Martin Myrvang
Anders H. Strømman
Ola Jonassen

MONGSTAD PILOT

Utilization of Excess Refinery Heat in Dehydration Processes

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Industrial Ecology Programme (IndEcol)
NTNU
NO-7491 Trondheim, Norway

Tel.: + 47 73598940
Fax.: + 47 73598943
E-mail: indecol@indecol.ntnu.no
Web: www.indecol.ntnu.no

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1 Introduction

The work presented in this report is performed as a part of the Mongstad Pilot project. This project was initiated and founded by Statoil Mongstad and involves several research institutions in Norway. The Industrial Ecology group at the Norwegian University of Science and Technology is responsible for research on industrial symbiosis within Mongstad Pilot. This involves identifying possibilities for utilization of the surplus heat generated at the petroleum refinery at Mongstad. Process heat is available in various qualities. However in this report we focus on the possible utilization of cooling water and low pressure steam in drying processes.

Several drying and dehydration processes have the potential to utilize heat at relatively low temperatures, such as low pressure steam. The temperature levels are often restricted in these processes, in order to avoid damage to the material that is dried. This makes dehydration technologies especially interesting, in terms of utilization of the excess heat for new industrial activities.

The use of heat for drying purposes has a wide range of products and applications. Different food processing technologies use heat for dehydration, and production of dried fish is a large exporting industry in Norway. Energy costs for heating air or surfaces are often an important economic factor affecting drying industries. Commercial driers have a number of features designed to reduce heat loss or save energy. These features include heat pumps and recycling of air or steam. This report will introduce different methods of drying, and give a basis for further studies and comparisons between conventional energy sources and excess hot water and steam in drying processes. Case studies of a few chosen industries will be presented.

Chapters 1 to 4 present some general drying theory and process explanations, while chapter 5 presents six different production cases. This report is intended for the Mongstad pilot project group at NTNU and affiliated interests. There are other process plants that can offer thermal energy at similar qualities hence this report may be relevant to other geographical areas and industries.

1.1 Energy utilities at Mongstad

Several qualities of thermal energy are utilized within the refinery, and some of these are available for settling industries at Mongstad. The refinery has approximately 30000 m^3/h of excess cooling water at a temperature between 18° and 25° C, depending on season and operation of the refinery. A total of 6000 m^3/h is planned to be delivered to an aquaculture facility near the refinery. Some low pressure steam is also available, and even higher qualities could be made available some time in the future, depending on changes in the refinery operation and design. Table 1 show the steam qualities presently used at the refinery (MP, 2006):

Table 1: Steam qualities in refinery at Mongstad.

Steam Quality	Normal pressure [bar]	Normal temperature [° C]	Enthalpy (sat. vap) [kJ/kg]
Low pressure (LP)	3,4	175	2803
Medium pressure (MP)	10,4	211	2853
High pressure (HP)	30,4	335	3083

The steam utility system at Mongstad is designed so that the excess high pressure steam is used in steam turbines, and expanded so that it can be fed into the medium pressure steam. Analogously steam turbines are also used to utilize excess medium pressure steam for the low pressure steam system. The LP condensate is fed into boilers together with make up water to generate HP steam. The amount of excess heat in the form of LP steam varies between 0-60 tons per hour, and the first half of 2005 the average waste heat was 25 tons/h. A stable delivery of steam is expected for any receiving industry.

Figure 1 shows an example of some production processes connected to unutilized utilities at a petroleum refinery, mainly aquaculture and processing of marine products. Drying processes are included in many of the industries shown, for instance fish meal and oil, fish feed and dry fish production. Although there are many industries that could utilize excess steam, this report focuses on industries connected to marine processing. These industries can prove to be a fitting participant in this type industrial park if low priced thermal energy can reduce the total operational costs significantly.

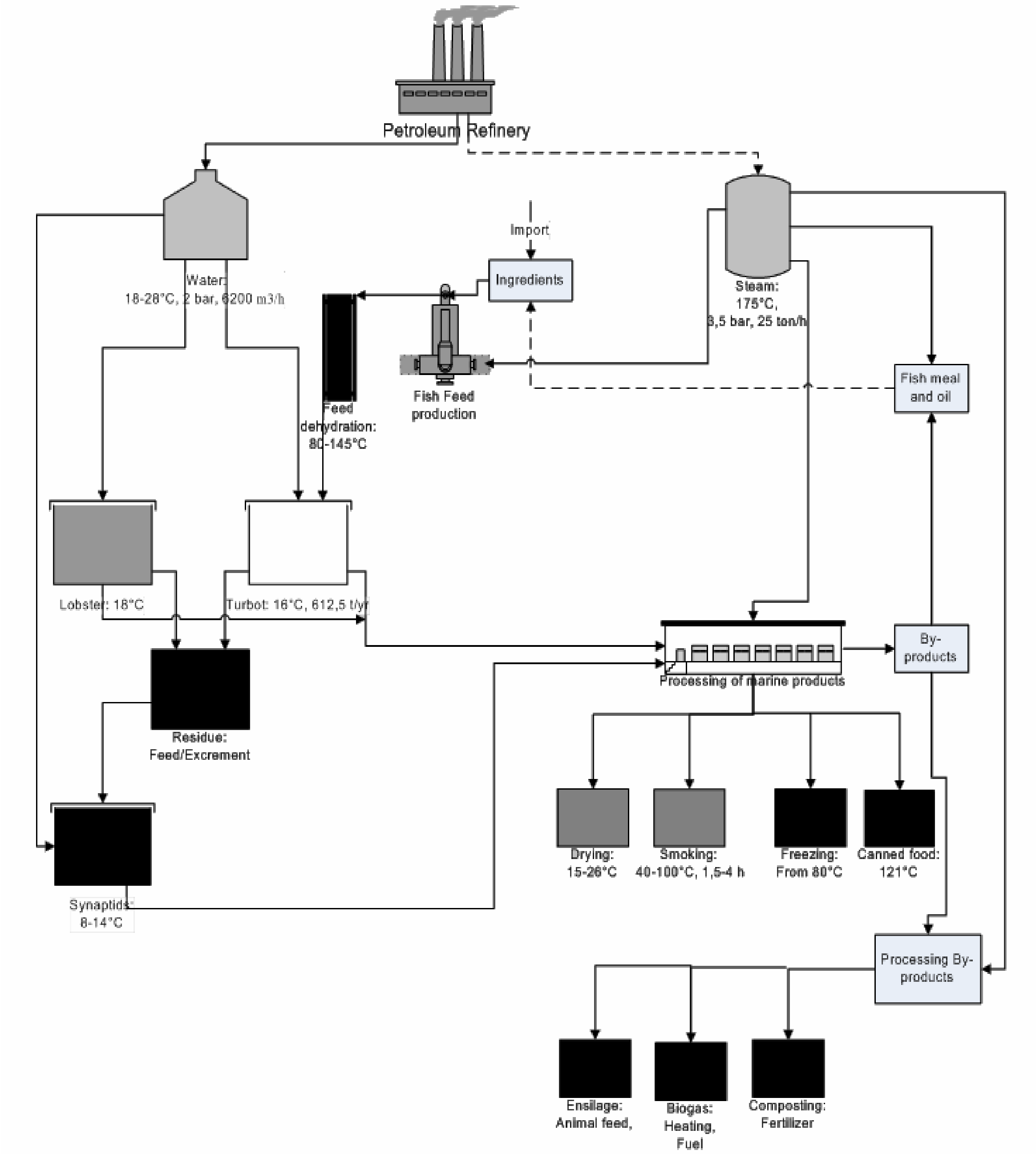

Figure 1: Aquaculture and marine product processing in connection with a refinery

2 Dehydration

2.1 Basic principles

In industrial drying and dehydration heat is applied to the product and moisture removal occurs by evaporation, thus involves heat and mass transfer. Psychrometrics is the study of inter-related properties of air-water vapor systems. These properties are represented in a psychrometric chart or the Mollier diagram (laterally reversed and flipped 90°), which is the European version. A Mollier diagram is shown in Figure 2. Three factors control the capacity of air to remove moisture from a product (Fellows, 2000):

1. The amount of water vapor carried by the initial air flow
2. The air temperature
3. The amount of air passing the product

The amount of water vapor in gases or solids is expressed as absolute humidity (moisture content) or relative humidity (RH). Moisture content is the mass of vapor per unit mass of dry air, shown as x in figure 2, while RH is percent of the partial pressure of water vapor in air to the pressure of saturated water vapor at the same temperature.

In drying the applied heat is absorbed by the product causing water to evaporate from its surface. The air temperature is measured by a thermometer and is termed the dry-bulb temperature. The wet-bulb temperature is lower, and is measured by a thermometer bulb covered with a wet cloth. The difference between the two temperatures is used to find RH in a psychrometric chart. Increased air temperature or reduced relative humidity cause water to evaporate more rapidly from a wet surface, and produce a larger temperature difference between the dry and wet bulb temperature. The dew point is the temperature at which the air is saturated with moisture (100 % RH).

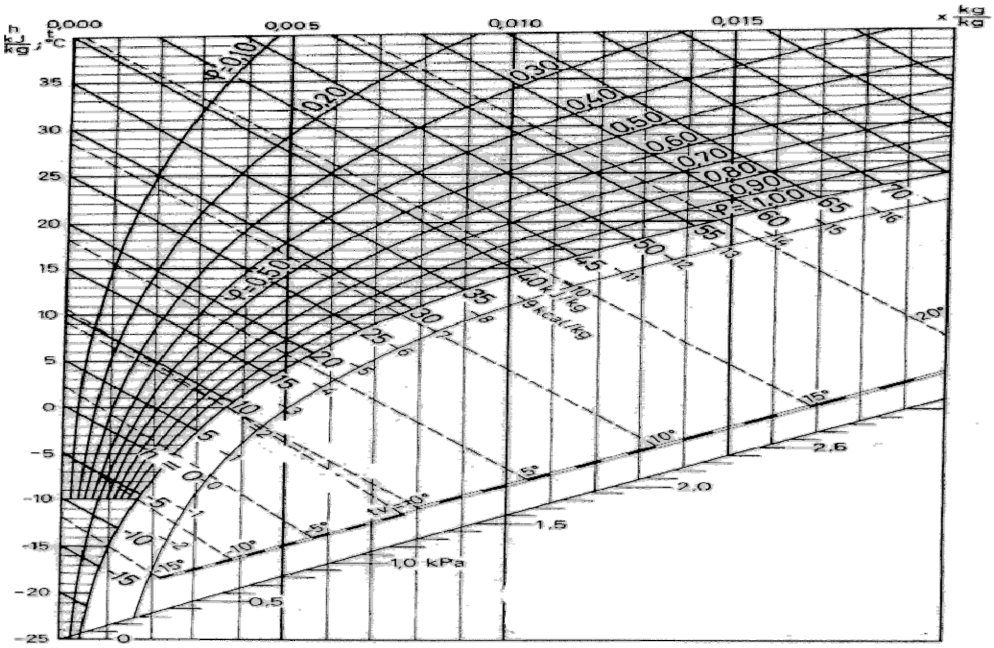

Figure 2: Mollier diagram

When hot air is in contact with a wet product, water vapor diffuses through a boundary film of air surrounding the product and is carried away by the moving air. The boundary film acts as a barrier to heat transfer and water vapor removal. The film is thicker when air velocity is low, and the product dimensions are large. Three characteristics of air are necessary for successful drying of a moist product:

1. A moderately high dry bulb temperature
2. A low relative humidity
3. A high air velocity

When a wet material is placed in a drier, the initial stage is bringing the material to the wet bulb temperature of the drying air. Then the drying starts, while the surface remains wet as long as water moves from the interior of the product at the same rate as it evaporates from the surface. This is known as the constant-rate period, and it continues until critical moisture content is reached. Then the rate of drying slowly decreases until it approaches zero at the equilibrium moisture content. This is known as the falling-rate period, and is the longest part of the drying operation. The rate of water movement from the interior to the surface walls falls below the rate at which water evaporates to the surrounding air, and the surface dries out when temperature, humidity and air velocity remains unchanged. In figure 3, A-B is called the settling down phase, drying commences with the constant rate period at B-C, and the falling rate period is C-D (ibid):

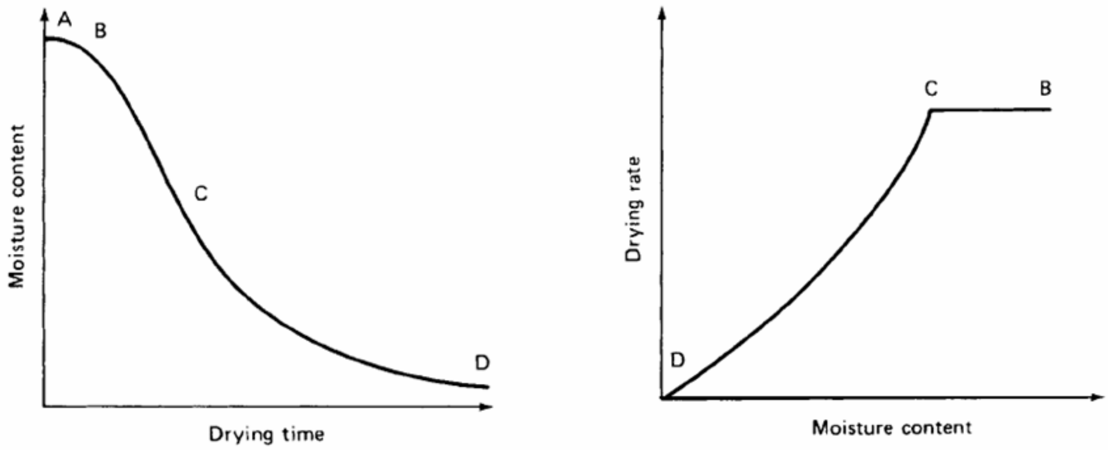

Figure 3: Drying curves when the temperature and humidity of the drying air are constant and all heat is applied through convection.

If the amount of heat is unchanged, the surface reaches the dry-bulb temperature of the drying air. Heat damage to the product can occur in this stage; therefore the air temperature is controlled to balance the rate of drying and avoid heat damage. Most heat transfer is by convection from air to the surface, but radiation and conduction can also play its parts. Calculation of heat transfer is often very complex in the falling-rate period (ibid).

2.2 Indirect drying Equipment

There are generally two ways of indirect drying: 1) Heating an air flow and blowing it over the material, drying the product through forced convection, and 2) A heated surface in contact with the material promotes heat transfer, and dries the product through conduction. Many dryers described in this chapter have variations when designed for different industries.

