass after processing, and the amount viscera discarded, all of which may change how the waste can be used. Changing factors can alter the physiology of fish within a single species and include fish size, time of harvest, and gender (Bechtel P. , 2003). Not only will these factors affect the characteristics of the stream as waste, but will affect the solubility, the palatability, and the stability of any potential by-products (Bechtel P. , 2003).

Seafood effluents contribute to some of the primary sources of organic input discharged into coastal waters, having an impact on the both water quality and food web dynamics of the organisms that inhabit the receiving waters. Characterized by high concentrations of nutrients, nitrogen, suspended solids, and increased biochemical oxygen demands, effluents can have detrimental impacts when the quantity of discharge exceeds the carrying capacity of the ecosystem (Theriault, 2007). However, while some evidence identifies seafood effluent as a pollutant, evidence also exists that shows that the resulting nutrient enrichment increases fish populations near the points of discharge (Jamieson, 2010).

Several studies have investigated the potential toxicity of seafood processing effluents, characterizing and noting negative affects on the organisms living at and near the point of discharge in coastal waters (Jamieson, 2010). Problems primarily occur near shoreside seafood processing facilities when the quantity of their discharge exceeds the carrying capacity of the affected ecosystems thus affecting the biota. One of the primary impacts of this discharge is the depletion of dissolved oxygen concentrations in the water column, caused by the dramatic increase in nutrient and organic matter and the increased potential for algal blooms (Jamieson, 2010). As a result of the anoxia created by the increase in BOD, the anaerobic decomposition of organic matter leads to the breakdown of proteins and other nitrogenous compounds, an increase in anaerobic organisms, and the release of potentially lethal amounts of hydrogen sulphide, ammonia, and methane (Islam, 2004). If maintained over long periods of time, these affects can cause major changes in species composition, structure, and the function of the marine communities over large areas (Lalonde, 2009). Long-term effects may also include an increase in phytoplankton biomass and a large-scale decrease in species diversity among benthic and fish communities (Islam, 2004).

Evidence also demonstrates that seafood effluents can supplement the nutrients in the receiving waters providing an alternative food source and allowing for increased fitness of the organisms feeding on the waste (Theriault, 2007, Yorio, 2004, Furness, 2007)(Gremillet, 2008) (Lalonde, 2009). Outfall sites are predictable sources of abundant food with nutrient rich qualities, by which piscivorous predators may find a source of energy without the typical energy expense. Many species benefit greatly from current dumping practices with some populations artificially inflated including several species of seabirds (Gremillet, 2008)(Jamieson, 2010). On the global scale, scavenging by albatross may represent the largest quantity of waste taken by seabirds with Northern Fulmar present as the predominate species following fishing vessels in the Eastern Bering Sea (Furness, 2007).

Despite the potential for seafood waste to supplement the diets of scavenging predators, the junk food hypothesis argues that the diminished quality of this food source may be causing declines in productivity and overall fitness of the seabirds and marine mammals feeding on the waste (Romano, 2006)(Rosen, 2000)(Gremillet, 2008). Rosen et al. (2000) state that the decline of Stellar sea lions in the Gulf of Alaska and the Aleutian Islands may be due in part to their diet of pollock rather than a more diverse diet. Pollock have a much lower energy density than other fish species commonly found in seabird and marine mammal diets (Romano, 2006). By the nature of seafood processing, the waste has a much lower energy density still.

The characteristics of the receiving waters play a commanding role in determining impacts of seafood waste, dictating how the waste moves through the water column and where it settles on the seafloor. Influence by tidal forces, current patterns, salinity, and thermal variations in the water column can determine which organisms will feed on the waste, how much of it will land on the seafloor, and whether or not it will accumulate in small or large areas (Lalonde, 2009). In shallow waters, less dynamic waters allow particles to settle and accrue in the sediment, increasing the potential for anoxic conditions (Ahumada, 2004).

2.5 Fishmeal and Fishoil By-product

The production of fishmeal and fishoil is the primary method for utilizing the inedible portions of fish, processing "waste," and types of trash fish in the world's fishing industry (Windsor, 1981). In Alaska, there are several fishmeal plants located in and near the large shoreside processing facilities (Bechtel P. , 2007). Fishmeal can be produced from fish offal as well as from whole fish (Brody, 1965). However, as of 2007 it was estimated that only 10% of fishmeal produced comes from offal (Bechtel P. , 2007). As demand for fishmeal is on the rise due to the dramatic growth in the aquaculture industry, fishmeal production has remained relatively static over the past 15 years at around 6.3 million metric tons (Bechtel P. , 2007).

Fishmeal is produced through the partial separation of the three main constituents of a fish: oil, water, and solids (Windsor, 1981). With increasing efficiency, water is discarded as the primary waste product of this process, which requires approximately 30-35kWh/ton of fish (FAO, 1985). The process (Figure 2) results in a stable high protein solid product and fishoil, which is often used in agriculture and aquaculture as fertilizer or an animal feed. Another innovative use for fishoil has emerged, in which it is converted into a biofuel and used as a fuel supplement in generators and engines (Steigers, 2002).

