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# Woodchip Fuel Supply Chain: From Forest to Hopper

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## Abstract:

This thesis is concerned with the establishment of a woodchip fuel supply chain in North Sutherland. It begins by looking at wood as a fuel and examining the processes involved in its preparation for use in woodchip boilers. It studies the drying process in some detail and a comparison of drying techniques available is made, based on the emission levels of each technique, their costs and the installations required. Generalised flowcharts are developed to allow for the methodology used throughout this thesis to be applied to future projects on woodfuel supply chains. Previous work on generalised cost calculations has been assessed and expanded to allow for more accurate woodfuel processing cost predictions. Finally, a case study of the woodfuel supply chain possibilities in North Sutherland has been made proposing the most cost effective, and environmentally benign options taking into account the environmental impact and cost of each process. The study, looks into two possible scenarios: a woodchip fuel market expansion and the possibility of only one end user being available. These scenarios vary on drying techniques and acquisition types: in one instance (expanding market), hot air blast drying of timber bought standing is preferable and in the other, open air drying of timber bought on roadside is most effective. The study concludes with a look into the socio – economic impacts the establishment of a woodchip fuel supply chain might have on the local communities.

## Contents:

# 1. Overview

## 1.1. The Kyoto Protocol and UK energy use trends

Four decades of scientific efforts, since 1957, have refined the theories of global warming and subsequently climate change. The Kyoto Protocol is an unprecedented achievement in international affairs whereby each industrialised country commits itself to cap emissions of green house gases ($CO_2$, $N_2O$, $SO_x$, $CH_4$, HFCs, PFCs, $SF_6$). The UK is one of the countries committed to reducing its $CO_2$ emissions; this has lead to the review of the UK's energy policy. The establishment of laws and legislations such as the Climate Change Levy (CCL) and the Renewables Obligations (RO) have centred in electricity generation. Although the generation of electricity from fossil fuels is a major contributor to $CO_2$ emissions, it is not the only one. The UK, and especially Scotland, has a long heating season. Therefore, emissions from boilers running on fossil fuels are also an area of interest and invite further investigation. Chart 1 indicates the trends in energy use in the domestic sector, 61% of the total energy used in a residence goes towards space heating. This percentage of energy translates to about 45% of the UK's fuel needs. Consequently, there is large room for investigation into the fuels used for heating. The following chapters will focus on the biomass fuels alternative.

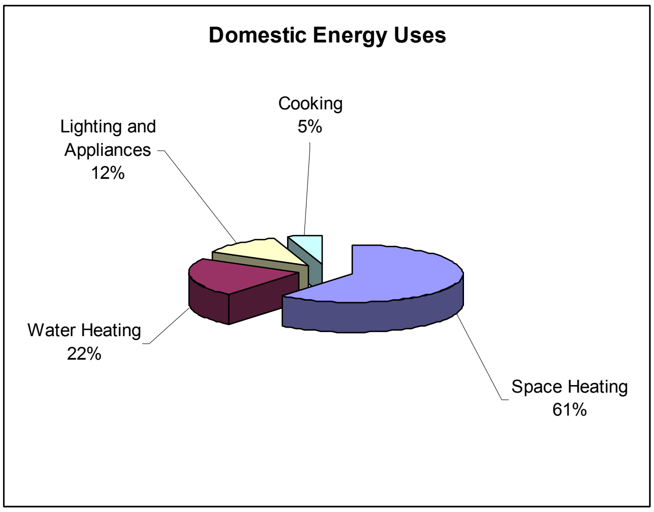


**Chart 1: Domestic Energy Use**[1]

[1] Royal Statistical Society

## 1.2. Biomass

Biomass, all earths living matter, is a very abundant source of energy. In an energy context, it can be defined as "all *non-fossil* organic materials that have intrinsic chemical energy content"[2]. This energy content is known as *Bioenergy***.** Bioenergy can be produced from various different biomass resources (or *feedstock*) through various processes making biomass one of the most versatile energy sources. In addition, biomass is a $CO_2$ emissions *neutral* source of energy. This is because $CO_2$ is absorbed from the atmosphere and used by plants in the photosynthetic process (see appendix I). Planting trees and crops soaks up an amount of carbon dioxide, if these are then harvested for biofuels; fossil fuel use is offset, therefore reducing $CO_2$ emissions. $CO_2$ is emitted when manufacturing and burning biomass fuels, it is ultimately equal to the carbon dioxide absorbed by the plants used to produce this fuel (if the crops and trees are sustainably managed). For example, the use of short rotation coppice (SRC) of willow and poplar, as a substitute for fossil fuels, produces no net $CO_2$ emissions and very low emissions of nitrogen and sulphur pollutants from its combustion (compared to coal burning). In this way, fuel produced by energy crops could help 'phase out' fossil fuel use, as it would be a carbon dioxide ($CO_2$) neutral energy source, providing the rate of consumption is equal to the rate of re-planting. Figure 2[3] shows many of the possible processes involved in harnessing bioenergy the highlighted boxes indicated the areas that will be discussed in this report. Applications that use biomass for heat represent the largest single contribution to renewable energy in Europe and in the UK (see Figure 1). The greatest contribution comes from landfill gas, followed by waste combustion and wood biomass use in industry and domestic heating with wood.