2.2.1 Hot air driers

For hot air driers the cost of fuel for heating air is decisive in terms of the overall economics of the process. Commercial driers have features that are designed to reduce heat losses or save energy, these include (Brennan, 1992):

- Insulation of cabinets and ducting
- Recirculation of high temperature exhaust air through the drying chamber if the product tolerates the temperature and reduced evaporative capacity
- Recovering heat from the exhaust air to heat incoming air using heat exchangers, thermal wheels or pre-heating the feed material
- Two stage drying (e.g. fluidized bed followed by bin drying or spray followed by fluidized bed)
- Pre-concentrating liquid products to high solid content by multiple effect evaporation (concentration by boiling)
- Computer controlled air humidity

Conveyor (belt) driers

Conveyor dryers are up to 20 m long and 3 m wide. The product is dried on a mesh belt in beds 5-15 cm deep. The air flow is initially from bottom to top through the bed, but can be shifted downwards or sideways in feed pellet drying, to prevent dried material from leaving the bed. The drier can have several stages with varying air temperatures and bed depth to distribute the drying uniformly. Products are dried to 10-15 % moisture content. This equipment can produce about 5,5 tons/h conditions are easily controlled. Figure 4 show a simple, and a three stage conveyor dryer (Fellows, 2000):

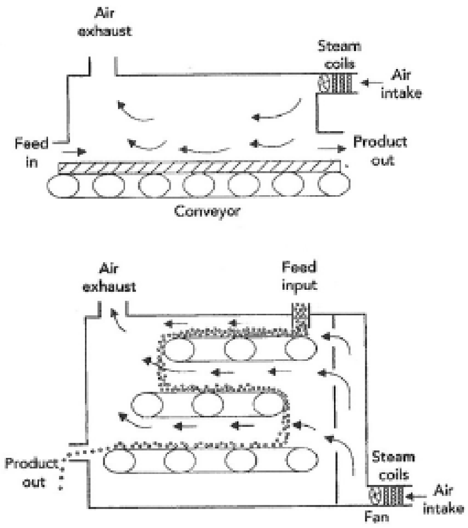

Figure 4: Top: Conveyor drier. Bottom: Three stage conveyor dryer.

Bin and cabinet dryers
Bin dryers are large containers with a mesh base. Hot air passes up through the bed of wet material with a velocity of about 0,5 m/s. They have a high capacity and low capital and running costs, and are often used to bring the moisture content to 3-6 % after initial drying in other types of driers.

Cabinet dryers (tray dryers) consist of an insulated cabinet with perforated or mesh like trays. Each tray has a thin layer of product (2-6 cm). Hot air is blown at 0,5-5 m/s through a system of ducts and baffles providing a uniform air distribution over and through each tray. These driers are mainly used for small scale production (1-20 ton per day). They have low capital and maintenance costs and are flexible in operation, covering different products. However, they have variable product quality and poor control options (ibid).

Tunnel driers
Tunnel driers consist of trucks programmed to move through an insulated tunnel. These trucks have the product in trays, and air is flowing over and around the material in variable ways, for instance countercurrent, parallel or cross flow to the moving trucks. The product is often finished in bin driers. Typically a 20 m tunnel contains 12-15 trucks with a total capacity of 5000 kg of product. The ability to dry large quantities in a short time made tunnel drying widely used the US. But the method have been superseded by conveyor- and fluidized bed drying since they are more energy efficient, have lower running costs and higher product quality (Fellows, 2000). Figure 5 shows the principle of a tunnel drier (Brennan, 2006):

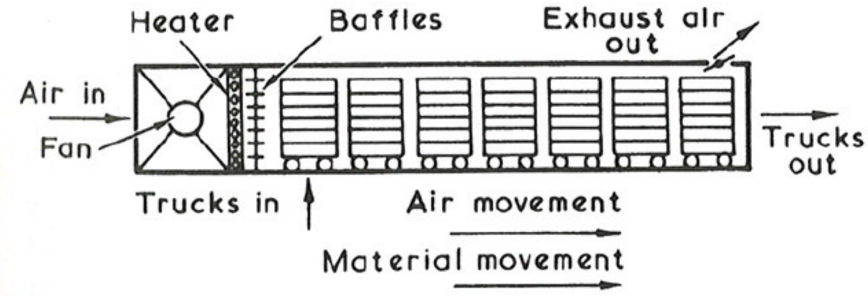

Figure 5: Principle of a tunnel drier where the material moves in the same direction as the drying air.

Rotary dryers
A rotary dryer consists of a hollow cylinder which is rotated and usually inclined towards the outlet. The wet granular material is fed at the high end as shown in figure 4, and move through the cylinder as it rotates. The figure below shows heating by a heated air flow where the granular particles move forward slowly before they are showered downward through the hot gases, but in some cases the heating is by indirect contact with steam heated walls of the cylinder, explained under indirect dryers as the rotary disc drier (Geankoplis, 1993).

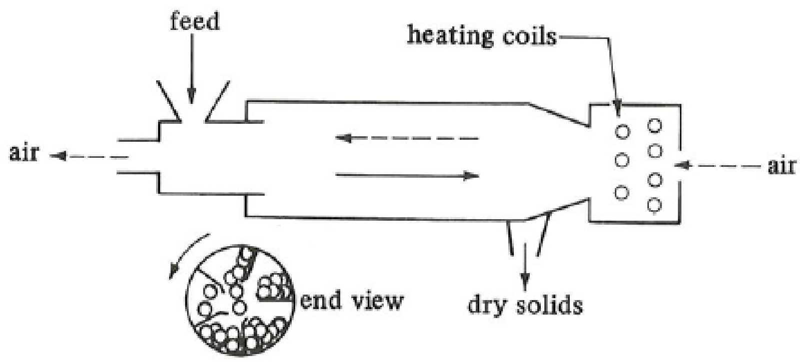

Figure 6: Schematic drawing of a rotary dryer.

Fluidised bed dryers

A fluidised bed dryer evenly distribute air at a uniform velocity around the bed of material. Air from the fluidized bed is usually fed into cyclones to separate out fine particles. The product is fluidized directly in the bed chamber, and normal bed height is 0,5 meters, but they can be up to 1,5 meters. Hot air is blown through the bed causing the material to become suspended and fluidized, exposing the maximum surface area of the material for drying. These driers have very small temperature gradients, good control over drying conditions and high drying rates (Fellows, 2000). Figure 7 shows the principle of a continuous fluidized bed dryer:

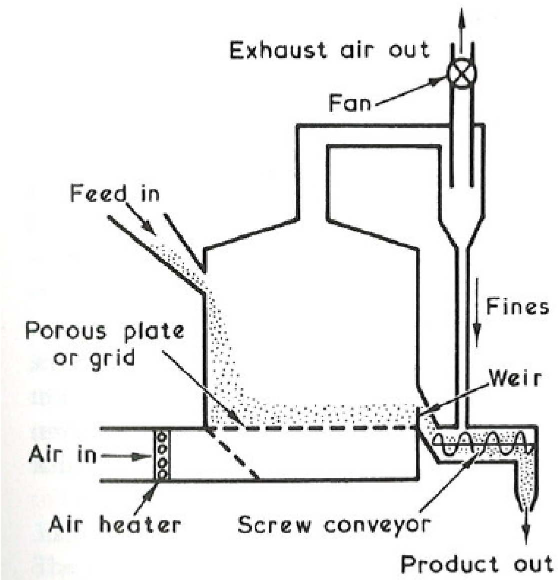

Figure 7: Principle of continuous fluidized bed drier (Brennan, 2006)

2.2.2 Contact driers

Heated surface or contact dryers supply heat to products by conduction, and have two advantages compared to hot air drying:

1. It is not necessary to heat large volumes of air before drying commences, therefore the thermal efficiency is high
2. Drying may be carried out in the absence of oxygen to protect components of the product that are easily oxidized (Fellows, 2000).
3. The small amounts of air in the exhaust stream simplifies cleaning and energy recovery by steam condensation

There are several types of industrial driers that may be used with steam from a refinery. Using steam for the drying process of fish meal production requires indirect heating by surface or air through heat exchanging. The drying process in steam conduction dryers is controlled by adjusting the steam pressure and by adjusting the level of the material in the dryer. In indirect dryers the material is at no stage in contact with flue gases (FAO, 1986).

Drum Dryers

Drum dryers are slowly rotating hollow steel drums, which are heated internally by pressurized steam to 120-170ºC; low pressure steam is used to heat sensitive products. A thin layer of material is spread uniformly over the outer surface by dipping, spraying spreading or by auxiliary feed rollers. Before the drum has completed one revolution (within 20s to 3 min), the dried solid is scraped off by a blade which has no or a small clearance to the drum surface. The dryers may have single or double drums. The single drum is widely used as it has a greater flexibility and is easily maintained. Drum drying is used to produce potato flakes, pre-cooked cereals, molasses, some dried soups and fruit purees, and soluble for animal feed formulations. Figure 8 show a single and a double drum dryer (Fellows, 2000):

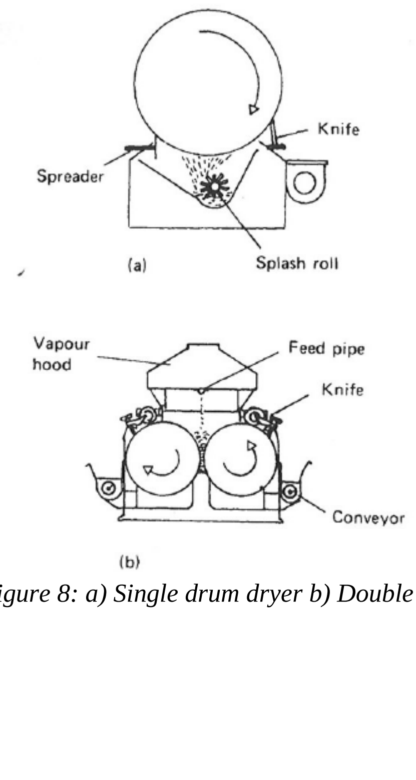

Figure 8: a) Single drum dryer b) Double drum dryer

Rotary disc dryers
The *rotary disc dryer* consists of a stationary cylindrical jacket and a rotor equipped with steam heated double walled discs perpendicular to the shaft which provide good agitation and heat transfer to the material. The evaporated water is removed by air drawn through the dryer by a centrifugal fan. There is an air dome on the top of the dryer to allow for the passage of air and water vapor, and reduce the particle entrainment. The meal discharge is controlled by a gate valve at the discharge opening. These dryers normally use steam at a pressure of 6 bars and are designed to remove up to 2700 kg water per hour, corresponding to about 300 ton of raw fish per 24 hours in fish meal production (FAO, 1986).

The *steam heated coil dryer* is different from the rotary disc dryer in the design of the rotating heating elements. The coils are mounted on a hollow shaft and supplied with steam at a pressure of about 6-7 bars. These dryers are available with heating surface ranging between 20 and 400 m^2 and of handling materials corresponding to as much as 400 ton of raw fish per 24 hours.

The *indirect tube dryer* is a horizontal rotating cylinder with internal steam heating in longitudinal tubes. To transfer heat from the tubes to the pulp and to remove evaporated water, air is drawn through the dryer.

Indirect hot air dryers offer the same advantage as the steam dryers in the sense that the gases of combustion do not come into contact with the drying material. The hot air is generated in a heat exchanger where the gases from the combustion chamber move on one side of the heating surface and uncontaminated air on the other. After having transferred the heat to the current of clean air, the flue gases leave the system through the stack (ibid).

2.3 Energy aspects of drying

A survey of food industries within the EU found large variations in energy consumption in different types of processing. Flour milling has the lowest energy input at 586 MJ/ton product, while cocoa and chocolate processing has the highest with 8335 MJ/ton product. On average 40 % of the heat loss from factories is contained in vapor and steam and 10-20 % is lost in hot water. In all types of food processing, most of the energy is used for actual processing, but significant amounts are also used for packaging, transport, cleaning water and storage (especially for deep-frozen foods) (Whitman et al, 1981). Values are given in table 2:

Table 2: Share of total energy use for production segments in percent.

	Average	Range
Processing	58 %	40-80 %
Packaging	11 %	15-40 %
Transport	12 %	0,56-30 %
Cleaning water	15 %	-

Drying is an energy intensive process. In the wood processing industry 70 % of the energy consumption is drying, in the textile industry 50 % and in cereal production up to 60 % (Bolland et al, 1997). Hence, it's convenient to have a characteristic measure describing energy consumption in drying processes. Energy consumption in this context relates to the amount of supplied high grade energy to the process (electricity, steam, oil, gas). Energy efficiency is commonly used, and is defined by:

$$\text{Energy efficiency} = \frac{\text{Energy for moisture evaporation at } T}{\text{Total energy supplied to the dryer}}$$

Here, T is the initial temperature of the material when fed to the dryer (Bolland et al, 1997). There can be large variations in energy efficiency for different processes and materials, and it is also dependent on the individual dryer configuration.

The energy efficiency is often regarded as a lumped parameter since it's calculated by initial-final or inlet-outlet based data. For batch drying, the energy efficiency is given as an average value over drying time. For continuous drying, the energy efficiency is averaged either over moisture content, dryer length, height or volume, depending on dryer configuration. The energy efficiency is useful when comparing different dryers but has limited application when analyzing a drying process and dryer configuration in the design stage or upgrading an existing process (Menshutina, 2004).

Typically heat consumption is 2,5-3 MJ per kg water evaporated in contact dryers, compared to 4-10 MJ per kg water evaporated for hot air driers. However, food products have a low thermal conductivity which becomes lower as the food dries and a thin layer of food is therefore needed to conduct heat rapidly, without causing heat damage (Fellows, 2000). Heat conductivity of most dried foods is approximately equal to insulation materials at 0,02-0,04 W/mK.

3 Extrusion

Extrusion is a process which combines operations such as mixing, cooking, kneading, shearing, shaping and forming, often the product is processed further by drying. Some principles are similar in all types of extrusion: Raw materials are fed into the extruder barrels and the screw(s) convey the food along it. The screw flights narrow down the barrel which restricts the volume and movement of the material. This results in the material filling up the barrel and the space between the screw flights and the material is compressed. Further along the barrel the screws knead the product into a semi-solid mass. The material is then passed to the smallest flights, where pressure and shearing increases. Finally, it is forced through restricted openings (dies) at the end of the barrel. The products can be processed further by for instance drying or coating (Fellows, 2000).

3.1 Basic principles

If the product is heated to 100° C or more it's called extrusion cooking or hot extrusion. Then additional heat and the frictional heat are used to make the temperature rise rapidly. In cold extrusion the temperature of the product remains approximately ambient. Common products are pasta and meat products. Low pressure extrusion, with temperatures below 100° C, is used to produce for instance liquorice, fish feed, fish pastes and pet food.

The two factors that influence the nature of the extruded product the most are the rheological properties of food and the operating conditions of the extruder. The properties of the feed material have some important factors:

- Type of feed material
- Moisture content
- Physical state
- Chemical composition, amounts of starch, protein, fat, sugar
- The pH of moistened material

All these factors affect the viscosity, which is a crucial factor that determines the operating conditions of an extruder, and hence the product quality. The most important operating parameters in an extruder are:

- Temperature
- Pressure
- Diameter of the die
- Shear rate

The shear rate is influenced by the internal design of the barrel, its length and the speed and geometry of the screw (ibid).

3.2 Extrusion equipment

Extruders come with single or twin screws. The figure below shows the principle of an extruder (Brennan, 2006):

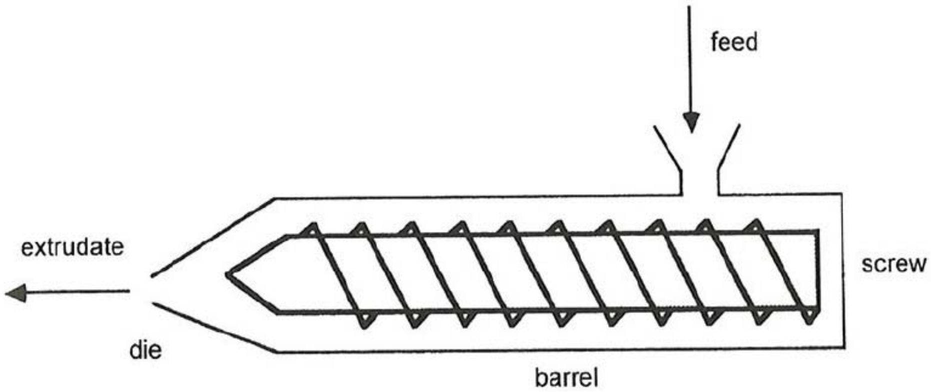

Figure 9: The principle of an extruder (single screw).