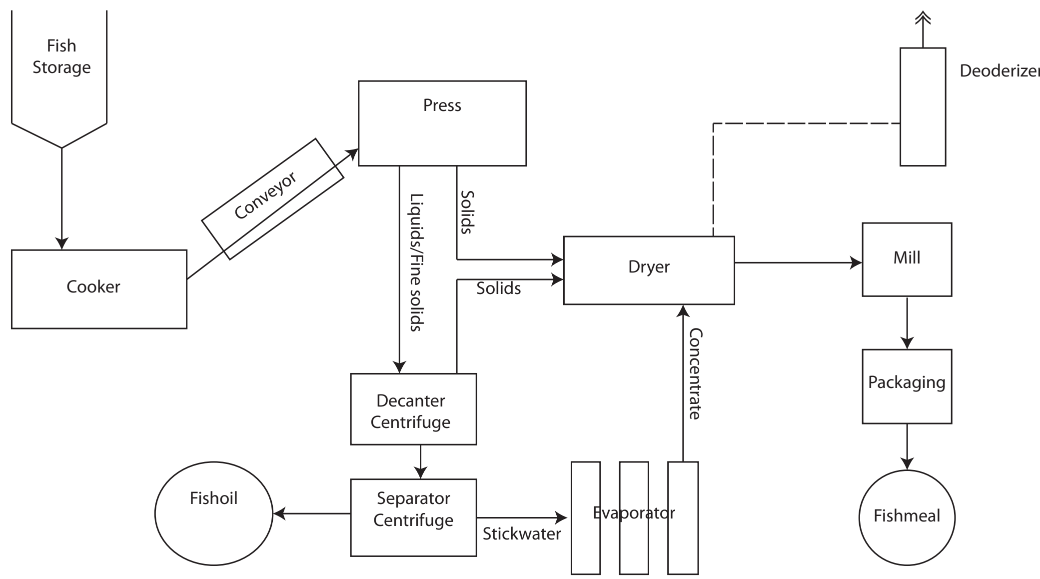


Figure 2. The three primary steps of fishmeal processing are cooking, pressing, and drying. Fishoil is produced as a co-product of this process.

2.6 Energy

Because all phenomena are accompanied by energy transformations and flows from one form to another, using energy is one way of representing a system in general terms (Odum H. T., System Ecology, 1983). The first two laws of energetics or thermodynamics explain the basics for how energy is governed. The first is the law of conservation, which states that energy is neither created nor destroyed in a system ((Odum H. T., System Ecology, 1983). Therefore, all energy entering a system will ultimately leave the system in one form or another: through a heat sink or another form of energy. The second law, the principle of universal depreciation is useful in examining the direction of energy transfer or conversion and states that it not possible to transfer of heat/energy from a lower state to a higher state (Singh, 2001). With respect to fish processing waste, the first two laws of thermodynamics state that any energy held within a quantity of waste will enter the system in one form and will either leave in the same form with less energy or in a completely different form with less energy.

Different forms of energy are of different qualities, measured by the embodied energy of one type required to produce energy of a different form (Odum H. T., System Ecology, 1983). Lower quality energy is more abundant and is widely dispersed, whereas higher quality forms are more concentrated and is capable of doing more work (Odum H. T., Environment, Power, and Society, 1971). The energy leaving the target system of this project leaves the system in three potential forms: dispersed heat (unaccounted for), raw fish waste, or the high quality form of fishmeal/fishoil fuel. So, despite the fact that energy is common to all interactions and flows of matter, in order to compare different forms of energy they must be converted into equivalents.

3.0 Method

To determine the impacts of reallocating energy in fish processing waste away from environmental discharge to conversion into a fishmeal/fish-oil fuel by-product, a suite of different analysis tools were assembled into a framework that supports both gathering data and evaluating the assembled information. This provides a way to predict how changes in the way fish-processing waste is used will impact each system to get an idea of where the energy can be used most efficiently. Data from the available literature was used to carry out the analysis. The analysis tools applied were a life cycle analysis, an energy system model, net energy analysis, and a multicriteria analysis.

3.1 Scenarios

To differentiate between impacts of the waste on offshore environments and coastal environments, three scenarios were used to examine potential pathways of waste processing from at-sea processors and from the shoreside processing plants. The use of the scenarios allows us to examine a range of plausible pathways, incorporating the economic and environmental system under the various conditions of uncertainty in an organized manner (Swart, 2004).

The scenarios used for this analysis are as follows:

1. All waste is dumped.
2. All waste is converted to a secondary product.
3. Hybrid: all shoreside waste (35%) is converted and all at-sea waste (65%) is dumped.

3.2 Life Cycle Analysis

The life-cycle analysis (LCA), often referred to as a “cradle to grave” analysis, is a methodological framework used to quantify the impacts associated with many of the energetic and material inputs and outputs required over the entire life cycle of a single product(Pelletier, 2007). LCA had its beginnings as an energy analysis tool in the 1960's and pollution prevention in the 1970's, and continues to evolve in its application to environmental impact assessments (Ciambrone, 1997; Ciambrone, 1997). While there are several ways of conducting a LCA, this project applies the commonly used four phases (Figure 3) in concurrence with the international standards for LCA as determined by ISO 14040: 1) goal definition, 2) inventory analysis, 3) impact assessment, and 4) interpretation, which interacts with the other phases (Rebitzer, 2004).

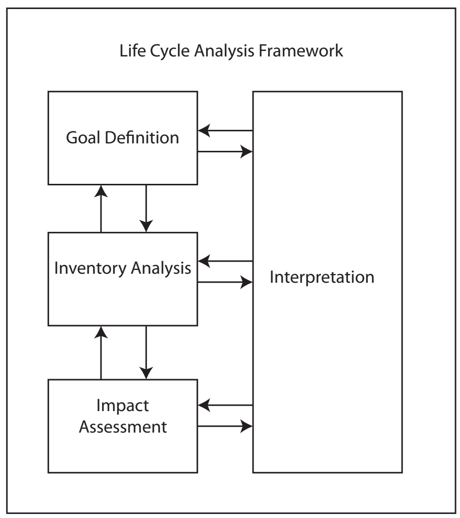


Figure 3. The Life Cycle Analysis (LCA) framework (Rebitzer, 2004).

The first phase, defining the goals, identifies the functional unit of the study, the boundaries of the system in question, and the overall goal of the analysis ((Rebitzer, 2004; Rebitzer, 2004). Looking specifically at waste management in the pollock processing industry, the functional unit for this investigation is 815,000 tons (the 2009 TAC) of whole pollock followed down two different pathways of post-production; one in which waste is reduced to 0.5 inch pieces for discharge, and one in which the waste is processed to produce a fishmeal/fish-oil fuel by-product. The life cycle stages of the post-production pollock are limited to the secondary processing unit (fishmeal unit) and availability in the respective environments.

The system boundary (Figure 4) is defined to isolate the energy difference between what is lost from the waste stream and from the fishmeal process. The system directly under analysis consists only of the discharge flow from the pollock processing plant and the inflow and outflows of the fishmeal-processing unit. In this way we are able to look specifically at the flows of energy leaving the system boundary and are easily able to compare their values.