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[2] www.bera1.org/about.html

[3] http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/index.htm

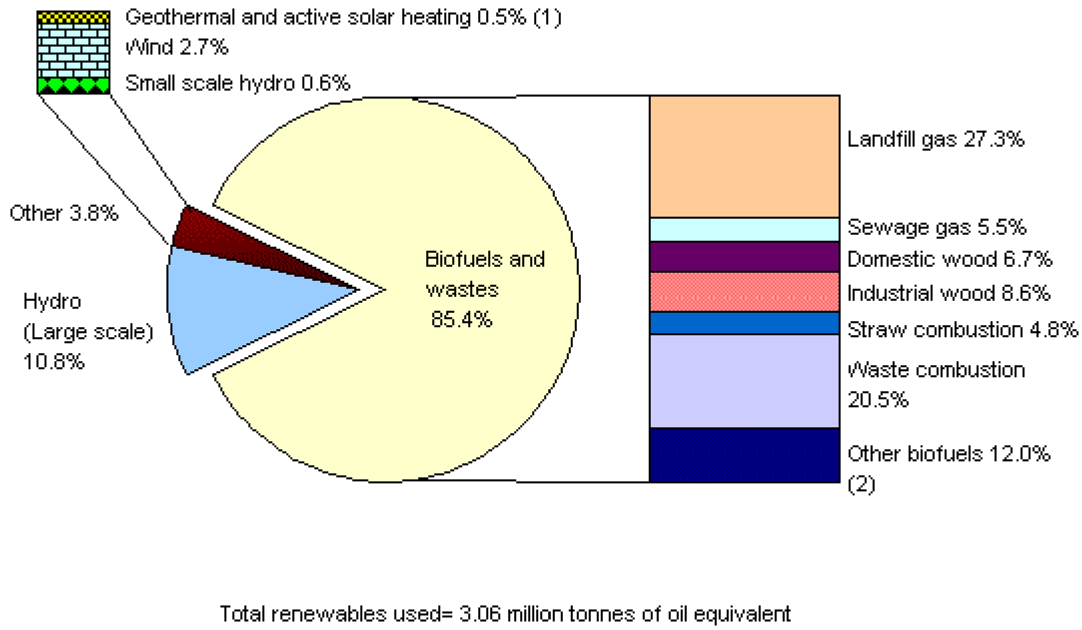


**Figure 1: Renewable energy utilisation in the UK 2001[4]**

*(1) Excludes all passive use of solar energy.(2) 'Other biofuels' include farm waste, poultry litter, meat and bone, waste tyres, industrial and hospital waste and short rotation coppice.*

This project studies the economics of harnessing energy for heating (column 4 in figure 2) from wood (column 2 in figure 2). Using biomass to produce heat *and* electricity from combined heat and power (CHP) plants was not included in the study; the communities in question are small and far apart so relatively large centralised plants power and district heating plants are not viable. Moreover, the establishments themselves are not large enough to justify using individual generators. Consequently, only the production of heat has been studied. In this case, the feedstock (column 1) comes from conventional forestry and forestry residues, as well as industrial wood residues from paper mills and furniture manufacturers. Feedstock from short rotational coppicing was not taken into account as the project is based on already existing feedstock, furthermore, the environmental particularities of the area studied do not allow for such developments at present.  The conversion (column 3 in figure 2) of this feedstock to heat will be through combustion, a thermo-chemical process. Most of these technologies have been used for years and are well established, leaders in the use of wood for energy are the Swedes.