Single screw extruders consist of a cylindrical screw that rotates in a grooved cylindrical barrel. It is made from hard alloys or steel to withstand the frictional wear. They can be classified according to the extent of shearing action on the material into the following

- High shear: High speeds and shallow flights create high pressures and temperatures. Used in production of cereal and snack foods
- Medium shear: For breading, some proteins and semi-moist pet foods
- Low shear: Low speed and deep flights create low pressure for forming pasta and meat

Additional heating can be achieved by using a steam jacketed barrel and/or by a steam heated screw. If cooling is necessary cold water can be used in the jacket.

Twin screw extruders have co-rotating intermeshing screws, where the flights of one screw sweep material from the adjacent screw. These types of extruders have the advantage of greater flexibility of operation, achieved by changing the degree of intermeshing of the screws and the number of flights. Twin screw machines handle oily, sticky and wet material, or other materials that slip in a single screw (Fellows, 2000).

4 Evaporation

An evaporator is used before the dryer in some production processes. The process saves the overall energy consumption and economic costs of the operation. The off-gas from an evaporator contains little pollutants, but olfactory pollution can occur. The solid fractions of the material have no losses in an evaporator, which makes an evaporator beneficial if the price of the solid fraction is high. Mechanical pressing is a very cheap and effective way of removing water and compressing the solids, but some of the solids are lost in the reject water. The moisture content in the material after pressing depends on the force of the mechanical press and the viscosity of the material.

4.1 Basic principles

Evaporation, or concentration by boiling, is the removal of water from liquid foods by boiling off water vapor. During evaporation, sensible heat is transferred from steam to the material, to raise the temperature to its boiling point. The rate of evaporation is determined by both the rate of heat transfer into the material and the rate of mass transfer of vapor from the material. These processes are shown schematically in figure 10 (Fellows 2000):

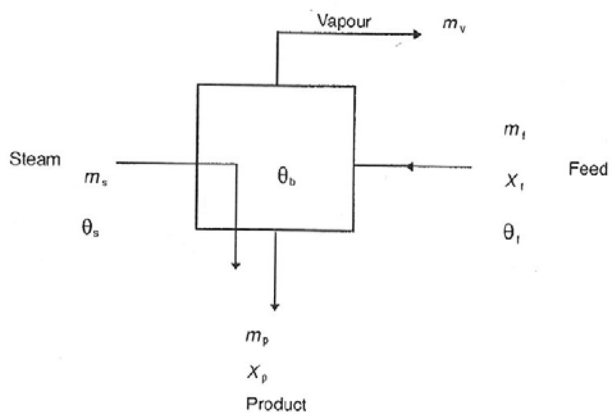

Figure 10: Schematic figure of an evaporator under steady state conditions (Fellows, 2000).

Steady state operation of the evaporator in figure 10 is given by these parameters (Fellows 2000):

- m_f, mass transfer rate of feed (kg/s)
- m_p, mass transfer rate of product out (kg/s)
- X_f, solids fraction of feed
- X_p, solids fraction of product
- m_v, mass transfer rate of vapour produced (kg/s)
- m_s, mass transfer rate of steam used (kg/s)
- θ_f, initial feed temperature (º C)
- θ_s, initial temperature of steam (º C)

The total mass balance of the process is:

$$m_f = m_p + m_v$$

For the water component, the mass balance is given by:

$$m_f(1-X_f) = m_p(1-X_p) + m_v$$

For solutes, the mass of solids entering the evaporator equals the solids leaving the evaporator:

$$m_f X_f = m_p X_p$$

Assuming negligible heat losses from the evaporator, the heat balance is:

$$Q = m_s \lambda_s = m_f c_p(\theta_b - \theta_f) + m_v \lambda_v$$

Where c_p = specific heat capacity of the feed material (J/kg ºC), λ_s = latent heat of condensing steam and λ_v = latent heat of vaporization of water (J/kg). In other words:

Heat supplied by steam = Sensible heat + Latent heat of vaporization

4.2 Evaporation equipment

There are many types of evaporators used for different purposes. This chapter presents a few of them. The material is taken from (Brennan, 2006).

Vacuum evaporation
A single effect vacuum evaporator has a heat exchanger, known as a *calandria*, where sensible and latent heat is supplied to the feed in order to evaporate some of the water. Saturated steam is usually the heating medium, but hot water and other thermal fluids are sometimes used. Tubular and plate type heat exchangers of various designs are widely used. A device is needed to separate the vapor from the concentrated liquid phase. A condenser is needed to convert vapor back to liquid and a pump or steam ejector to remove the condensate, thus creating and maintaining the partial vacuum in the system. Figure 11 shows a natural circulation evaporator (Brennan, 2006).

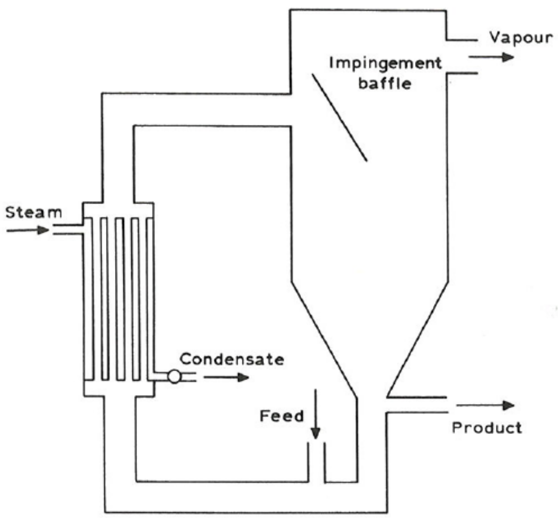

Figure 11: Natural circulation evaporator (Brennan, 2006).

In this design of a *short tube* evaporator the calandria is external to the separator chamber and may be at an angle to the vertical. Short tube heat exchangers have a number of bundled tubes that typically range between 25-75 mm in diameter and are 0,5-2 m long, while long tube evaporators have tubes that are 3-15 m long and 25-50 mm in diameter. The liquid circulates by natural convection within the heat exchanger and through the separation chamber. A swirling flow pattern generates centrifugal force, which helps separating the vapor from the liquid (ibid).

Multiple effect evaporation (MEE)
In a single effect evaporator it usually takes 1,1-1,3 kg of steam to evaporate 1,0 kg of water, while a triple effect evaporator consumes 0,37-0,45 kg. Vapor leaving a single effect evaporator is commonly used to preheat the liquid, or heat water. This reduces the specific steam consumption. However, the most widely used method of recovering heat from the vapor is MEE (Brennan, 2006). The principle is shown in figure 12 (Fellows, 2000):

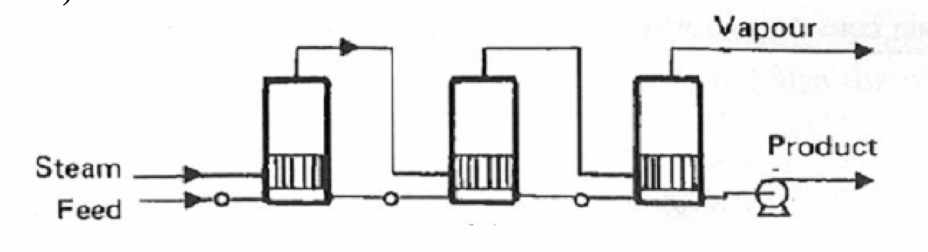

Figure 12: Multiple effect evaporator with forward feeding.

In figure 12 the vapor leaving the separator of the first evaporator, effect 1, enters the steam jacket of effect 2, where it heats liquid, causing further evaporation. The vapor from effect 2 is used to heat liquid in effect 3 and so on. The vapor from the last effect goes to a condenser. The liquid travels from one effect to the other becoming more concentrated. The arrangement shown in the figure is forward feeding and this is the most commonly used (Brennan, 2006), but the flow can also be in reverse, parallel or mixed.

Vapor recompression
This procedure involves compressing some or all the vapor from the separator of an evaporator to a pressure that makes it useful as a heating medium. This reduces the amount of steam required and the specific steam consumption in thermal recompression. The vapor can be compressed thermally (TVR) or mechanically (MVR). In TVR the vapor from the separator is divided into two streams. One goes to the condenser or to the next stage in a MEE system. The other enters a steam jet compressor fed with fresh high pressure steam, which is mixed with vapor from the evaporator. Then the pressure is increased and enters the jacket of the calandria. In MVR all the vapor from the separator is compressed in a mechanical compressor which can be driven by electricity, gas or a steam turbine. The compressed vapor then enters the jacket of the calandria. MVR is best suited for large capacity duties, and does not need live steam inputs. A specific steam consumption of less than 0,1 kg steam per kg water evaporated is possible (Brennan 2006).

5 Relevant production cases

The industries presented in the case studies in this chapter are not currently utilizing waste heat. They have in common that one or several processes involve water removal, which operate with heat levels that theoretically can be supplied by the low pressure steam mentioned in chapter 1.1. The utilization of steam is intended for heat exchange with air or by conduction. Direct steam drying is not treated in this report.

5.1 Fish meal and oil production

5.1.1 Fish meal and oil in General

Fishmeal is flour made by cooking and milling fresh raw fish and/or fish trimmings. Fish oil is produced in the same process, but is often a more attractive product in the market. The oil is a clear yellow liquid pressed from the cooked fish and refined. 85-90 % of the world's fish meal is produced from small, bony, oily and in some cases inedible fish such as anchovy, horse mackerel, menhaden, capelin and sand eel. The rest is produced from trimmings of oily fish like herring and mackerel or gut from for instance cod (liver). Fishmeal is used as a high-protein ingredient in feed for farmed land animals and for farmed fish. Fish oil is used mainly in feed for farmed fish but is also used to make capsules containing omega-3 fatty acids as human health supplements (IFFO, 2006). The production of fish meal in Norway from 2000 to 2004 is given in Table 3 (SSB, 2004):

Table 3: Raw fish consumption in the fish meal industry, production of fish meal 2000-2004 and Import/Export of fish meal 2004.

Production year [Year]	Raw fish consumption [1000 tons]	Fish meal production [1000 tons]	Fish meal Import [1000 tons]	Fish meal export [1000 tons]
2000	1295,2	274,6	-	-
2001	1316,8	279,2	-	-
2002	1371,6	290,8	-	-
2003	1263,9	267,9	-	-
2004	1214,6	257,5	162,8	69,6

The raw fish consumption for fish meal, oil and feedstuffs in 2004 were 1,21 million tons in Norway. The fish meal production, export and import was 257,5, 162,8 and 69,6 thousand tons respectively. Fish meal and fish oil are two of the most internationally traded commodities in the world; it's estimated that each ton of fish meal and fish oil travel an average distance of 5000 km to reach its end-user. The estimated global fishmeal production in 2004 was 6.33 million tons with turnover of more than 3 billion USD. Global production of fish oil is estimated at about 930000 tons, representing a turnover of approximately 0.56 billion USD (IFFO, 2006). Peru and Chile are the major exporters with about 1,85 million tons and 500000 tons fish meal per year, respectively. Denmark and Iceland are the largest Scandinavian exporters of fish meal with about 200000 tons per year each. China is the largest world importer of fishmeal with more than 1 million tons per year. The major fish oil exporting countries in the world are Peru (200000 t/yr), Denmark and USA (70000 t/yr), and Iceland (60000 t/yr). With 200000 tons/yr, or 20 % of the world production, Norway is the world's largest importer of fish oil (IFFO, 2006).

5.1.2 Production process of fish meal and oil

The process of fish meal and oil manufacture is the *wet-rendering process*. The process separates liquid from solids by use of hot water or steam. The purpose of the process is to separate the three fractions of the raw material, which in general is small pelagic fish, by-catch or offal. The three fractions consist of fat free solids, oil and water. The following processing stages are included (Schmidtsdorff, 1995):

1. Heating, which coagulates the protein, ruptures the fat depots and liberates oil and water.
2. Pressing (or centrifugation), which removes a large fraction of the liquids from the mass
3. Seperation of the liquid into oil and water (stickwater)
4. Evaporation of the stickwater into a concentrate (fish solubles)
5. Drying of the solid material (presscake) plus added solubles, which removes sufficient water from the wet material to produce a stable meal.

Figure 13 is a diagram of a typical fish meal plant. The raw material is first unloaded from the fishing vessel by a pump, pneumatic elevator or a mechanical conveyor. The fish is weighed or measured by volume before transported to the pits or tanks for storage.

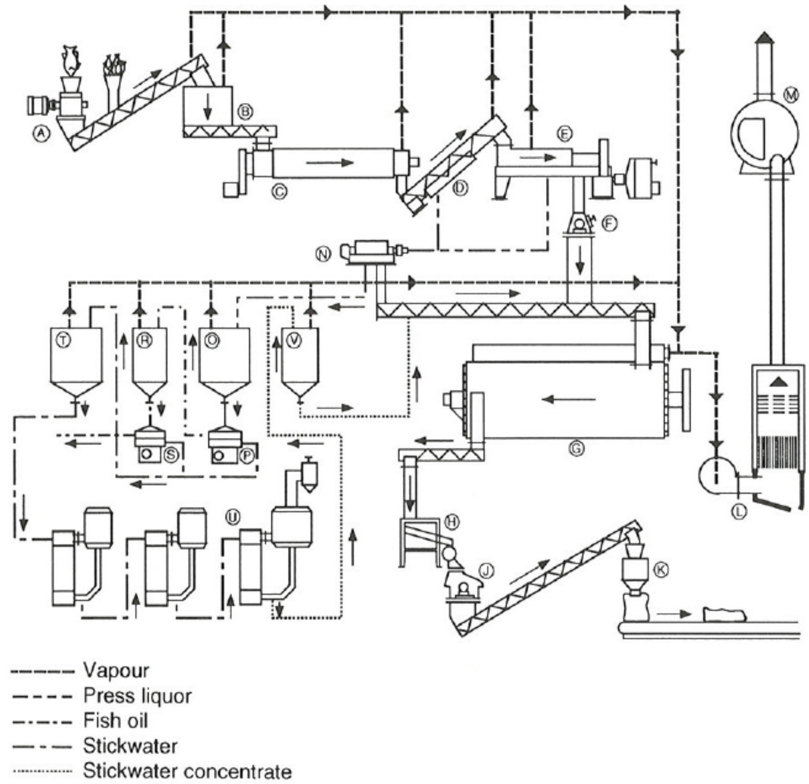

Figure 13: Diagram of a fish meal plant (Schmidtsdorff, 1995)

The general steps of the process are cooking, pressing, decanting, centrifugation, evaporation and drying. The different processes, denoted by letters in the diagram, are explained in the following:

A) Large fish are hashed

B) Feed machine: Smaller fish intended for meal production are fed at a constant rate directly to the processing

C) Indirect steam cooker

D) Strainer conveyor: The coagulated mass is pre-strained

E) Twin screw press: Producing presscake and press liquor

F) Wet mill (tearing machine): Presscake is disintegrated, and then mixed with stickwater concentrate

G) Indirect steam dryer

H) Vibrating screen: Removal of unwanted matter (e.g. wood, metal)

J) Hammer mill: Cooling may occur before milling

K) Scales: Fish weighed out in bags, alternatively stored in silos

L) Scrubber: Factory deodorization by suction, where air can be reused as combustion air in the boiler

N) Decanter centrifuge: Removes most of the sludge

O) Buffer tank: Press liquor

P) Stickwater centrifuge: Separation into oil, stickwater and fine sludge, which is added to the presscake

R) Buffer tank: Fish oil

S) Oil separator (polishing): Water and impurities are removed

T) Buffer tank: Stickwater

U) Multi effect evaporator: Concentration of stickwater

V) Buffer tank holding concentrate which is then mixed with decanter sludge and presscake in the conveyor leading to the dryer

An example of a mass balance is given in Figure 14. Here the stream of the three fractions of the raw material (oil, fat free solids and water) can be followed through the processing. The figures will vary from one factory to another, partly because of varying raw material composition. The diagram is sufficient to illustrate the general trend (Schmidtsdorff, 1995). It shows that 1000 kg raw fish yields 212 kg fish meal and 108 kg fish oil, a total of 0,32 kg product per kg of raw material. The initial water content is 68 %. The diagram also shows the size of the fractions that are separated in each processing step.