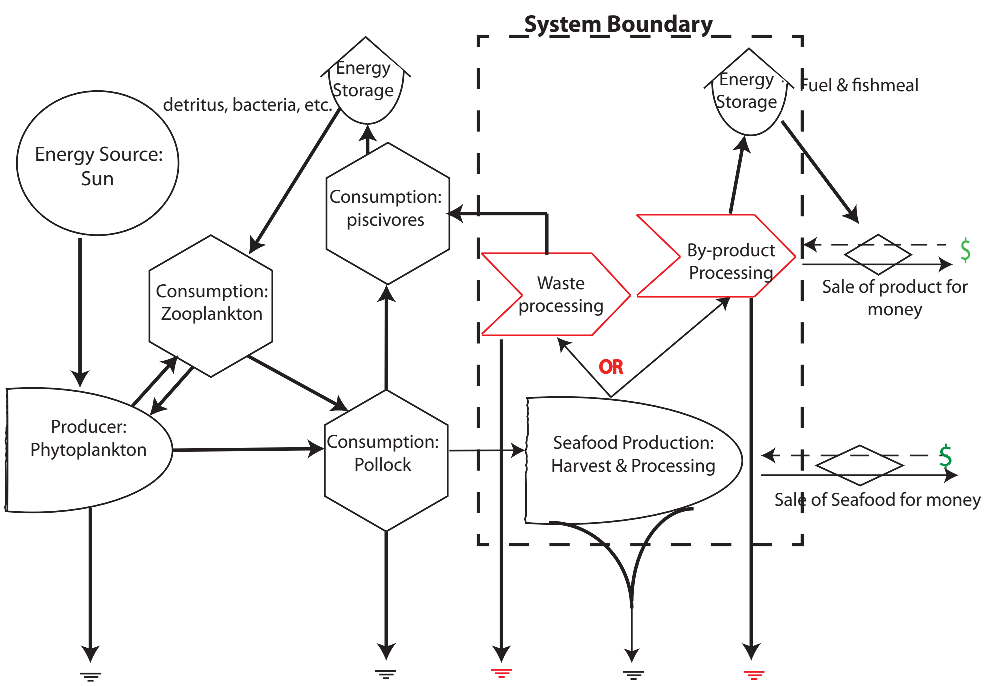


Figure 4. Energy map of the system

While the primary energy exchanges of interest are within the system boundary, the energy flows beyond the boundary still tell a key part of the story and will be accounted for in the impact assessment. Due to the quality and quantity of the available data in reference to these flows, it was not possible to complete a comprehensive energy analysis for the whole system.

The overall goal of the analysis is to determine the energetic tradeoffs between two different processes for dealing with pollock processing waste: 1) processing for discharge and 2) fishmeal/fish oil processing for use in aquaculture feed and biofuel.

The life-cycle inventory (LCI) analysis is essentially a model of the target systems and consists of compiling data on all the environmental exchanges of energy associated with the processing and provisions for the two fish waste options, such as emissions and resource consumptions(Rebitzer, 2004). Energy exists in several forms so it is important that these data be quantifiable and measureable in the same way for consistency and valid comparisons (Odum H. T., 1976). Based on the information on the boundaries laid out in phase one, the LCI consists of the energy values for whole pollock, consumption for processing waste for discharge, consumption for converting waste to fishmeal/biofuel, and a discussion on the conversion rates of energy to power in the ecological system as well as the economic system. In addition to identifying and collecting the primary data, this phase also identifies the necessary assumptions and limitations of the analysis (Figure 5 and Tables 1 and 2).

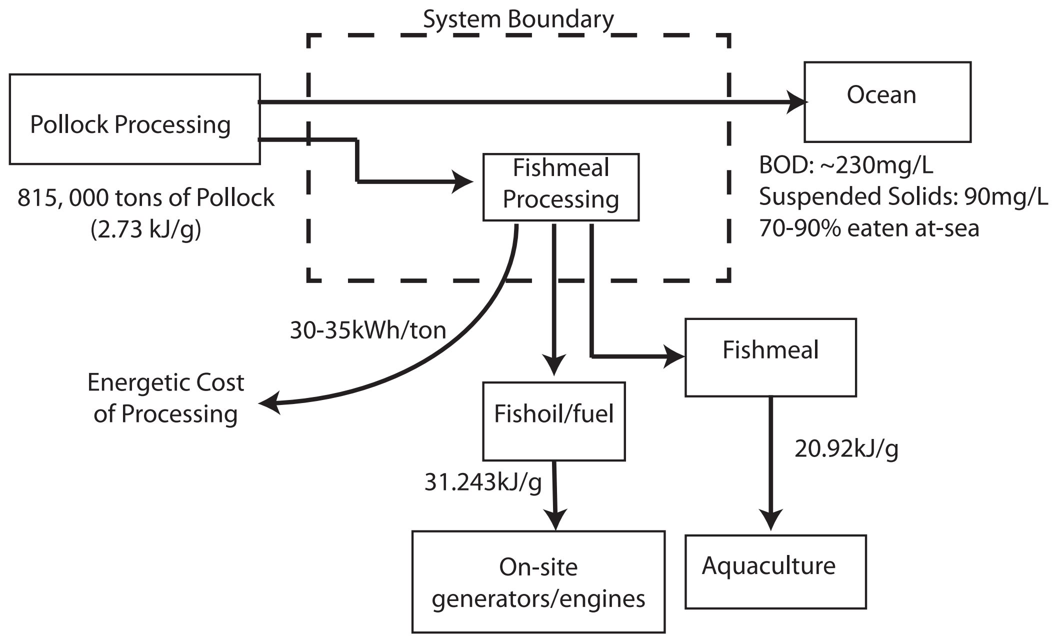


Figure 5. Refined energy map of the waste management portion of the system. Energy values are noted on the stocks and flows.

The third phase of the evaluation is the life-cycle impact assessment (LCIA). This phase indentifies the impacts of the inventory data, evaluated on a set of categories. Based on the ISO 14042 standards on the elements of the LCIA, there are three mandatory components of the LCIA : 1) selection of impact categories and category indicators, 2) assignment of LCI results with selected impact categories and impacts, and 3) the calculation of category indicator results (Pennington, 2004).