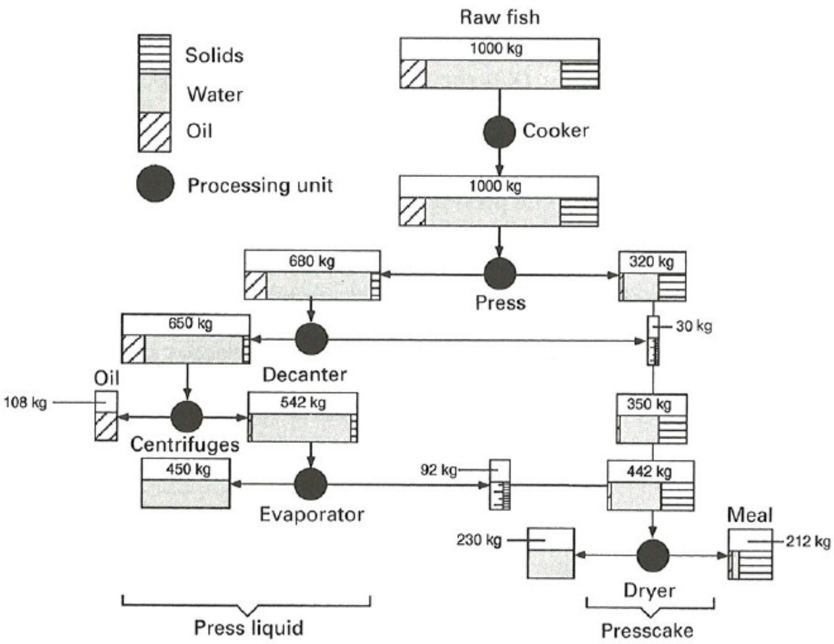

Figure 14: Mass balance in fish meal and oil production (Schmidtsdorff, 1995).

Manufacturers may estimate their expected yield of meal on the basis of the dry matter content of the raw material plus residual moisture and oil in the meal. Likewise the oil yield will be the fat content of the raw material minus the small amount remaining in the meal (Schmidtsdorff, 1995).

Heating

Heating or cooking has the purpose of liberating the oil from the fat depots of the fish, and to condition the material for the subsequent treatment in the various processing units of the plant. The raw material is cooked using a temperature of 85º C to 100º C for approximately 15 to 20 minutes to coagulate protein and allow some oil to be released. The most common practice is to cook the fish in a steam cooker, through which it is conveyed continuously. Heat is generally transferred indirectly from a surrounding jacket and a heated rotary screw conveyor. Cooking leads to some of the oil and water being drained from the mass directly through a process called pre-straining (FAO, 1986, Schmidtsdorff, 1995).

Pressing

Pressing has the purpose of squeezing out as much liquid as possible from the solid fish pulp. This is important to improve the oil yield and meal quality, and to reduce the moisture content of the presscake as far as possible, thereby reducing energy consumption of the dryers and increasing their capacity. The common type of press is the twin screw press. Modern presses yield press-cakes with moisture contents at approximately 50 %. Some plants use centrifugation, through a decanter, to separate the solids and liquids (Schmidtsdorff, 1995). Under average conditions one may estimate the volume of press liquor at about 70% of the raw material while the remaining 30% makes up the presscake.

Separation
The liquor is centrifuged to remove further solids, and to spin off oil and separate out an aqueous phase called stickwater, a mixture of water and oil. The press liquor should be reheated to 90-95º C before entering the centrifuges. The suspended solids are removed in a horizontal centrifuge, a so-called decanter. Seperation of stickwater takes place in vertical disc centrifuges. Stickwater with a dry matter content of 6-9 % is concentrated in the evaporators (Schmidtsdorff, 1995).

Evaporation
Evaporation of stickwater adds an extra 20-25 % to the fish meal output, mainly in the form of protein. The energy demand for evaporation of 1 kg water in the evaporator system can be less than a quarter of the necessary energy needed in the dryers. Figure 15 shows a quadruple effect evaporator plant. Here the stickwater flows in parallel with the flow of steam. It is fed continuously to stage I and then undergoes concentration during the subsequent passage through stages II, III and IV. Steam from the boiler supplies the pre heater and the heat exchanger in the first stage. The vapor emanating from stage I is used in stage II, the vapor in stage II is used in stage III and so on. Vapor from stage IV can be used to pre-heat the raw material (Schmidtsdorff, 1995).

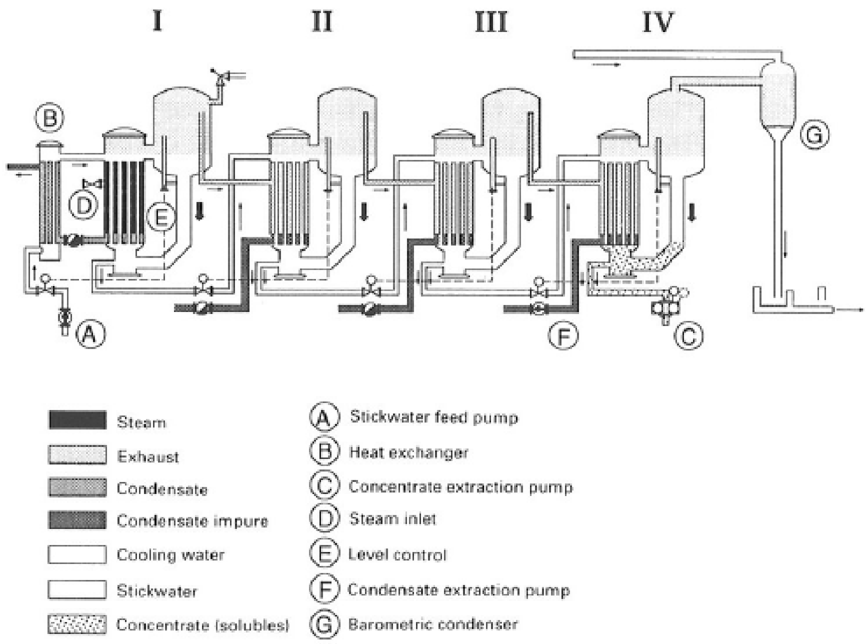

Figure 15: Evaporator plant

The stickwater concentrate is mixed with the presscake and dried to “whole fish meal”. Sometimes the stickwater concentrate is sold separately as “fish solubles”. Typical figures for steam consumption are 0.2 to 0.35 kg steam per kilogram water evaporated in quadruple effect evaporators (FAO, 1986).

Drying
The purpose of the drying process is to convert the wet and unstable mixture of presscake, decanter sludge and concentrate into a dry and stable fish meal. This means

drying to a moisture content of below 10 %. One typical dryer type contains coils through which super-heated steam passes. Fish oil may go on to be purified to remove solid impurities. More sophisticated refining is used to produce a clear odorless liquid for pharmaceutical or nutrition for humans (IFFO, 2006, FAO, 1986). In Norway only LT fish meal is produced. This type of fish meal is processed with a low temperature, and yields a higher protein quality. A common dryer for this type of production is the rotary dryer with hot air as heating medium.

The indirect steam dryer can also be used in the production of fish meal, and works on the following principle: the mixture of presscake and stickwater concentrate is fed continuously into one end of the rotary apparatus, and is dried in direct contact with steam heated elements (tubes, discs, coils, etc.). The heated elements bring the temperature of the material to approximately 90º C or lower. The heat is transferred from the steam to the pulp through the heating surface, and rotary agitation of the pulp promotes the heat transfer. The steam temperature is limited by the dimensions and strength of materials of construction. A maximum steam temperature of 170°C corresponding to 6 atmospheres gauge pressure is most frequently used in steam dryers. A drying period of 30 min or longer is required. Figure 16 shows a ring channel drier (FAO, 1986; Schmidtsdorff, 1995).

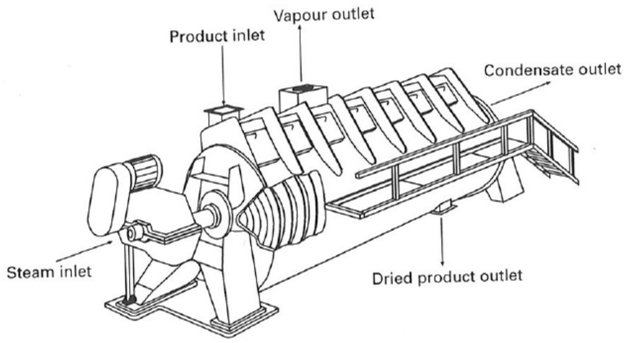

Figure 16: Example of indirect dryer, the ring channel dryer.

These driers are normally designed to remove up to 3000 kg of water per hour corresponding to 350 tons of raw fish per 24 hours (Schmidtsdorff, 1995).

5.1.3 Energy and water consumption

Steam production is an essential process in meal manufacture because of the steam requirements of the main machines, cookers, presses, steam dryers and evaporators. The energy consumption varies from plant to plant, but roughly estimated average values are given in the table below. The values are calculated based on fuel oil consumption from FAO (1986):

Table 4: Approximate resource consumption in fish meal plants of various sizes.

Plant size [ton raw material/day]	Heat (steam) [GJ/ton raw]	Electricity [kWh/ton raw]	Water [m3/ton raw]
100-200	1,79	33,00	22,40
250-500	1,84	31,00	18,35
more than 500	1,71	30,00	16,30

The different processing steps in the plant need various steam qualities depending on the process specific pressure and temperature requirements of the material. Steam in the drying process is delivered at 6 bars and 170° C. Table 4 show the resource consumption of fish meal plants of different sizes. These figures assume combustion of fuel oil to generate steam. To calculate the energy from oil consumption on a mass basis, two assumptions were made (SSB, 2000): Average theoretical energy content of fuel oil set to 40,6 GJ/ton, and a boiler efficiency of 90 % was assumed. The steam generation through fuel oil combustion represents 94 %; the use of electricity only adds up to 6 %.

Fishmeal plants require water for the following purposes:

a) As feed water for the boiler
b) For operation of the sludge separators
c) To clean machinery and tanks
d) To clean floors, raw fish pits, etc
e) For condenser of concentration unit
f) For cooling and deodorizing
g) For staff bathroom and canteen

For purposes a), b), c) and g) the water has to be fresh. For purposes d), (e) and f) sea water could be used. 67 % of the water consumption is used for cooling and deodorizing (f), 31 % is used for the condensing and concentration unit (e) and 2 % is used in the other operations (ibid).

5.1.4 Energy use in Norwegian fish meal production

Figures for energy use in Norwegian fish meal plants have been obtained through contact with Egersund Sildoljefabrikk AS (Ulseth, 2006). Most Norwegian plants have a raw material capacity of 1000-1500 tons per day, and the largest fish meal plant in the country has a capacity 2500 tons/day of raw material. There are large variations in specific energy consumption depending on fish species and condition. The distribution of water, oil and solids in the raw material, which the processing separates, must also be taken into account.

Egersund Sildoljefabrikk AS is a fish meal and oil plant with capacity of 1000 tons of raw material per day. They receive 130000 tons of fish per year. Saturated steam is used in the processes, and the boilers provide it at a pressure of 10-12 bars. Normally the steam is regulated down to 8-9 bars. The amounts of steam used vary with production capacity and type of equipment at the plant. The plant in Egersund has two 12 tons/h steam boilers (10 MW), and a small back up system. The costs have in recent years been approximately equally distributed between facility, energy and labor. After an MVR evaporator was included in the system the share of electricity has increased. Annually the plant use 7500 MWh (27 TJ) of electricity, and the boilers consume 5500 tons of fuel oil which is equivalent to about 1,89 GJ per ton of raw material, based on the same assumptions as in 5.1.3. Compared to the values from FAO (1986) in the previous chapter, the heat consumption is 11 % higher for Egersund sildoljefabrikk AS. Table 5 shows the resource consumption at the plant:

Table 5: Resource use in Egersund (Ulseth, 2006)

Annual values for fish meal		
Raw material (Fish)	130000	[tons]
Electricity	27	[TJ]
Fuel oil	248	[TJ]

Electricity stands for 12 % of the energy consumption, while fuel oil is used for 88 % of the energy requirements. The electricity consumption has increased after a MVR unit was installed. Common steam consumption in the cooker is 0,14 kg steam per kg fish, but this is dependent of the steam quality, which is at 7-8 bars in this plant. In the drier the consumption is 1,1 kg steam per kg exhaust vapor, and the steam has a pressure of 6 bars. The exhaust vapor usually enters the evaporator. The plant has a two stage evaporator which require 0,3 kg steam per kg exhaust vapor. Using the mass balance sheet in Figure 11 the total steam consumption for these purposes can be calculated, but there is also a demand for steam in other parts of the production in various heat exchanging processes. Table 6 show the amount of saturated steam needed in the cooker, evaporator and drier according to process specified steam qualities.

Table 6: Steam consumption at Egersund Sildoljefabrikk

Process	Pressure [bar]	Steam consumption [ton/yr]
Heater (cooker)	8	18200
Evaporator	-	17550
Drier	6	32890
Total		68640

The steam consumption in these three processes equals 13,5 ton steam per hour, assuming steam production during 5100 hours through the year, and 528 kg steam per ton of raw material. The steam is delivered to parts of the system with a pressure of 10 bars.

5.1.5 Fish meal production with excess heat at Mongstad

The steam used at fishmeal plants is delivered at a higher quality than the low pressure steam from the refinery at Mongstad, specified in chapter 1.1. However, modifications in equipment such as using hot air dryer and waste heat evaporators can make utilization of the steam at Mongstad possible, since the product specific temperatures are relatively low. Table 7 shows the steam consumption and other parameters for production of fish meal and oil at Mongstad:

Table 7: Energy parameters for production at Mongstad

	Heat demand [GJ/ton prod]	H_2O removal [kg/kg prod]	Steam [ton/h]	Steam, P [bar]	Drying T. [° C] in product
Fish meal & oil	5,91	2,125	13,5	6, 8, 10	90

The steam consumption, using LP steam with an enthalpy of 2,8 MJ/kg, at Mongstad amounts to 13,5 ton per hour. With a potential for receiving 25 tons of steam per hour from the refinery, a fish meal plant with a capacity of 1850 tons raw material per day could theoretically utilize all of this steam. A matter of necessity is that the provided amounts of steam are stable throughout the year.