Table 1. Life Cycle Inventory Analysis

Life Cycle Inventory	**Component**	**Energy**
Inputs	Whole pollock	2.73kJ/g (VanPelt, 1997)
	Energy: fishmeal	30-35kWh (FAO, 1985)
	Energy: oil	30-35kWh (FAO, 1985)
Outputs	Energy/pollock waste	~70% (Furness, 2007)
	Surimi/fillets	~30% (Furness, 2007)
	BOD	~230mg/L (Jamieson 2009)
	nutrients	~90mg/L (Jemieson 2009)
	Fishmeal	31.243kJ/g (Steigers, 2002) 20%
	Fuel	20.92 kJ/g (Odum, 2000) 0.5%

Table 2. List of Assumptions

Assumptions:
1. Energy is distributed evenly throughout the whole fish
2. Energy content of pollock does not vary fish to fish
3. Conversion of raw waste to effluents requires no energy
4. fishmeal contains 97.56% of the initial energy input and fishoil contains 2.44% (FAO, 1985)
5. The only energetic costs considered is the 30-35kWh/ton required for fishmeal processing (FAO, 1985)
6. Ignore the energy costs of labor
7. 70%-90% of discharged waste is eaten (Furness, 2007)

Some commonly used impact categories include climate change, water use, acidification, and energy use. These can be grouped into three broad groups; resource use, human health consequences, and ecological consequences (Pennington, 2004). Selection of appropriate impact categories should reflect the goals set out in the initial phase of the LCA (Scientific Applications International Corporation (SAIC), 2006). Since the goal of this project is to determine the energetic tradeoffs in the management of pollock processing waste, this project looks specifically at energy use through the lenses of resource use and ecological consequences using the values and assumptions determined in the LCI.

3.3 ENERGY IMPACTS: RESOURCE USE

This impact category looks specifically at the net energy values across the system boundary and is characterized by a simple net energy analysis. Net energy analysis is based on the idea that energy is a limiting resource, and evaluates the energy inputs and outputs of a product to determine a net energy value of a process (Odum H. T., 1976). Accounting for the different energy values entering the system in each of the three scenarios, net energy efficiency is also calculated to determine which scenario is most efficient. This identifies the energetic costs of each process and reveals the energy tradeoffs between the scenarios.

For each scenario there are three process streams leaving the system boundary; these are the focus of the energy analysis. The input consists of the energetic value for the percentage of effluents allocated to each stream, varying with each scenario. The energy analysis is based on three primary constants, the energy value for pollock is 2.73 kJ/g (VanPelt, 1997), 30kWh/ton required to process fishmeal/fishoil (FAO, 1985), and a 70% waste generation rate. These three constants were used to calculate the energy inputs and outputs of the system (Table 3). The output for each scenario was the total amount of energy lost in each process; for this study the output was the electrical power required for processing as the energy is no longer available for use in the system.

Table 3. Energy Calculations

Item	**Calculation**
Inputs	
1. Round Pollock	Energy of pollock (J/ton) x Functional Unit
2. Electric Power	Energy demand of processing (J/ton) x (*Tons of waste to by-product* x %waste)
3. Waste to By-Product	(Waste to by-product (tons) x Energy of pollock (kJ/ton)) x 0.7

Once energetic values are calculated, net energy values can then be determined by subtracting the outputs from the respective inputs (Table 4). From the net energy values the amount of energy available at the end of each process stream is determined. Energy efficiency is then calculated for each process stream by dividing the outputs by the inputs, providing a different means of comparing each scenario.

Table 4. Net Energy Calculations

Inputs (J) – Outputs (J) = net energy (J)

Item	**Calculation**
Discharge	Total Energy Value for Discharge (Item 4)
Fishmeal	Fishmeal (Item 5) – Electric Power (Item 2)
Fishoil	Fishoil (Item 6) – Electric Power (Item 2)

Output (J)/Inputs (J)= energy efficiency

Interacting energy flows such as these are of different qualities, making it more difficult to clearly calculate ultimate energy costs and benefits. The effluent flow taking seafood waste straight from the processing plant to the point of discharge requires no energy input, but produces no new energy. The process stream in which fishmeal and fishoil/are produced requires significantly more energy, but also produces a by-product with higher energy quality.

3.4 Energy Impacts: Ecological Consequences

Characterization of this impact category is based on the energy availability and usability in the environment beyond the system boundaries. There is some uncertainty about the fate of discharged seafood waste and how it impacts the aquatic system. However, using seabird consumption rates observed by Furness et al. (2007), this project investigates the impacts of the discharge on the three predominate seabirds observed feeding on waste. Assuming an 80% consumption rate (Furness, 2007) of discarded waste and knowing the approximate energy needs of the top three seabirds following fishing boats (Table 5), this portion of the analysis provides a prediction of the number of birds potentially supported by discharged fisheries waste. Since the functional unit of this analysis is the 2009 TAC, the energy values are representative of the energy allocations in a single year. Therefore, dividing the energy discharged into the aquatic environment by the energy needs of each bird per year provides the maximum number of each individual species potentially supported by discharged waste.

Discharge Energy (J) ÷ Yearly Requirement (J)= Maximum Number of Species Support

Table 5. Energy Requirements for Top Three Scavenging Birds.

Bird	Daily Energy Requirement (Hunt, 2000)	Yearly Energy Requirement (daily requirement x 365)
Northern Fulmar	1116.6 kJ/day	407,559 kJ/year
Layson Albatross	3901.3 kJ/day	1,423,874.5 kJ/year
Western Gull	1750.4 kJ/day	638,896 kJ/year

3.5 Sensitivity Analysis

This step provides a way of accounting for some of the uncertainty in the data used in this analysis. Taking the values used in the primary analysis as a baseline to systematically change the parameters of the calculations, the sensitivity analysis can provide a broader picture of the energetic impacts.

3.6 Multicriteria Analysis

Once net energy values have been calculated for each scenario, it is important to understand the impacts beyond the energetics as well to get a more comprehensive understanding of the different scenarios. A multicriteria analysis (MCA) aims to objectively quantify and compare the various priorities, synthesizing the ecological, economic, social, and political perspectives in a single analysis (Kiker, 2005). MCA provides a means to rank each scenario against a set of criteria, revealing the ideal scenario. Each criterion is identified to reveal the various impacts of the issue on the different associated systems. The following criteria were identified for this project in order to synthesize the impacts revealed in this analysis and to highlight some of the impacts beyond the scope of this project.

Criteria A: Net energy values are high

This criterion identifies the scenario with the highest return on energy on a scale of joules lost and joules gained. Scenario one, in which all the waste is discharged, reveals a negative net energy and so scores very low for this criterion. Scenario two is ranked higher since all the waste is converted into a by-product and the net energy value is positive. However, due to the amount of energy required to produce the by-product relative to the amount of energy required for discharge (zero), scenario two did not score higher than a three. Scenario three scored a two on this criterion since the net energy associated with this scenario is less negative than scenario one, but is still a net loss of energy.

Criteria B: The bioenergetic impacts are positive

The rankings on this criterion are directly related to the results from the analysis on the energy impacts on the environment, and are based on a scale of number of birds fed. Scenario one is capable of feeding the most birds, while scenario two feeds less and scenario three feeds no birds. Scenario one did not receive a score of five due to the uncertainty associated with the results presented in the previous section.

Criteria C: Potential Economic profits are maximized

The scores for this criterion are not based on the results presented in this report, but are inferred from the literature review and experiences from the author. These scores are based on a more qualitative scale, in which we estimate the potential profits on a scale of potential dollars earned. Scenario one scores very low since all waste is being discharged with no potential for profit. Scenario two and three capture some capital from the waste by producing the secondary by-product. There are some external economic costs associated with each of scenario two and three that prevent them from scoring higher such as transportation costs, storage fees, and general production costs. Further investigation into this criterion would provide greater insight into the issue.

Criteria D: System feasibility is high

This criterion gets at the ability for the industry to carryout each scenario, which can be indication of acceptability among stakeholders. Like the previous criterion, this is not based on the results presented in this report, but reveals an aspect of the issue that can be explored further. These scores are also based on a more qualitative scale, in which we estimate the feasibility of the industry to carry out the required system designs and technology required in each scenario. Scenario one scored very high, since there is no significant obstacle to discharging all waste. However, scenario two scored very low since it is unlikely that the seafood industry would be capable of producing a by-product out of 100% of their discards.

Once the criteria are identified, each criterion can be weighted depending on the priorities of the analysis. Each scenario is then ranked on a scale of 1-5 for their ability to satisfy each criterion, where one is the lowest ranking and five is the highest. The rankings can be provided by several individuals or groups, representing the various stakeholders involved in the issue. However, this project relies on the data and information provided in this report to inform each score and uses a very simple additive approach to score the scenarios.

Weights

In order to increase the certainty of the results, we also applied weights according to Ullman's (2006) "Rank Order Centroid" (ROC), in which each criterion was ranked first, second, third, or fourth then weighted appropriately to reveal the results under all the possible prioritizations. The weights applied are listed in table 6. The final score for each scenario, accounting for the appropriate weight, is sum of each score multiplied by the associated weight.

Score= ∑ [criteria A weight (score)+ criteria B weight (score) + criteria C weight (score)+ criteria D weight (score)]

Table 6. MCA Rank & Weights

Rank	Weight
1	52.1
2	27.1
3	14.6
4	6.2
Total	100

This step provides an indication of which scenario is preferred under all the possible priorities. For example, if the net energy values were of the highest concern for making a decision between the three scenarios, then criterion A would be ranked highest and given a weight of 52.1. The score given to criterion A then has the greatest impact on the final score for each scenario, revealing a different outcome than when each criterion is weighted equally. If criterion A scores very low for each scenario, it may not matter where it is ranked and will not have a strong impact on the final outcome. This step provides a more complete analysis of the problem, revealing how priorities may or may not alter the outcome.

4.0 RESULTS

4.1 ENERGY IMPACTS: NET ENERGY

The following results provide an idea of the parameters of this issue. Having made all the necessary assumptions, the results are not an absolute representation of the energy impacts associated with this system, but provide relative values for comparison (Table 7). In scenario one, all the waste is discharged so 141.291x10^{13} J. Nothing is done to this energy so no energy is extracted from this total, making the output 0 and the net energy 141.291x10^{13} J. Scenario one therefore has an energy efficiency of 100%.

Table 7. Energy Impacts

	Net Energy (Joules x10^{13})		
	Scenario 1	**Scenario 2**	**Scenario 3**
Description	All waste (815,000t) is discharged	All waste (815,000t) is converted	Hybrid: shoreside waste (285,250t) is converted and at-sea waste (529,750t) is discharged
Input	141	203	163
Output	0	63	22
Net Total	**141**	**140**	**141**
	Energy Impacts: Energy Efficiency (%)		
	100	**69**	**87**

4.2 ENERGY IMPACTS: ECOLOGICAL CONSEQUENCES

With a reported seabird consumption rate on fisheries discards of 70-90% (Furness, 2007) in the ocean environment, at least 3 miles from the coast, these results assume an 80% consumption rate for all seafood waste discharge and rely on the data from the 2000 PICES Scientific Report No.14 on predation by marine birds in the subarctic North Pacific (Hunt, 2000). Table 8 indicates that if only Northern Fulmar were feeding on the discharge at an 80% consumption rate, the discharge in scenario one would feed up to 2.7734 million Fulmar. If Layson Albatross were the only birds feeding at the same consumption rate, scenario one would support up to 0.7938 million Albatross, and if the Western Gull was the only bird feeding, scenario one would support up to 1.7691 million gulls.

By definition, scenario two discharges no waste into the environment thus providing no food/energy for any scavenger. Whereas, scenario three involves the discharge of 370,825 tons of waste, supporting up to 1.8027 million Fulmar, 0.5159 million Albatross, **or** 1.1499 million Gulls.

Table 8. Bird Consumption of Discharge: Birds Fed **(**x10^6**)**

	Energy Requirement (Hunt, 2000)	**Scenario 1**	**Scenario 2**	**Scenario 3**
Seabird		All waste (815,000t) is discharged	All waste (815,000t) is converted	Hybrid: shoreside waste (285,250t) is converted and at-sea waste (529,750t) is discharged
Northern Fulmar	407,559 kJ/year	2.7734	0	1.8027
Layson Albatross	1,423,874.5 kJ/year	0.7938	0	0.5159
Western Gull	638,896 kJ/year	1.7691	0	1.1499

Since it is unrealistic to assume that the composition of birds feeding on the discharged waste is completely uniform, the following results (Table 9) use data from Furness et al. (2007) to predict the number of birds supported if 65% are Fulmars, 17% are Albatross, and 18% are Gulls.