5.2 Drying of Cod heads

5.2.1 In general

Fishery and aquaculture industries focus on by-product utilization. Guts, offal, fishbone and fish heads are studied to find a way of utilizing them for producing characteristic components or for human consumption. Fish heads are in general are not landed in Norwegian fishery; traditionally they have been regarded as waste. The reason has to do with quota regulations and unfair setting of prices for cod delivered to shore with heads (RUBIN, 2007). Dried fish heads from cod, haddock and pollack can be used for human consumption or as animal feed. The markets for human consumption require a higher quality, both regarding the drying process and the way the head is cut (Fiskeriforsk, 2004).

Norway produced 1725 tons fish heads in 2002. The production method is old fashioned and based on drying bundles of heads outdoors, which leads to varying and low quality. Iceland and the Faroe Islands produce fish heads industrially, where they utilize cheap energy such as combustion facilities and geothermal heat for the drying process. Iceland exported 13659 tons dried cod heads, with a value of 243,3 million NOK, to Nigeria in 2002. Historically, one of the most important markets for Norwegian stockfish has been West Africa, and Nigeria has been importing much of the secondary quality products from Norway (Fiskeriforsk, 2004). Most of the Norwegian dried fish heads production is exported to EU, where it is used as animal feeds and obtain an average price of 2 NOK/kg. The market in Nigeria had a price of 13,2 NOK/kg in 2002. The figure below shows the export of dried cod heads to Nigeria from Norway and Iceland in the years 1995-2002, the left axis shows tons/yr, while NOK/kg is on the right side (Fiskeriforsk, 2004).

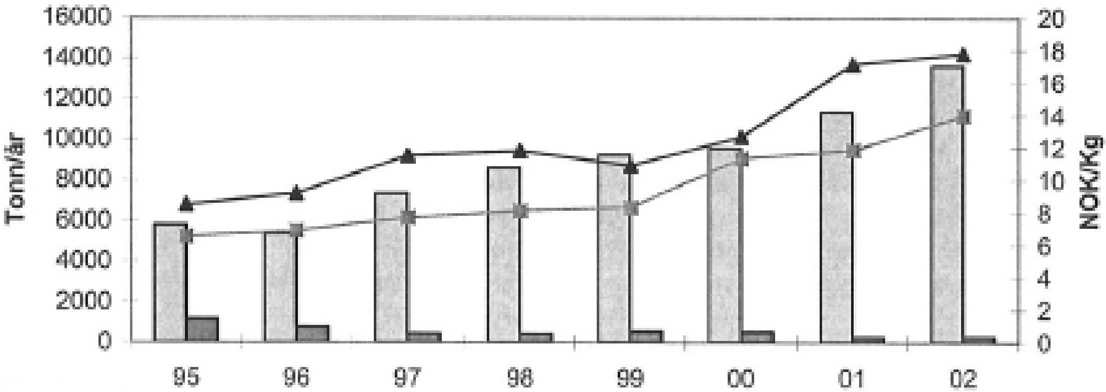

Figure 17:Export of dried cod heads to Nigeria from Norway (dark gray) and Iceland in tons/yr, NOK/kg given in lines with values on the right axis. The higher price is the price of Icelandic heads, while the lower price is for Norwegian heads.

This shows that the consumption of cod heads as well as the price of cod heads is increasing in Nigeria. It is clear that Iceland has had a successful marketing strategy in Nigeria, and benefits from its established production and geothermal heat sources. With preparations, cheap thermal energy and appropriate system design, the Norwegian cod heads should be able to obtain the same quality and price as Icelandic cod heads.

5.2.2 Production

Transport of the heads from fishing grounds to shore, and from the receiving facility to the production company has cooling and conservation requirements. The quality of fish heads is easily deteriorated, and must be handled as an article of food. Both fresh and frozen heads can be used in the production, but the fresh heads shouldn't be older than two weeks. At the receiving facility the fish heads are rinsed and weighed, before they are manually placed into single trays which then are automatically stacked. The dryer type is a tunnel or cabinet drying system. The production line for the heads is given in Figure 18 (Fiskeriforsk, 2004):

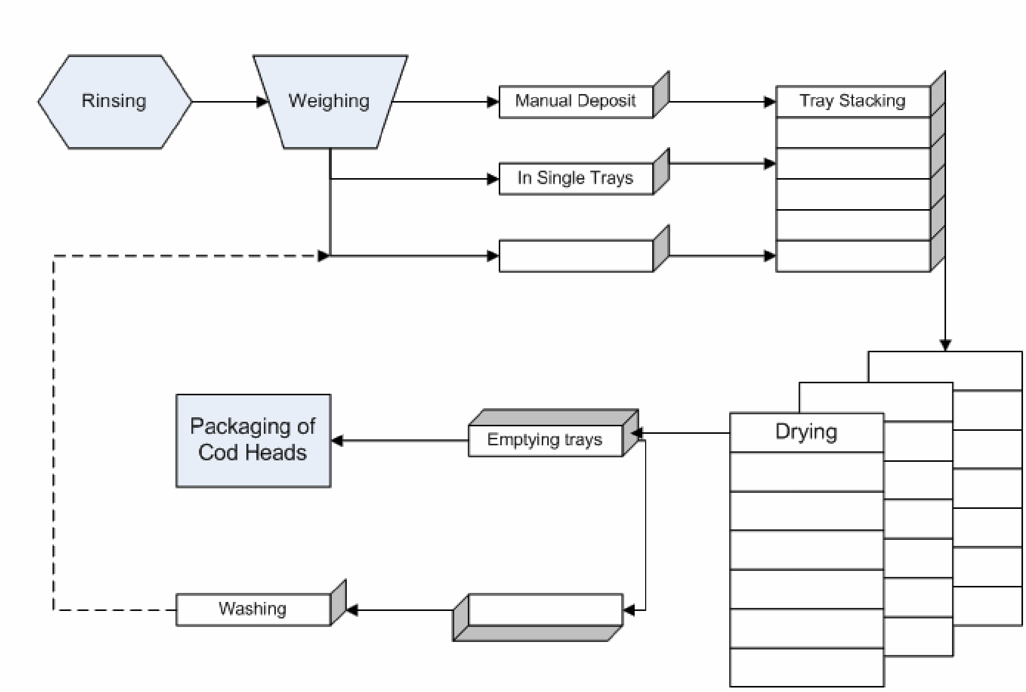

Figure 18: Production line for dried cod heads production

The drying process goes through two stages, primary and secondary drying. Primary drying is done in a rack cabinet with fish heads arranged in one layer on the racks where about 25 kg/m^2 can be stored. Secondary drying of semi-dried heads is done in rying containers of 1-2 m^3, with hot air blown through. The water content of cod heads before entering the dryer is 82 %. The drying conditions are given in table 8 (Arason, 2003):

Table 8: Drying conditions for cod heads

	Temperature	Air velocity	Relative humidity	Cod water content	Duration
Primary Drying	18-25° C	3 m/s	20-30 %	50-55 %	24 -40 hrs
Secondary Drying	22-30° C	0,5-1 m/s	30-50 %	15-20 %	3 days

The optimal temperature for primary drying is 25° C, and 30° C for secondary drying. The relative humidity is approximately 20-50 %. The air velocity is higher in the rack cabinets used in the primary drying, than in the container cabinets used in the secondary drying stage. The water content of the finished product is 15-20 %. The total drying process takes approximately 4 days, and 1 kg dried heads is generated from approximately 5 kg raw cod heads (Arason, 2003).

After drying the heads are packed automatically or manually, and the common unit size is 30 kg. The minimum size for a production facility handles 20-30 tons raw fish heads per day, and has 15-20 employees. Investment costs, excluding buildings and infrastructure, are 15-20 million NOK (Fiskeriforsk, 2004).

5.2.3 Energy consumption

The consumption of energy in this type of facility is dependent on whether the system includes a heat pump, has energy recovery measures or utilizes excess heat. In 2002 there were 5600 tons cod heads available for production in Vest-Finnmark alone. A plant with this capacity and 5100 operating hours per year, can handle 26,4 tons cod heads per day. The water to be removed from 5600 tons is 80 % or 4480 tons. An energy consumption of 6 MJ/kg water evaporated from the heads is an approximate estimate, which takes relevant heat loss measures into account (Arason, 2003, Fiskeriforsk, 2004). Electricity is needed in the system to run the fans in the drying chamber. An effect of 20 kW is needed in the primary stage and 5 kW in the second stage. Table 9 shows the assumptions made for a potential drying facility for cod heads at Mongstad (Fiskeriforsk, 2004):

Table 9: Production parameters for a drying facility

Raw material	5600	[ton/yr]
Water content	80 %	
Raw material per drying cycle	10	[ton]
Product	1120	[ton/yr]
Specific energy requirement	6000	[kJ/kg evap]
Drying time 1st stage	48	[hrs]
Drying time 2nd stage	72	[hrs]
Fan effect 1st stage	20	[kW]
Fan effect 2nd stage	5	[kW]
Operation	5100	[h/yr]

This means that 4480 tons of water needs to be evaporated for processing 5600 tons cod heads. The specific energy needed for evaporation of water in this system is 6 MJ/kg. The heat demand is then 26,88 TJ per year. Electricity needed per drying cycle is 1320 kWh, and 560 drying cycles per year gives 739,2 MWh (2,66 TJ) per year, and 2,4 MJ per kg product.

5.2.4 Marginal contribution in production of dried cod heads

Fiskeriforskning (2004) have set up a marginal contribution for the production of 1 kg dried cod heads. The plant has the same specifications as in Table 7, and is used in this chapter with a few modifications. The facility has 15 employees with average wages at 300000 NOK. Investment at the facility is projected to be 15 million NOK, and depreciation is annually set to 10 % of investment costs. The system has an electric heat pump with a coefficient of performance of 4, which according to Fiskeriforskning (2004) reduces energy costs to one third compared to using electricity directly in the system when the electricity price is set to 0,5 NOK/kWh. If excess heat is utilized instead of electricity in a heat pump, the investments and energy costs will change considerably. The marginal contribution is shown in table 10.

Table 10: Marginal contribution in production of cod heads (Fiskeriforsk, 2004)

	NOK/kg product	NOK/kg product
Selling price		13,21
Operational costs		
Raw material	2,50	
Transport, storage	1,00	
Labour costs (15 employees)	4,02	
Packaging	0,70	
Water, Energy	1,00	
Electricity for fans	0,11	
Electricity for drying w/heat pump	1,12	
Tax	0,36	
Sum operational costs		10,81
Marginal contribution 1		2,4
Depreciation		1,34
Marginal contribution 2		1,06

From Table 9, the energy costs are 18 % of the operational costs, when using a heat pump in the system. If excess steam from a refinery is to compete with the price of energy delivered by the heat pump it, the price of steam must compensate for the increase in electricity price for the fans, and the reduction of specific energy price in the drying process. The increase in electricity cost without heat pump will be 0,22 NOK/kg product. Combining Table 8 and 9 the price of steam must be less than 0,9 NOK per 8,7 kg steam, corresponding to an energy price of 0,14 NOK/kWh.

5.2.5 Processing of cod heads for human consumption in Norway

Arctic Innomar AS have recently established a facility for processing cod heads intended for the Nigerian market running in Kvalsfjord in Vest-Finnmark. The processing is done in two steps as explained in 5.2.2. The energy source in the first step is fuel oil, and the consumption is 800 tons fuel oil per year processing 6000 tons (wet weight) of raw heads per year. In the second step electricity is used to heat an energy carrier which then is used to heat the cod heads. The drying air flow is not recycled, since this reduces the quality of the product. Another facility in Botsfjord in Øst-Finnmark is planned and the capacity of the two plants will increase to 20000 tons cod heads per year. The raw material will be delivered from 10 participating fish landing facilities in the region. The turnover will be 50-60 million NOK, and provide 40 employments. The energy costs are substantial, but the access to and transport of raw materials is important as well. (Fredriksen, 2007).

5.2.6 Processing of cod heads at Mongstad

The temperature of low pressure steam at Mongstad is sufficient for heating the drying air in the production of cod heads. Assuming that the facility operates with the parameters given in 5.2.3, the theoretical amount of steam used in the facility can be calculated. Table 11 shows relevant steam consumption values:

Table 11: Theoretical values for steam consumption, using LP steam.

	Steam [ton]	Energy [GJ]
Per year	9589,7	26880
Per hour	1,9	5,3
Per ton raw material	1,7	4,8
Per ton product	8,6	24

The facility requires approximately 1,9 ton low pressure steam per hour of operation, and 1,7 ton steam per ton raw material. If the refinery can deliver 25 tons LP steam per hour, such a facility can theoretically process 73700 tons cod heads annually. The drying of cod heads is a batch process which goes over approximately four days. This means that the production can occur when excess steam is available, but the delivery has to be stable until the batch process is finished. The utilization of excess heat at Mongstad could lead to a substantial decrease in energy costs, but it would involve a more complicated logistic system, with regard to the raw material mostly landed in Finnmark. Transporting the raw material from Northern Norway is possible, but leads to an increase in costs.

The heat used to dry the cod heads requires a low ΔT, heating air from ambient temperature to a maximum of about 30° C. This means that steam from Mongstad, which is 175° C, could be used in a process requiring higher temperatures before it enters the cod heads production. This depends on the equipment design. With higher temperature on the supply side, a smaller heat exchanger is needed to heat the air volume.

5.3 Clip fish

5.3.1 In general

Clip fish, along with other types of dried fish, is a large and traditional industry in Norway, and the product is widely used in the Latin kitchen. In 2005, 30 clip fish producers delivered 75720 tons of clip fish. The smallest producer delivered 65 tons and the largest delivered 12000 tons (Fjordlaks AS). An average clip fish producer delivers 2000 tons annually. The export value of clip fish and salt fish was 2,5 billion NOK and 974 million NOK respectively (FHL, 2005). The price of clip fish from cod is approximately 45-55 NOK/kg, while salt fish from cod is 32-38 NOK/kg, as can be seen from figure 19 (SSB, 2005):

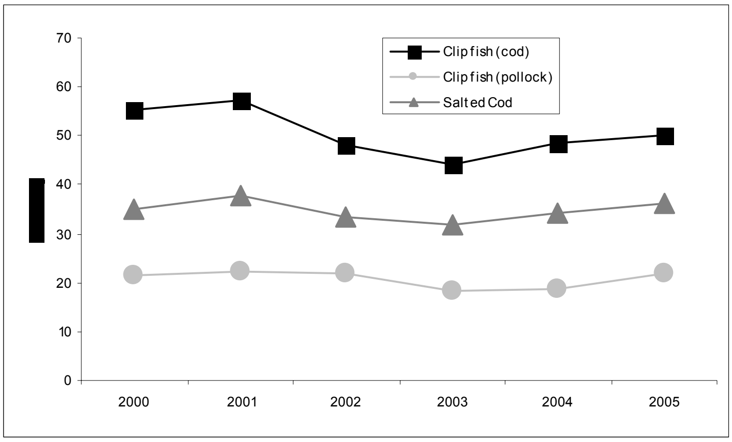

Figure 19: Export prices of clip fish from cod (squared markers), salted cod and clip fish from Pollack (circle markers)

The figure below show the export of clip fish from cod, which is regarded as the clip fish with best quality because of the white flesh, in tons (Vassdal, 2006):

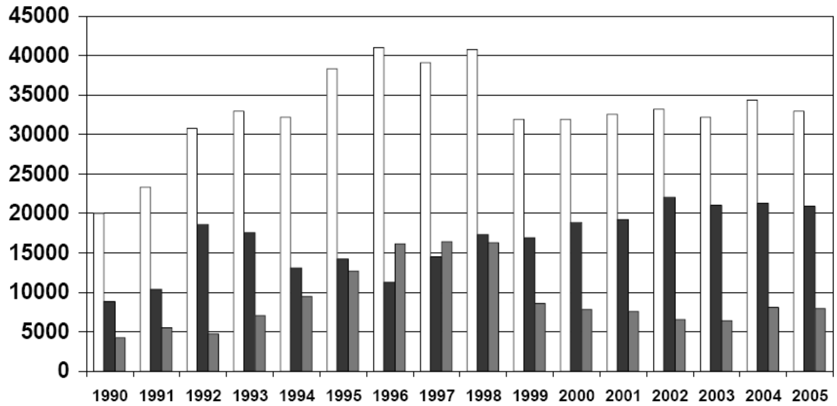

Figure 20: Norwegian export of clip fish in ton; White: total; Black: Portugal; Gray: outside EU

Figure 20 show the export amounts from 1990 to 2005, and in 2005 the export was 33000 tons. The white columns represent the total amount of exported clip fish from cod, while the red columns show the export to Portugal and the green columns show export to countries without EU membership.

5.3.2 Production

Clip fish is salted and dried fish, mainly from cod and pollack. The fish is headed, gutted and cleaned before it is salted in layers for 3 weeks. The water content of the fish has now been reduced from 80 % to about 55-60 %. The fish is then dried in conditioning rooms or drying tunnels with trucks loaded with trays of fish moving from one end to the other, manually or automatically. The result is clip fish which has a water content of approximately 45-50 % (ibid). Using smaller conditioning rooms makes the drying operation more flexible by sorting the fish in terms of size, quality and species. Since larger fish need longer drying time than smaller fish this type of production gives a more uniform product quality (Lindquist et al, 2000). During drying, the fish is exposed to constant air flow with a temperature of approximately 23° C. The air flow varies with equipment, size of the tunnel and the direction of the air flow. Figure 21 show a clip fish tunnel drier with a heat pump using ammonia (NH_3) as heating medium.

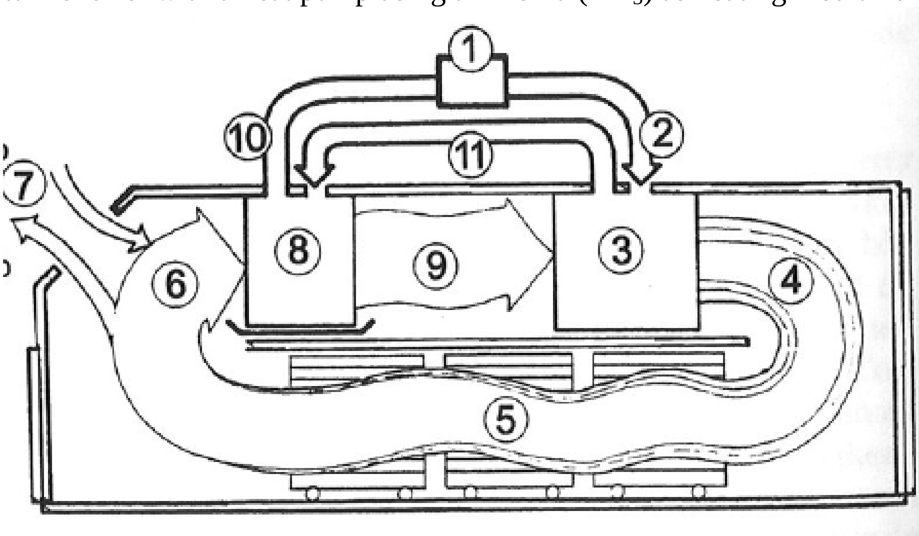

Figure 21: Clip fish dryer (Hemmer et al, 2001)

1. NH_3 compressor (pressure reduction)
2. NH_3 liberates heat
3. Condenser (Air flow is heated)
4. Relative humidity of the drying air 30-50 %
5. Drying air take up moisture from the fish
6. Relative humidity of the drying air 60-70 % (never over 76 %)
7. Air change (not used in heat pump driven dryers)
8. Ammonia evaporator
9. Cooled and dehumified air
10. NH_3 draws heat from air
11. NH_3 flow (fluid)

A report written by Sintef AS for Bacalao Forum (Jonassen et al, 2006) presents drying parameters for three clip fish dryers in Norway. Table 12 shows drying conditions for a clip fish dryer using a heat pump with ammonia as heating medium.

Table 12: Drying conditions for clip fish

	Air temp	Air velocity	Air flow rate	Absolute humidity	Relative humidity
In	23° C	3 m/s	16 m3/s	0,0053 kg/kg air	30 %
Out	19° C	-	-	0,0067 kg/kg air	50 %

The drying temperature should be 23° C, and air velocity entering the drier approximately 3 m/s. When using a heat pump system there is cooling of the exhaust air; a process which draws water from the air in the form of condensate. This makes it possible to recycle the air and save energy. When heating the air flow with steam or hot water there will be a heat exchanging process between the hot stream and the drying air. In such a system there will not be a need for recycling and cooling of the air flow (items 6, 7, 8 in figure 21). All of the air will be drawn from the surroundings, heated, blown over the product and then expelled to the outside air. This is comparable to the old oil fueled clip fish dryers used in Norway. The quality of the finished product will then depend on the temperature and humidity of the outside air.

5.3.3 Energy requirements for drying clip fish

A clip fish dryer using electricity and a heat pump has an energy requirement of roughly 0,25 kWh per kg clip fish, including the fans in the dryer. Assuming that the heat pump has a coefficient of performance of 4, the heat needed in the system is 0,6 kWh and electricity needed for the fans is 0,4 kWh. Table 13 shows the energy requirements of a clip fish dryer producing 2000 tons:

Table 13: Energy requirements in clip fish production.

Clip fish production	2000	[tons]
Energy for heat	4,32	[TJ]
Electricity (fans)	2,88	[TJ]

The fans utilize 40 % and heat stand for 60 % of the total energy used in the drier. Note that in a heat pump driven dryer, the recycled air is cooled and the air condensed. This will not be an option in a system utilizing excess steam.

5.3.4 Clip fish production at Mongstad

The theoretical steam consumption is given in table 14, calculated by using the enthalpy of the available steam at Mongstad refinery, and an operation of 5100 hours per year:

Table 14: Steam consumption in clip fish production

	Steam [ton]	Energy [GJ]
Per year	1541	4320
Per hour	0,30	0,85
Per ton raw material	0,71	1,96
Per ton product	0,79	2,16

It’s assumed that 0,1 kg water is removed from the raw material to obtain the specific clip fish quality. The steam consumption is 0,30 tons per hour, which means that 166000 tons of clip fish can theoretically be produced with a stable delivery of 25 tons per hour from the refinery.

The energy requirements show that excess heat could be utilized in clip fish production, but the drying conditions will be dependent on the outside air, and there would be no recycling of the air flow. For instance in the summer the ambient air is often humid, and the relative humidity will not decrease much from heating it to 23° C. The heat pump would give a more uniform product quality, and a less complex operation of the drying process. Therefore it is unlikely that clip fish production will occur by excess steam utilization, based on the old oil fired drying methods.

The use of sorption materials (silica gel), which is ingrained in a sorption wheel, is marketed by Alfsen & Gunderson AS. The air to be dehydrated is blown through the impregnated wheel so that the air releases moisture. The wheel rotates slowly, and arranged in a way that exposes approximately 75 % of the wheel to the moist air. Moisture is removed by a hot air flow in the remaining 25 % of the wheel, and excess steam may be used for this purpose. The energy requirements for such an operation are uncertain, but the quantity of energy delivered by the heat pump in Table 13 could be an acceptable assumption.

5.4 *Alginate production from kelp*

5.4.1 In general

Kelp (Laminaria hyperborea) and knotted wrack (Ascophyllum nodosum) are the only species of algae that are commercially harvested in Norway. Annually, between 130000 and 180000 tons of kelp and 10000-20000 tons wrack, are harvested by trawling. Kelp is harvested from Rogaland in the south to Sør-Trøndelag in the north, while wrack is harvested from Sør-Trøndelag to Nordland. Kelp is used for alginate production entering pharmaceutical, medicine, food, paper and paint industries as a thickening agent. Wrack is used for meal production for food supplements, animal feeds and fertilizer production (Steen, 2005). Table 15 shows the amount of kelp and wrack harvested in Norway, together with value and average price of the catch, from year 2000 to 2004 (SSB, 2004).

Table 15: Harvested kelp and wrack, value and average price 2000-2004.

Kelp and wrack [Year]	Harvested [1000 tonne]	Value [million NOK]	Price [NOK/kg]
2000	192,4	35,7	0,1856
2001	175,2	32,5	0,1855
2002	182,6	33,4	0,1829
2003	153,2	28,0	0,1828
2004	148,3	27,9	0,1881

The amounts of kelp harvested have declined in recent years, while the unit price remains stable.

5.4.2 Alginate Production

FMC biopolymer annually produces approximately 5000 tons of alginate from kelp harvested along the Norwegian coast, at its factory in Haugesund. A smaller fraction of the raw material is dried Lassonia seaweed from Chile. Alginate occurs in the seaweed as a mix of calcium, magnesium, sodium and potassium salts. The alginate molecule consists of two monomers called mannuronic acid (M) and guluronic acid (G). FMC have two production lines, one produces G-rich alginate and M-rich alginate is produced on the other line. G-rich alginate forms strong gels, while M-rich alginate forms weaker gels (Jevne, 2006). More than 20 stages of processing are required in order to obtain high quality alginates. The alginate most customers want is sodium alginate (Na-alginate). Figure 22 gives an overview of the production steps (FMC, 2006).

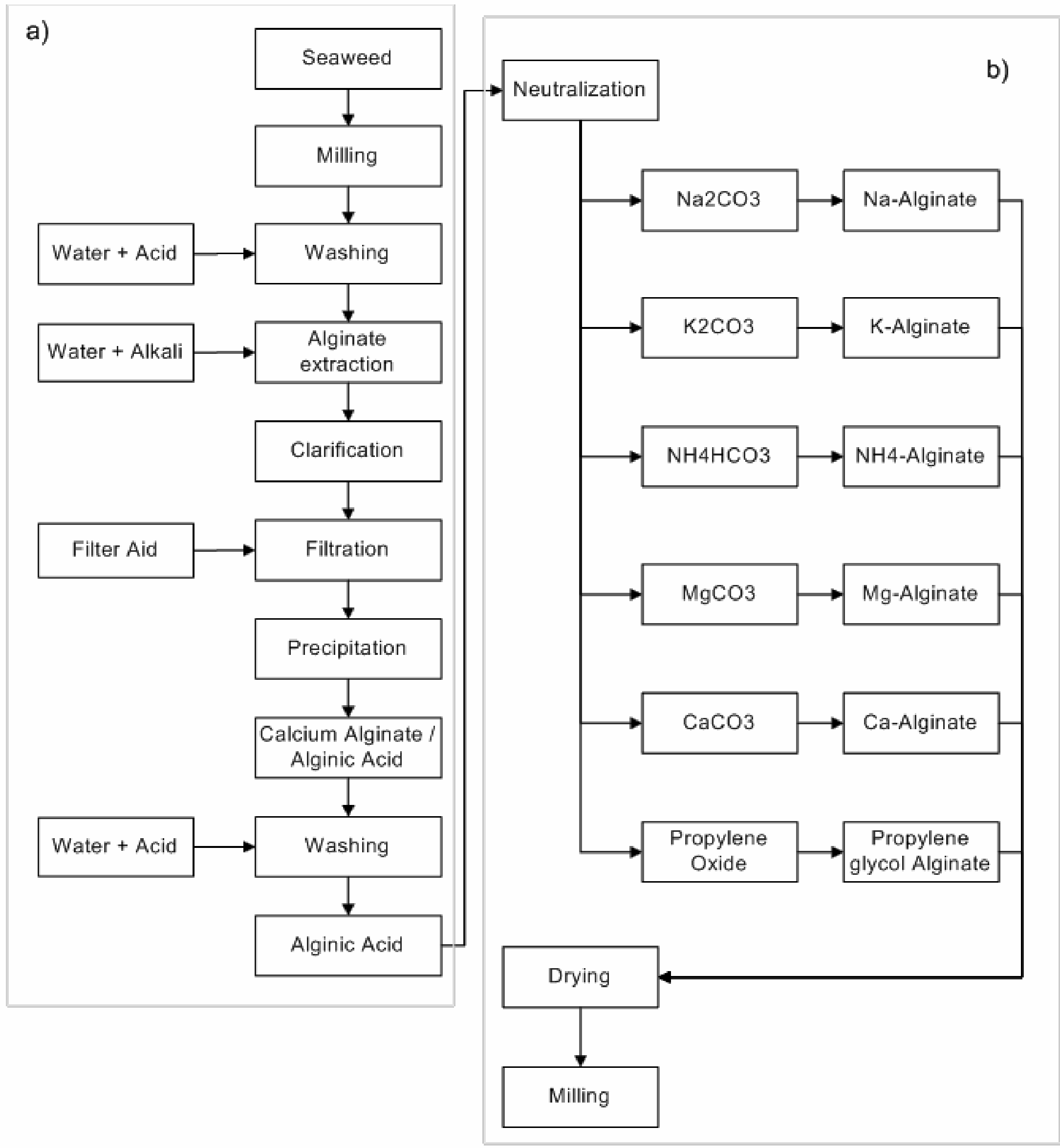

Figure 22: Alginic acid production (a), and salts and ester production (b), at FMC BioPolymer

Washing and grinding

When the seaweed enters the factory, it is already cut into pieces and preserved in formalin at terminals along the Norwegian coast. The seaweed is washed with acid to remove sand and an outer layer of slime. Leaves and stalk are separated by a rotating drum and a powerful fan. The stalk and leaves enters two separate production lines (Jevne, 2006).

Acid wash and steaming

The raw material goes through acid wash. The calcium alginate (Ca-alginate) is transformed into alginic acid (H-alginate) by the addition of sulfuric acid and hot water at approximately 50° C. Some of the acid water is sieved off, and recycled back into the process. Most of the unwanted brown color matter is dissolved by the acid, and removed.

Now it is necessary to break the long molecular chains of alginic acid into smaller parts. This is done in a steam screw, where steam is injected into the acidic seaweed mass. Unwanted parts of the raw material are then sieved off, together with water at approximately 40° C containing Ca^{+} ions (ibid).

Extraction of alginate
Lye, sodium carbonate (Na_2CO_3) and hot water at bout 65° C is added to transform the alginic acid into soluble sodium alginate (Na-alginate). The mass is then pumped through several tanks. This process takes several hours, and requires heat. When the mass exits the tank it is very viscous. In the next steps the viscosity is reduced by using large amounts of hot water at about 44° C, in order to be able to extract the alginate (ibid).