Table 9. Bird Consumption of Discharge: Birds Fed ($x10^6$)

	Percent of Total Bird Composition (Furness, 2007)	**Scenario 1**	**Scenario 2**	**Scenario 3**
Seabird		All waste (815,000t) is discharged	All waste (815,000t) is converted	Hybrid: shoreside waste (285,250t) is converted and at-sea waste (529,750t) is discharged
Northern Fulmar	65%	1.8581	0	1.2078
Layson Albatross	17%	0.1349	0	0.0877
Western Gull	18%	0.3184	0	0.2069
Total	100%	2.3114	0	1.5024

4.3 Sensitivity Analysis

The results obtained in the sensitivity analysis (Table 10) reveal the limits at which increasing recovery rates significantly reduce the energy return on the by-products. At a 70% waste production rate, or a 30% product recovery rate, scenario two indicates an energy loss for both fishmeal and fishoil. Scenario three maintains a gain in energy from fishmeal production up to a 90% product recovery rate. However, while energy production in by-products decreases with increasing product recovery rates, this energy is simply now being allocated into the primary product.

Table 10. Net Energy Sensitivity Analysis

Waste Rate	**Scenario 1**	**Scenario 2**		**Scenario 3**		
	Discharge	**Fishmeal**	**Fishoil**	**Discharge**	**Fishmeal**	**Fishoil**
0.8	-1.614E+15	9.592E+14	-5.767E+14	-1.049E+15	8.083E+14	-1.900E+14
0.7	-1.412E+15	7.622E+14	-5.816E+14	-9.183E+14	6.803E+14	-1.932E+14
0.6	-1.211E+15	5.653E+14	-5.865E+14	-7.871E+14	5.523E+14	-1.964E+14
0.5	-1.009E+15	3.684E+14	-5.915E+14	-6.559E+14	4.243E+14	-1.996E+14
0.4	-8.073E+14	1.715E+14	-5.964E+14	-5.247E+14	2.963E+14	-2.028E+14
0.3	-6.055E+14	-2.538E+13	-6.013E+14	-3.935E+14	1.683E+14	-2.060E+14
0.2	-4.036E+14	-2.223E+14	-6.062E+14	-2.623E+14	4.034E+13	-2.092E+14
0.1	-2.018E+14	-4.192E+14	-6.112E+14	-1.311E+14	-8.765E+13	-2.124E+14

4.4 Multi-Criteria Analysis

For a straightforward MCA, where each criterion was treated equally, the simple summation of ordinal scores revealed that scenario three is preferred as indicated in table 11.

Table 11. MCA

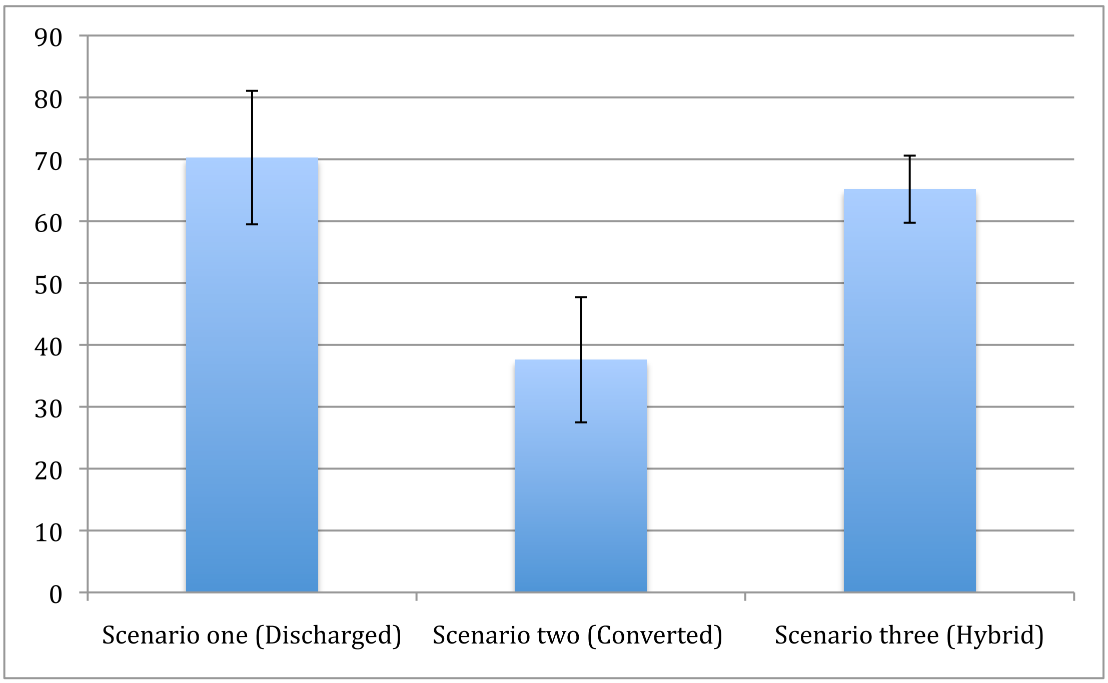
Criteria	**Scenario one**	Scenario two	Scenario three
1. Net energy values are high.	**5**	2	3
2. The bioenergetic impacts are positive.	**4**	1	3
3. Potential economic profits are maximized.	**1**	3	4
4. System Feasibility is high.	**5**	1	4
Addictive score	**15**	**7**	14

Applying all possible permutations of rank order for each criterion revealed the trends associated with different priorities. As described in table 12, on average scenario three still scores the best while scenario one scores best the most times and scenario two only scores best on two occasions when criteria A is top priority.