Filtration
The first step of the filtration process is to remove the largest undissolved particles from the mass. This is done by filtering it through hydrasieves. Medium sized particles are then removed by a flotation process, where air bubbles aid moving the particles to the surface, where they are easily removed. The remaining mass is filtered through a number of vertical filters. The mass that is filtered off is recycled back into the process (ibid).

Precipitation and pressing
Heat exchangers are used to cool the mass from 45° C to below 20° C. G-rich alginate precipitates easily when sulfuric acid is added, while M-rich alginate needs calcium chloride and acid to precipitate. In the precipitation process, sodium alginate is transformed back to alginic acid. The alginic acid forms fibres, and water is removed in series of presses. In the presses, bleaching agents are added to remove the rest of the unwanted brown color.

Drying and milling
The alginic acid is dried in insulated channels, using large amounts of hot air heated in steam and electric batteries. The steam batteries operate with a pressure of 6 and 12 bars. When the alginic acid reaches the correct moisture content, it is incorporated with sodium carbonate in a kneader. The alginic acid is hence transformed back to sodium alginate, which is the form of alginate customers usually prefer. The alginate is then dried further, milled to different granule sizes and loaded into bags (ibid).

5.4.3 Energy requirements in alginate production

The process has a relatively large energy demand, in the form of electricity and heat. The energy system at the factory consists of two gas fired steam boilers delivering steam at 11 bars, which is used to heat air and process water in steam batteries at 11 and 6 bars. Steam is also injected directly into the process stream. A heat pump supplies hot water for the initial processing stages, and steam and electric heating batteries are used when additional heating is required. Electricity is largely used for drying and milling of the products into different specified qualities. Heating process water to about 44° C represents a large part of the total energy consumption. In 2005, the factory consumed 4 MSm^3 (142,16 TJ) of natural gas and 40 GWh (144 TJ) of electricity. Energy accounted for more than 20 % of the total production costs. Table 16 shows consumption of energy in alginate production at FMC biopolymer (Jevne, 2006):

Table 16: Resource use and production at FMC.

Annual values for alginate production		
Raw material (Kelp)	160000	[tonnes]
Production (Alginate)	5000	[tonnes]
Electricity	144	[TJ]
Natural gas	142	[TJ]

A pinch analysis of the plant has been conducted by Sigurd Jevne (2006), and it shows that the thermal energy used in the plant is 7886 kW in the summer and 8123 kW in the winter, which averages at approximately 8000 kW, equivalent to a thermal heat consumption of 252,3 TJ annually. This means that 76 % of the electricity is used for heating purposes, probably in the heat pump. Unfortunately, the detailed data on process specific energy requirements is left out of the official report.

5.4.4 Alginate production at Mongstad

Approximate values for steam consumption for potential alginate production at Mongstad is found assuming that low pressure steam can be used for all heating purposes and has an enthalpy of 2803 kJ/kg, and assuming 160000 tons of wet weight kelp is used to produce 5000 tons alginate per year. Table 17 show approximate figures for steam consumption:

Table 17: Steam consumption using LP steam to cover thermal energy.

		Steam [ton]	Energy [GJ]
Per year	[1/yr]	90006,4	252288
Per hour	[1/h]	10,3	28,8
Per ton raw material	[1/ton]	0,56	1,6
Per ton product	[1/ton]	18,0	50,5

A plant producing 5000 tons of alginate annually at Mongstad would need 10,3 tons of low pressure steam from the refinery per hour with continuous production throughout the year, and 0,56 kg steam is required per kg raw material. If a stable delivery of 25 tons of excess steam per hour could be delivered from the refinery, 12136 tons of pure alginate could be produced with the given energy requirements.

The calculation of values for steam assumes that all the processes in the production of alginate can cover their heat requirements by use of low pressure steam at Mongstad with a temperature of 175° C and a pressure of 3,4 bars. The temperatures needed in the processes should be obtainable with the use of excess steam. Most of the process water has a temperature of about 45° C, a small fraction of the process water need a temperature of 85° C. Although the drying process in the system uses saturated steam with a pressure of 6 to 12 bars on the supply side, it should be technically feasible to implement a dryer that could use the energy of low pressure steam.

5.5 *Fish feed production*

5.5.1 In general

Aquaculture is a large industry in Norway; the export of salmon and trout was 595931 tons at a value of 14769 million NOK in 2005. Increased fish production leads to an increase in the demand for fish feed. Figure 23 show the traded fish feed amongst the members of the Norwegian seafood federation (FHL). The vertical axis shows the amounts in 1000 kg (FHL, 2005).

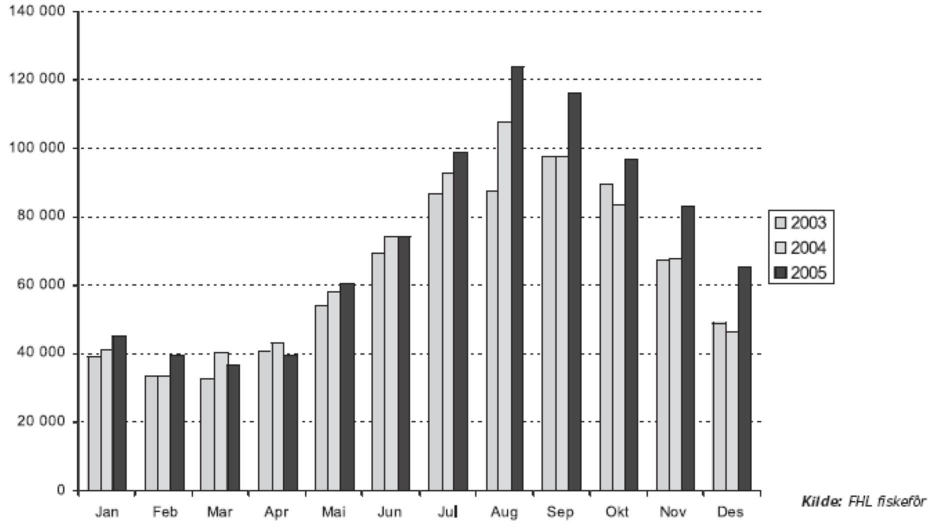

Figure 23: Traded fish feed among the members of Norwegian seafood federation (FHL) in 1000 kg.

The total trade was 881000 tons of fish feed from the Norwegian producers in 2005, which is an increase of 12 % from 2004. In addition there was an import of 24000 tons. The trading of fish feed for marine fish species increased by 68 % in 2005 (FHL, 2005).

5.5.2 Production

Fish and animal feeds have a number of different ingredients to create the best possible nutritional value and growth rate. The technology of feed processing has developed from simple mixing by hand of several ingredients to continuous mechanical mixing, and to computer controlled mixing and pelleting. For successful mixing of the different ingredients, they need to be grinded to similar particle size. Some plants are designed to produce one product type, while others are more flexible. There is a need for specialized equipment and technological expertise in feed processing, but the material flow follows a basic pattern, as shown in figure 24 (FAO, 1980):

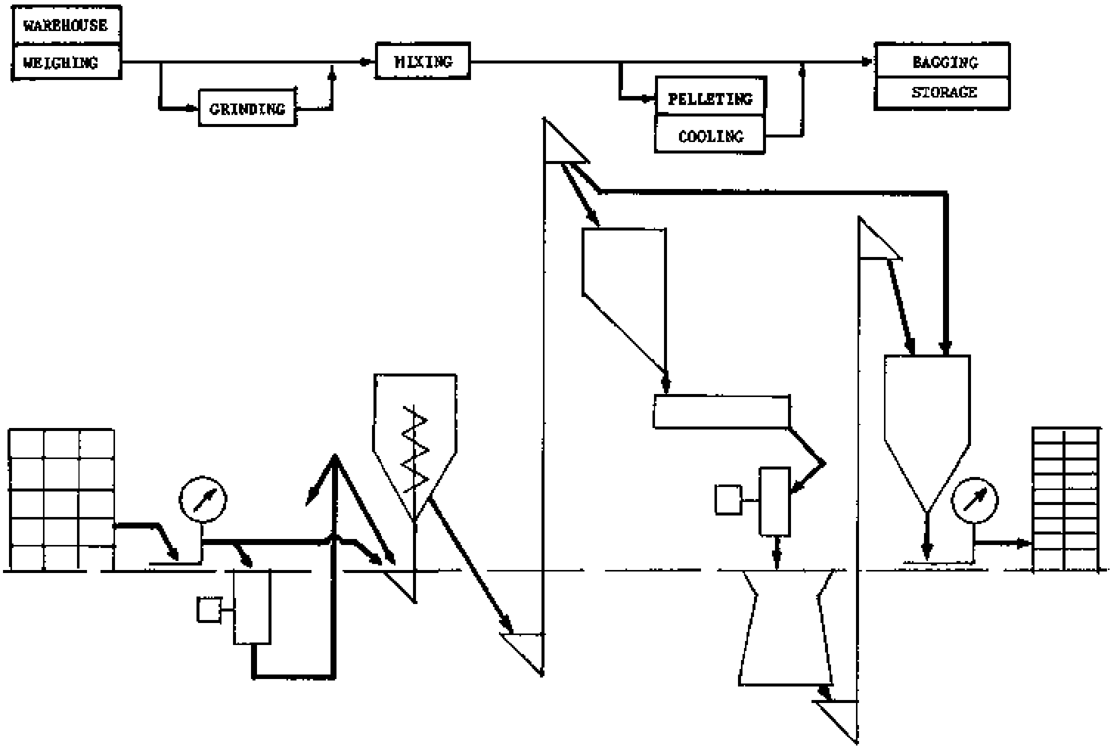

Figure 24: Principal sketch of feed processing.

The first operation is receiving the raw materials. They arrive in bulk, and liquids such as oils are stored in tanks while dry materials are stored in sacks. The material processing includes:

a) Grinding: Particle size reduction.
b) Premixing
c) Mixing
d) Pelleting
e) Sacking

There are two mixing operations in feed milling. One is for the mixing of micro nutrients such as vitamins and minerals, and is called premixing. The other mixing operation is the actual blending of all the components of the diet. The final mix is checked periodically to ensure homogeneity of the mix. The feed mash is conditioned with steam before it enters the die, where it is extruded to the specific pellet sizes. After extrusion the pellets need to be cooled and dried with hot air. Fish oil is added at this stage if it's necessary. Most fish feeds are sacked; an operation which includes weighing, sacking, taping and sewing. The bags are then ready to be distributed (FAO, 1980). The upper temperature limit for hot air drying when producing feed containing wheat is 82°C, and the finished moisture content of the product should not exceed 13 % to avoid deterioration (FAO, 1984).

5.5.3 Energy and other inputs of production

Data on energy use for producing trout feed can be found in the Danish LCA food database (2006). The data was gathered in 2000, and has been collected from three larger and quite uniform factories, which together covers nearly 100 % of the Danish market for trout feed. The inputs in this production are a non-weighted average over the year from the three factories. Table 18 shows the amount of energy used in the production of 1 kg trout feed:

Table 18: Inputs and outputs in the production of 1 kg trout feed

Inputs	Material	Unit	Value
	Fish oil	kg	0,20
	Fish meal	kg	0,47
	Wheat	kg	0,14
	Soy meal	kg	0,18
	NaOH	l	1,90E-06
	HCl	l	5,50E-06
	Boric acid	l	1,70E-06
	Petroleumether	l	1,90E-06
	H2SO4	l	3,80E-05
	Energy		
	Heat	MJ	0,71
	Electricity	kWh	0,12
Outputs	**Product**		
	Trout feed	kg	1,00

The energy used in the production of the Danish fish feed, both heat and electricity, is produced from natural gas. Electricity is 38 %, and heat 62 % of the total energy consumption.

5.5.4 Utilizing excess steam at Mongstad for fish feed production

The heat demand in the process is 0,71 MJ per kg product. This relates to a steam consumption of 0,25 kg steam per kg fish feed, calculated by the enthalpy of the LP steam (2803 kJ/kg). If 25 tons excess steam per hour is available for fish feed production at Mongstad, the heat energy alone is enough to produce 100 tons of trout feed per hour.

The energy use per kg product is very low compared to the other cases presented in this report. There is a heat demand for mixing the materials, and in drying of the pellets, but some types of feed pellets can be dried or cooled in a dry environment at ambient temperature. It is therefore not likely that fish feed production will occur at Mongstad based on the excess heat alone. However, with several aquaculture facilities in near proximity, and if the feed production is connected to fish meal and oil production plant at the same site, it may be incentives for fish feed production at Mongstad.

5.6 Bio-pellets production utilizing excess steam at Mongstad

5.6.1 In general

Bio-pellets are compressed biological material with a diameter smaller than 20 mm. The most common raw material in Norway is sawdust which is dried to 9 % moisture content. The small dimensions make the handling properties comparable to fuel oil. The lower heating value of bio-pellets is 5,2 kWh/kg. There are 8 factories in Norway producing bio-pellets, and the production figures are given in Table 19 (Nobio, 2006):

Table 19: Production, import, export, sales and stock in Norway 2003-2005 in tons.

	2003	**2004**	**2005**
Pellet Production	20296	33567	42339
Import	300	237	232
Export	1297	5566	17980
Sales Norway	15322	22055	19497
Stock (Annual average)	2437	7004	12147

The annual production of pellets has nearly doubled from 2003 to 2005. The production in 2005 was of 42339 tons. The import of pellets has declined, while the export has increased by more than a factor of ten. The domestic sales have increased by 27 % over the same time period. The decline in domestic sales from 2004 to 2005 was caused by large sales to stock at Norwegian distributors. Bio-pellets can be bought in three categories, small sacks, big sacks or bulk. The prices excluding VAT and a conservative assumption of 4800 kWh/ton bio-pellets are given in table 20 (Nobio, 2006).

Table 20: Prices for bio-pellets in different forms of packaging per ton and per kWh heat potential

	NOK/ton	*NOK/kWh*
Small sack	1518	0,32
Big sack	1307	0,27
Bulk	1123	0,23

5.6.2 Production

A student project initiated by Statoil Mongstad looked into the possibility of bio-pellets production utilizing excess low pressure steam (175°C, 3,4 bar) at Mongstad (Christensen et al, 2005). The local forestry has large quantities of wood waste that could be utilized in this production. The report has looked at a potential plant utilizing 199 TJ of excess steam from the refinery annually, and using 135000 solid m^3 of raw materials to produce 61200 tons bio-pellets annually. The production line is given in figure 25:

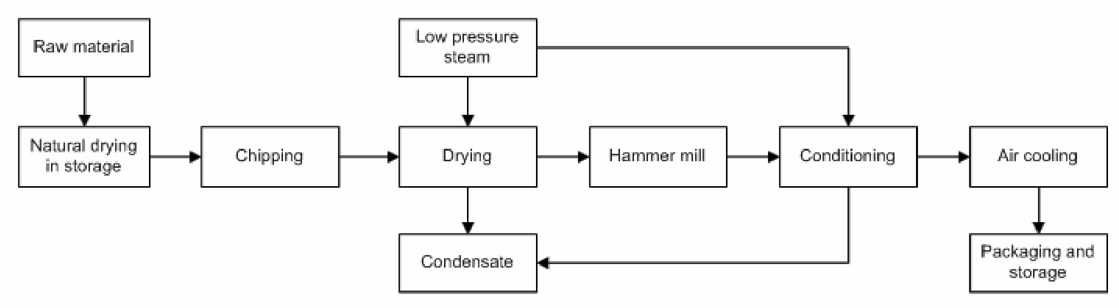

Figure 25: Production line for wood pellets.

The report concludes that the steam qualities from the refinery can be used in the drying process of bio-pellets production, where optimal temperature is 130° C. The production costs per ton bio-pellets are 860,46 NOK, including the price of raw material and infrastructure investments. The distribution of production costs are given in figure 26:

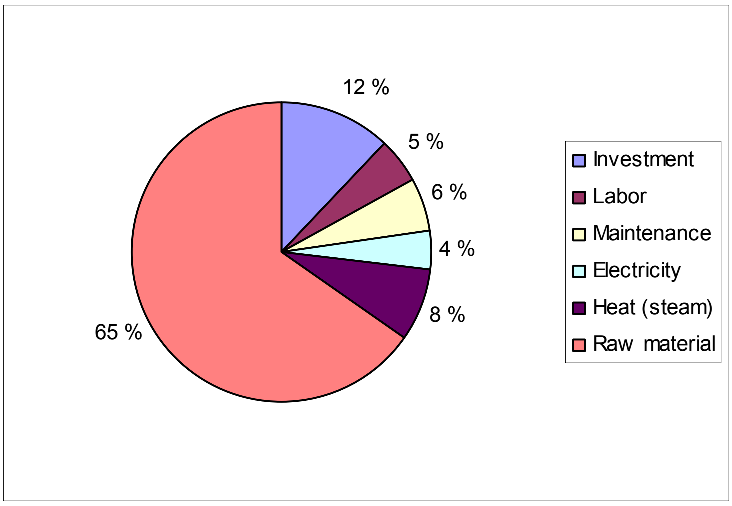

Figure 26: Distribution of production costs for production of 61200 tons/yr bio-pellets

The main expenditure is on the raw material (65 %), followed by the investment costs (12 %). The price of heat has been given by Statoil to be 72 NOK/ton steam. The costs related to heat equals to 8 % of the total costs.

As opposed to the production of for instance fish meal and oil, the drying of bio-pellets does not need a continuous delivery of steam, since closing down the dryer and restarting is possible.

5.6.3 Operation parameters and energy considerations

The common way of generating heat in bio-pellet factories is using a rotary drier using heat from natural gas, oil or bio-pellets. The rotary drier utilizes steam with a higher temperature than the low pressure steam available at Mongstad. If by-product steam from the refinery is used, then a conveyor bed drier should be used. The by-product steam then needs to heat air which is blown through the transporter bed. As opposed to using a rotary dryer this will lead to a low temperature drying process. At temperatures above 130° C the lignin doesn't liberate from the raw material. Thus, more of the flammable material can be utilized when incinerating the pellets, and steam conditioning and the use of adhesives is avoided. The heat energy parameters are given in Table 21 (Christensen et al, 2005):

Table 21: Production parameters for bio-pellets production at Mongstad

	Value	Unit
Pellet production	61200	ton/yr
	12	ton/h
Operation	5100	h/yr
Water content	7344	ton/yr
Water removal	46512	ton/yr
Heat energy for drying	116280	GJ/yr
	32300	MWh/yr
Steam consumption	41484	ton/yr
	10,76	ton/h
Electricity	6717	MWh/yr

The projected facility operates 5100 hours per year and produces 12 tons of bio-pellets per hour. Removing 46512 ton/yr of water from the raw material means that 9,12 tons of water is evaporated per hour of operation. The need for heat energy is 116280 GJ/yr which corresponds to a consumption of 10,76 tons low pressure steam per hour at Mongstad, 95 % of the steam is used in the initial drying process while 5 % is used for conditioning. The heat demand represents 83 % and electricity 17 % of the total energy demand. If 25 tons of excess steam is available at Mongstad, and all of this is used to produce bio-pellets, an amount of 144517 tons/yr bio-pellets could be produced.

5.7 Further studies and other processes

There are several processes which are of interest to further studies in order to determine industries with a potential for excess heat utilization at Mongstad. The processes described earlier in this chapter give an indication of the variety in some known drying industries. Further studies should focus on specific processes, for instance as part of life cycle assessment or feasibility studies. The chosen industries or processes will need detailed projection of operation and system design, and the applicability of further analysis relies on careful planning of what industries and processes to proceed with. Available methods and equipment for heat exchanging from steam in hot air dryers and contact dryers should be a priority. Knowledge of these processes and energy balances will enable further modeling of specific processes, and a model of an industrial park with several by-product exchanges.

The industries suitable for further studies should have the potential to cover all or most of their heat demand by utilization of low pressure excess steam from the refinery. This approach points out the economic and environmental benefits from by-product utilization more clearly, as opposed to an industry with a need for both low pressure steam from the refinery and self-production of high pressure steam. Gathering energy and production costs data in production processes is challenging without cooperation with the related industry e.g. a specific company, industry organizations or research centers. Further studies should therefore include such potential partners.

The fact that the existing industries related to drying processes have other sources of energy than steam makes it difficult to make a unisonous decision on what industries might fit into an industrial park at Mongstad. Going from using a heat pump or oil fired steam boilers to the utilization of excess heat could lead to large implications for system design, influencing both investment and operating parameters of the production. The excess cooling water from the refinery should be studied with regards to efficient heat pumps for industries using this type of energy technology e.g. clip fish.

Comparisons between the excess heat qualities at Mongstad and geothermal heat sources, in for example Iceland, can lead the Mongstad Pilot project to interesting industries. This was the case when investigating the production of dried cod heads in chapter 5.2, where geothermal heat sources has turned dried cod heads production into a relatively large industry on Iceland. Organic fertilizers based on seaweeds is another industry utilizing this type of energy in drying operations on Iceland.

The description of the processes mentioned in chapter 5, can serve as a basis for deciding what type of processes are suitable for detailed analysis. There are also other industries that could be appropriate to investigate, when it comes to by-product heat utilization. This includes the production of several types of animal feed production, lumber drying and production of fuel energy from sludge or other types of biological material.

6 Conclusions

This report has described the basics of drying theory, and presented different drying equipment. Hot air dryers that require relatively low temperatures seems most suitable for utilization of excess steam utilities from the Mongstad refinery. The steam based contact dryers often operate at a pressure of 6 bars and more, hence, the excess steam from the refinery is not directly transferable to the technology for such dryers. If materials with very good thermal transmission properties are used, and the design of the drying equipment is changed the waste heat at Mongstad is not limited to hot air dryers, as long as the temperature levels are low enough.

Six industries with accompanying drying processes were described in chapter 5. Table 22 gives a summary and a basis for comparison of these industries:

Table 22: Summary and comparison of the industries described in ch. 5.

	Heat demand		H_2O removal	Steam, P	Drying T.	Moisture content	
	[GJ/ton prod]	[GJ/ton raw]	[kg/kg prod]	[bar]	[° C]	[% in prod]	[% in raws]
Fish meal	5,91	1,89	2,125	6, 8, 10	90	<10	68
Cod heads	24	4,8	4	LP	30	15-20	80
Clip fish	2,16	1,96	0,15	LP	23	45-50	55-60
Alginate	50,5	1,6	39	6, 12	45-85	N/A	>80
Fish feed	0,71	N/A	N/A	N/A	82	13	N/A
Bio-pellets	1,9	1,15	0,75	LP	130	12	50

The heat demand per ton product and raw material, and the amount of water removed in each industry tells us how energy intensive the industries and drying processes are, for instance the alginate production has a removal of 39 kg water per kg product. This is because the large use of raw materials compared to finished product. The difference in moisture can explain the difference between energy consumption for cod heads, dried from 80 % moisture content and clip fish, which is dried from 55 % moisture content.

Steam can be used as heating medium in all of the described processes. Cod heads, clip fish and bio-pellets production can theoretically use low pressure steam at 175° C and 3,4 bar for their heating purposes. Clip fish production is not recommended for use of excess steam, because the quality and ease of operation of the plant will be reduced as a result. The possibility for potential added value in the production of clip fish from utilizing excess steam is therefore scarce. For production of fish feed the energy demand is not large enough to start production at Mongstad based on savings in energy cost alone.

In the Steam pressure column in Table 22 it becomes clear that the fish meal and alginate production processes utilize steam at higher qualities than what is available at Mongstad. This means that utilization of by-product steam from the refinery can not be obtained without alteration of the presented production methods and equipment. By engineering these processes to utilize excess heat, savings in resource consumption and operational costs can be obtained. The alginate production has a large amount of waste heat in its processes and this could be reduced if energy at a lower quality is used.

7 References

Arason, Sigurjòn, 2003: *The drying of fish and utilization of geothermal energy; the Icelandic experience*. International Geothermal Conference, Reykjavìk, September 2003. Session 08, Paper 76.

Bolland, Olav. Strømmen, Ingvald. Et al 1997: Kompendium i fag *SIO7060 Næringsmiddelteknologi*. Kap. 5.1 Avvanningsteknikk, 5.2 Tørketeknikk. Norges teknisk-naturvitenskapelige universitet, institutt for klima og kuldeteknikk.

Brennan, James G.; 2006: Food Processing Handbook. (Ch. 3 and 8) WILEY-VCH GmbH & Co. KGaA, Weinheim Germany.

Brennan, J. 1992: *Developments in drying*. In: A. Turner (ed), Food technology International Europe. Sterling Publications International, London. In (Fellows, 2000)

Christensen, O, Jahre, J, Roaas A; 2005: Statoils summer project: Næringsutvikling på Mongstad, Produksjon av biopellets ved hjelp av overskuddsvarme fra oljeraffineriet på Mongstad.

FAO, 1986: Food and agriculture organization of the United Nations, *The production of fish meal and oil*, FAO fisheries technical paper – 142, ISBN 92-5-102464-2.

FAO, 1984: Food and agriculture organization of the United Nations. ADCP/REP/84/21 - Inland Aquaculture Engineering. AQUACULTURE DEVELOPMENT AND COORDINATION PROGRAMME Lectures presented at the ADCP Inter-regional Training Course in Inland Aquaculture Engineering, Budapest, 6 June-3 September 1983

FAO, 1980: Food and agriculture organization of the United Nations, Lectures presented at the FAO/UNDP Training Course in Fish Feed Technology, held at the College of Fisheries, University of Washington, Seattle, Washington, U.S.A., 9 October-15 December 1978.

FHL – Fiskeri- og havbruksnæringens landsforening, 2005:
Årsrapport 2005: http://coreweb.nhosp.no/fhl.no/html/files/FHL_AArsraport_2005.pdf (27.11.2006).
Statistikkbilag til årsrapport 2005:
http://coreweb.nhosp.no/fhl.no/html/files/FHL_Havbruk_statistikk_05.pdf (02.02.2007)

Fiskeriforskning, 2004: Rapport 11/2004. *Tørkede fiskehoder – Etablering av en produksjonslinje for tørkede fiskehoder*. www.fiskeriforskning.no

Fellows, P.J. 2000: *Food Processing Technology*. Woodhead Publishing Limited and CRC Press LLC

FMC biopolymer, 2006: *www.fmcbiopolymer.com*. Processing of FMC Alginates: http://www.fmcbiopolymer.com/PopularProducts/FMCAlginates/Processing/tabid/796/Default.aspx (07.12.2006).

Fredriksen, Jan; 2007: Arctic Innovar. Personal communication: 78406605 (11.01.2007).

Geankoplis, Christie J; 1993: Transport, process and unit operations. Third edition. Prentice Hall, Englewood Cliffs New Jersey.

Hemmer, Ellen; Askim, Merete; Karlsen, Hanne; Lynum, Leif; Nordeng, Anita; Nybraaten, Gerd; 2001: *Næringsmiddellære – Råstoff-, produksjons- og ferdigvarekunnskap*. Teknisk fagskole næringsmiddelteknikk. Yrkeslitteratur AS.

IFFO, 2006: International fish meal and fish oil organization; www.iffo.net (14.11.2006)

Jevne, Sigurd; 2006: *Pinch analysis for the efficient use of energy in a process for hydrocolloid production*. Master thesis at the department for energy and process engineering. Norwegian University of Science and Technology.

Jonassen, Ola, Walde, Per Magne, 2006: *Energianlegg og luft fordeling i 3 klippfisktørker*. Technical report executed by Bacalao Forum and Arnt Olav Aarseth. Confidential report.

Kudra, T. 2004: *Energy aspects in drying*. Drying technology, Vol. 22, No. 5, pp. 917-932, 2004.

Lindquist, Knut Bjørn; Hauge, Sørfjorddal Elisabet; 2000: *Innovasjoner i norsk saltfiskindustri i 1990 årene, noen eksempler*. Perspektiver på norsk fiskerinæring, Rapport 4/2000 (Kystnæringssenteret, Honningsvåg). http://www.nhh.no/geo/gib/gib2000/gib240/gib240.pdf (01.12.2006)

Menshutina, N.V., Gordienko, M.G., Voynovskiy, A.A., Kudra, T., 2004: *Dynamic analysis of drying energy consumption*. Drying technology Vol 22 No10, pp2281-2290, 2004.

MP, 2007: Internal document. Steam utilities at Statoil Mongstad.

NOBIO, 2006: Norsk Bioenergiforening, markedsrapport for perioden 2003-2005. www.nobio.no (03.01.2007).

RUBIN, 2007: Resirkulering og utnyttelse av organiske biprodukter I Norge. Personal communication with Sigrund Bekkevold: 73545630, www.rubin.no. (11.01.2007)

Schmidtsdorff, W. 1995: Fish meal and fish oil – not only by-products. In: Fish and Fishery Products (ed. A. Ruiter), pp. 347 376. CAB International, Wallingford.

SSB, 2006: Statistics Norway, *Minifakta om Norge 2006*. http://www.ssb.no/emner/00/minifakta/no/main_10.html (27.11.2006)

SSB, 2005: Statistics Norway, Utenrikshandel med varer 2005: http://www.ssb.no/emner/09/05/uhaar/tab-26.html (05.01.2007).

SSB, 2004: Statistics Norway, *Fiskeristatistikk 2004*. http://www.ssb.no/emner/10/05/nos_fiskeri/nos_d348/nos_d348.pdf (14.11.2006)

SSB, 2000: Statistics Norway, *Energistatistikk 2000*, Appendix B, C. http://www.ssb.no/emner/10/08/10/nos_energi/ (14.11.2006)

Steen, Henning; 2005: Institute of Marine Research (IMR): *Høsting av Tang og tare*. Kyst og Havbruk 2005. Report ch. 2: http://www.imr.no/__data/page/6473/2.5_Hoesting_av_tang_og_tare.pdf (01.12.2006)

Ulseth, Bent Inge; 2006: Contact person at Egersund Sildoljefabrikk AS, http://www.egersund-seafood.no/. Personal communication by e-mail: biu@fishmeal.no (13.12.2006).

Vassdal, Terje, 2006: Lecture at the clip fish conference 30.08.2006 in Ålesund: www.godfisk.no/binary?id=51916&download=true (27.11.2006).

Whitman, W. E., Crawford, A. G. and Elsen, C. R. ,1981: *Energy Use in the Food Manufacturing Industry, Final Report to the Commission of the European Communities*, No. EUR 7073 en. Commission of the European Communities, Brussels. In Fellows, P.J. 2000: Food Processing Technology. Woodhead Publishing Limited and CRC Press LLC.

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Industrial Ecology Programme
NO-7491 Trondheim

Tel.: + 47 73 59 89 40
Fax: + 47 73 59 89 43
E-mail: indecol@indecol.ntnu.no
Web: www.indecol.ntnu.no

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