Table 12. MCA results for all rank order permutations

Criteria Order	Scenario one (Discharged)	Scenario two (Converted)	Scenario three (Hybrid)
All Equal	**70**	38	65
ABCD	**78**	45	72
ACDB	73	53	**74**
ADBC	**85**	48	73
ABDC	**84**	44	72
ACBD	72	51	**73**
ADCB	**81**	52	74
BCDA	**64**	22	57
BACD	**74**	28	62
BCAD	**65**	26	59
BADC	**79**	26	63
BDAC	78	22	59
BDCA	**72**	20	57
CDAB	55	45	**65**
CDBA	53	39	**62**
CBAD	53	38	**62**
CBDA	52	35	**60**
CABD	55	47	**67**
CADB	56	49	**68**
DABC	**83**	38	67
DACB	**79**	42	68

DBAC	**81**	30	63
DBCA	**75**	28	60
DCAB	**71**	40	65
DCBA	**69**	34	62
TOTAL	1757	940	1629
AVERAGE	70.28	37.6	65.16
#of times on top	16	0	8



5.0 DISCUSSION

This study looked at the life cycle of seafood processing waste and fishmeal-fishoil by-products to explore the energetic tradeoffs. Comparing the energy impacts of three scenarios of waste management in an applied life-cycle analysis, the study produced net energy values for the three scenarios and a basic bioenergetic analysis. Our results demonstrate that the energetic implications of seafood waste are more complex than they appear at first glance. It is evident that the discharge of raw seafood waste can provide some benefit to the aquatic environment, but it is unclear the tradeoffs that exist when waste is allocated between the ecosystem and by-product production. The results of this project help to identify the parameters of the tradeoffs and provide a framework for investigating this issue further.

5.1 ENERGY IMPACTS

Scenario three appears to be the most balanced scenario, in which less energy is lost than scenario one, but more birds are fed than scenario two. This is an indication that, while it seems ideal to utilize fisheries resources completely, there can be some benefit to discharging some of the waste into the ocean. Given the list of assumptions required to complete the simple analysis presented here, there are a number of factors that will provide more insight into the energy tradeoffs. A more comprehensive analysis will potentially reveal a more complete picture of this system, indicating where resources can best be allocated to make the fish processing industry more efficient.

Assumption number five states that the only energetic costs considered is the 30-35kWh/ton required for fishmeal processing, ignoring some major energy costs associated with other elements of the system such as harvest, primary processing, transportation, and storage. Considering these aspects could alter the energy impacts dramatically, and reveal greater energy losses in each of the three scenarios. Scenario two may be the most impacted due to the quantity of waste being processed. If all at-sea waste were processed into a by-product, at-sea processors would either require the by-product processing equipment on board their vessels or an increase in storage space to hold the waste in the right conditions for processing at a shore side processing plant. Both options for scenario two would require a significant increase in energy costs and may reveal a net loss rather than a net gain as indicated by the analysis in this project. The energy costs associated with scenarios one and three would also increase.

Assumption number seven states that up to 70%-90% of discharged waste is eaten by scavenging seabirds(Furness, 2007), but this is an assumption that can only be applied to discharge associated with at-sea processors in waters more than three miles from shore. The characteristics of the nearshore waters are different enough from the offshore region that they could be considered as separate entities within the whole system. There are likely other ecological impacts of the influx of energy from seafood waste that are unaccounted for in this study such as feeding by other scavenging organisms, environmental carrying capacities, tides, and seasonal variations.

In addition to the two mentioned assumptions, the remaining assumptions reveal a lack of available data with respect to the energetic characteristics of fisheries and seafood processing. It is clear that the energy impacts can provide some insight into providing the means for efficient seafood processing.

5.2 Future Research

Reduction of discards for more sustainable fisheries management has been an objective of FAO, ICES, and the US Commission on Ocean Policy. Together with a move towards more ecosystem-based management in fisheries, it becomes important to understand these issues on both the economic and environmental level. Energy is one starting point, from which impacts on both systems can be analyzed and compared. The assumptions discussed above provide a means of better understanding the resource allocation problem associated with seafood processing discards, provide a different way of assessing the issue, and highlight some of the future needs of this type of analysis.

- Consider the use of other energy analysis tools such as energy return on investment (EROI), Emergy, and Entropy to account for differences in energy quality.
- Account for the difference between the shoreside environment and the ocean environment.
- Investigate further into how seafood-processing waste is being used in the environment, by which organisms, and assess the level of dependency.
- These energetic considerations should be included alongside more traditional economic and environmental analyses when evaluating options for addressing waste from fish processing.
- Expand the scope of the MCA and incorporate perspectives of the various stakeholders.
- There is a need for more robust and complete energy use data to complete energy analysis of tradeoffs.
- Direction and magnitude of energetic tradeoffs will vary from fishery to fishery, so investigations into other types of fisheries and other regions would provide more useable information.

6.0 Acknowledgements

Partial support for this project comes mainly from USAID Grant No. EPP-A-00-06-00012-00 through the AquaFish Collaborative Research Support Program (CRSP). The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of the AquaFish CRSP or the US Agency for International Development.

7.0 LITERATURE CITED

Ahumada, R. A. (2004). Evaluation of Coastl Waters Received Fish Prcoessing Waste: Lota Bay As a Case Study. *Environmental Monitoring and Assessment , 90*, 89-99.

Alaska Energy Authority. (2009). *Alternative Energy and Energy Efficiency Assistance Plan.* Girdwood.

Bakshi, B. (2002). A Thermodynamic Framework for Ecologically conscious process systems engineering. *Computers and Chemical Engineering , 26*, 296-282.

Bechtel, P. (2007). By-Products from Seafood Processing for Aquaculture and Animal Feeds. In F. Shahidi, *Maximizing the Value of Marine By-Products* (pp. 435-449). Boca Raton, FL, USA: CRC Press.

Bechtel, P. (2003). Properties of Different Fish Processing By-Products from Pollock, Cod, and Salmon. *Journal of Food Processing Preservation , 27*, 101-116.

Brandt, S. a. (1993). Innovative Approaches with Bioenergetics Models: Future Applications to Fish Ecology and Management. *Transactions of the American Fisheries Society , 122*, 731-735.

Brody, J. (1965). *Fishery By-Product Technology.* Westport, CT, USA: The Avi Publishing Company, Inc.

Ciambrone, D. (1997). *Environmental Life Cycle Analysis.* Boca Raton, FL: CRC Press LLC.

Dubreuil, J. a. (2009). Energy Density of Anchovy Engraulis encrasicolus in the Bay of Biscay . *Journal of Fish Biology , 74*, 521-534.

FAO. (1985). *Planning and Engineering Data: 2.Fish Canning.* (A. Myrseth, Ed.) Rome: FAO.

Findley, C. E. (1995). Total Maximum Daily Load (TMDL) for Settleable Solid Residues in the Waters of Akutan Harbor, Alaska. *The United States Environmental Protection Agency* , 1-23.

Furness, R. A. (2007). Influence of Management Practices and of Scavenging Seabirds on Availability of Fisheries Discards to Benthic Scavengers. *Marine Ecology Progress Series , 350*, 235-244.

Gremillet, D. L. (2008). A Junk-Food Hypothesis for Gannets Feeding on Fishery Waste . *The Proceedings of the Royal Society: Biological Sciences , 275*, 1149-1156.

Hunt, G. H. (2000). *Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean.* PICES. B.C. Canada: Secretariat North Pacific Marine Science Organization.

Ianelli, J. S. (2009). *Assessment of the Walleye Pollock Stock in the Eastern Bering Sea.* North Pacific Fisheries Management Council. Alaska Fisheries Science Center NMFS.

Islam, M. S. (2004). Waste Loading in Shrimp and Fish Processing Effluents: Potential Source of Hazards to the Coastal and Nearshore Environmentas. *Marine Pollution Bulletin , 49*, 103-110.

Jamieson, B. L. (2010). Toxicology Evaluation of Atlantice Canadian Seafood Processing Plant Effluent. *Environmental Toxicology , 25* (2), 137-146.

Kiker, G. T. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. *Integrated Environmental Assessment and Management , 1* (2), 95-108.

Lalonde, B. P. (2009). Toxicity Testing of Sediment Collected in the Vicinity of Effluent Disharges from Seafood Processing Plants in the Maritimes. *Archives of Environmental Contamination and Toxicology , 56*, 389-396.

Marine Stewardship Council. (2009, March). *MSC Fishery Fact Sheet: Alaska Pollock.* Retrieved October 07, 2010 from The Marine Stewardship Council (MSC): http://www.msc.org/documents/fisheries-factsheets/Alaska%20pollock%20FFS%20-%20final%20-%20US%20paper%20size.pdf

McAllister, D. (1980). Energy Analysis. In D. McAllister, *Evaluating in Environmental Planning: Assessing Environmental, Social, Economic and Politcal Tradeoffs* (pp. 172-183). MIT Press.

Morell, V. (2009). Can Science Keep Alaska's Bering Sea Pollock Fishery Healthy? *Science , 326*, 1340-1341.

Odum, H. T. (1976). *Energy Basis for Man and Nature.* USA: McGraw Hill Inc.

Odum, H. T. (1971). *Environment, Power, and Society.* New York: WIley Interscience.

Odum, H. T. (1983). *System Ecology.* New York: Wiley-Interscience Publications.

Pelletier, N. N. (2007). Impact Categories for Life Cycle Assessment Research of Seafood Production Systems: Review and Prospectus. *International Journal of Life Cycle Assessments , 12* (6), 414-421.

Pennington, D. J. (2004). Life Cycle Assessment Part 2: Current Impact Assessment Practice. *Environmental International , 30*, 721-739.

Rebitzer, G. T.-P. (2004). Life Cycle Assessment Part 1: Framework, Goal and Scope Definition, Inventory Analysis, and Application. *Environmental International , 30*, 701-720.

Romano, M. J. (2006). Testing the Junk-food Hypothesis on Marine Birds: Effects of Prey Type on Growth and Development. *Journal of the Waterbird Society , 29* (4), 407-524.

Rosen, D. a. (2000). Pollock and the Decline of the Stellar Sea Lions: Testing the Junk-food Hypothesis. *Canadian Journal of Zoology , 78*, 1243-1250.

Scientific Applications International Corporation (SAIC). (2006). *Life Cycle Assessment: Principals and Practice.* USEPA. Cincinatti, OH: U.S. Environmental Protection Agency through its Office of Research and Development TECTION AGENCY.

Singh, P. a. (2001). *Introduction to Food Engineering: 3rd Edition.* San Diego: Academic Press.

Steigers, J. (2002). Demonstrating the Use of Fish Oil as Fuel in a Large Stationary Diesel Engine. In P. Bechtel (Ed.), *Advances in Seafood byproducts 2002 Conference Proceedings* (pp. 187-200). Fairbanks, AK: Alaska Sea Grant.

Swart, R. P. (2004). The Problem of the Future of Sustainability Science and Scenario Analysis. *Global Environmental change , 14*, 137-146.

Theriault, M.-H. S. (2007). The Effect of Seafood Processing Plant Effluent on Sentinel Fish Species in Coastal Waters of the Southern Gulf of St. Lawrence, New Brunswick . *Water Quality Research Journal of Canada , 42* (3), 172-183.

Torres, J. (2007). Recovery of By-products from Seafood Processing Streams. In F. Shahidi, *Maximizing the Value of Marine By-products* (pp. 65-90). Boca Raton, Florida, USA: CRC Press LLC.

Tyedmers, P. R. (2005). Fueling GLobal Fishing Fleets. *Ambio , 34* (8), 635-638.

US Council on Environmental Quality. (2010). *Final Recommendations of the Interagency Ocean Policy Task Force.* Washington DC: THE WHITE HOUSE COUNCIL ON ENVIRONMENTAL QUALITY.

VanPelt, T. J. (1997). Proximate Composition and Energy Density of Some North Pacific Forage Fishes. *Comparative Biochemistry and Physiology , 118A* (4), 1393-1398.

Wilen, J. E. (2003). The Pollock Conservation Cooperative. *Workshop on Cooperatives in Fisheries Management* .

Windsor, M. a. (1981). *Introduction to Fishery By-Products.* Surrey, England: Fishing News Books Ltd.

Wu, T. a. (2009). Quality of Crude Oil Extracted from Aging Walleye Pollock (Theragra chalcogramma) Byproduct . *Journal of the American Oil Chemists Society , 86*, 903-908.

Wuenschel, M. A. (2006). Estimating the Energy Density of Fish: The Importance of Ontogeny . *Transactions of the American Fisheries Society , 135*, 379-385.

Yorio, P. a. (2004). Fish waste as an alternative resource for gulls along the Patagonian coast: Availability, use, and potential consequences. *Marine Pollution Bulletin , 48* (778-783).