[4] http://www.etsu.com/RESTATS/utilisation.html

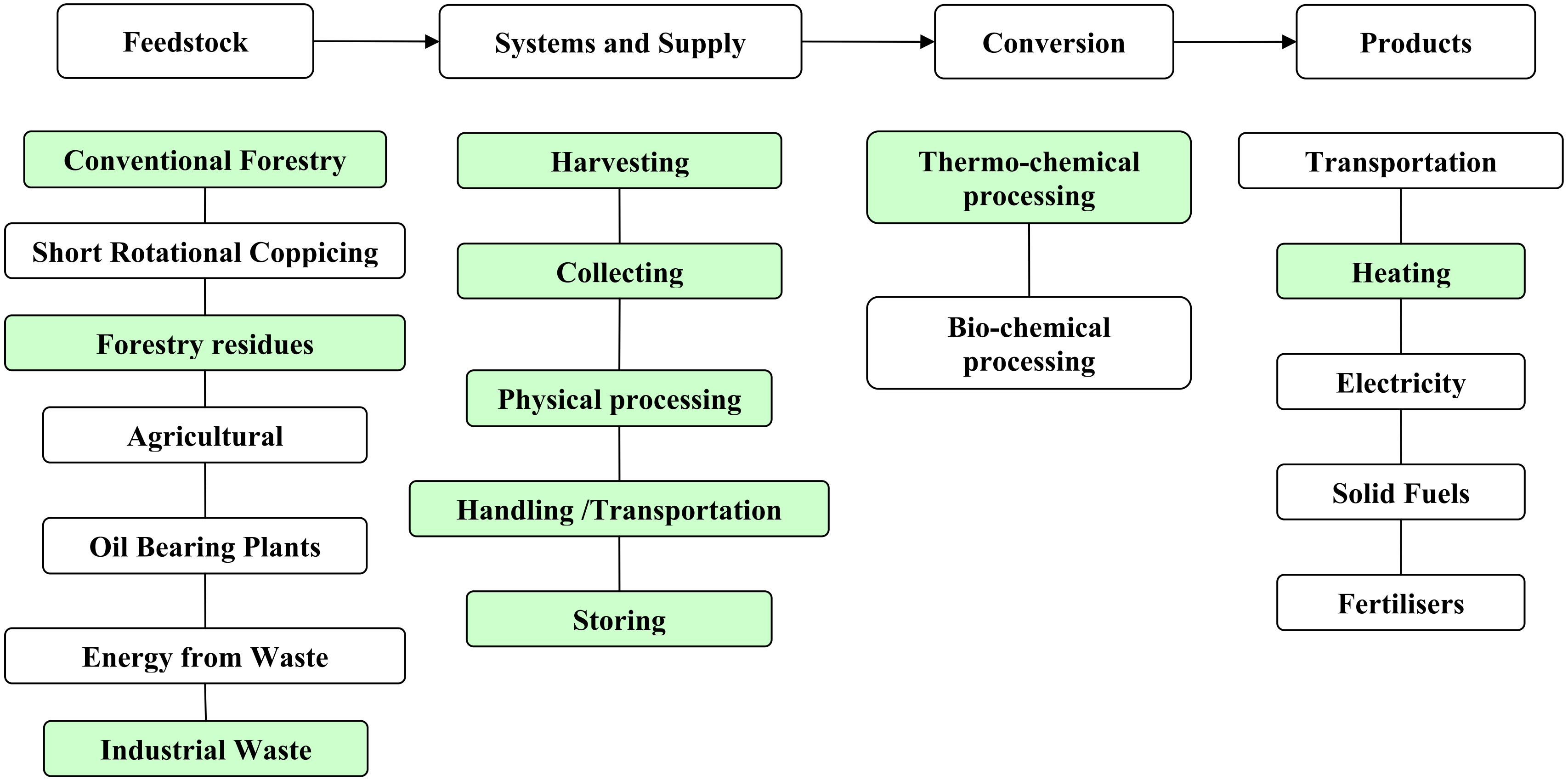


**Figure 2: The Bioenergy Process**

## 1.3. Sweden's example

As the Swedish economy and energy supply is dependent on imported fuels (mainly oil and uranium), the government focused on reducing this dependency. Through a series of energy bills, the parliament was principally concerned with energy efficiency, and conservation. A legislative infrastructure was established to promote the use of renewable and indigenous energy sources (an example is the taxes imposed on $CO_2$ emissions). Today more than 16% of Swedish energy needs are met from biofuels and principally wood (logs, barks, chips and energy forests)[5]. The use of wood for district heating systems and combined heat and power systems has been on the increase since even before the 1980's. For example, Sweden has over 400 wood-fired district heating plants each with a capacity of over 5MW amounting to a total of over 15TWh in 2000[3]. The fuel used for these systems mainly originates from felling wastes and by products of the forest products industry, in addition, processed fuels such as briquettes and wood pellets are used. Moreover, the detached house sector used more than 6.7TWh for heating in 2000[4]. The country implements a wide variety of technologies from wood pellet boilers for heating small residences to large installations for supplying villages and small towns. This use of resources puts Sweden on the top of the list of countries with biofuels in their energy systems within the EU. Scotland and especially the north Highlands have potentially high volumes of biofuels but little use is made of them within the area's energy systems. Sweden sets the example for such use. The many years of experience the country has, could prove to be helpful in identifying available technologies along with the possible problems associated with their use. Furthermore, the climatic similarities with Scotland and the success of the Swedish applications bode well for any similar projects in Scotland. Therefore, bearing in mind this success, the possibility of using woodchips for heating in the North Highlands has been the main focus point in this project, as the resource is abundant, the heating season is large and local communities are keen to develop a sustainable strategy in the area.

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[5] Energy in Sweden 2001, Swedish National Energy Administration

## 1.4. The project

This project aims to determine the feasibility of establishing a market for woodchips to use as fuel in the North Highlands namely North Sutherland. The market should be created so that the source of the wood and the end users should all be local in order to keep profits (both economical and environmental) within the area.

### *1.4.1. Objectives*

- To develop flowcharts that illustrate the methodology behind the development of the study and to allow for such a study to be undertaken in other sites around the UK and Europe.
- To establish a basic understanding of the nature of wood and the various processes involved in harvesting timber for fuel.
- To compare technologies based on their individual emissions and energy sources used
- To identify the costs involved throughout the process.
- To outline the effects such a development would have on the local communities and their economies.
- To outline the effects such a development would have on the environment.
- To identify and deal with the possible problems arising from transportation of these woodchips.

### *1.4.2. Methodology:*

In order for this to be achieved, the North Sutherland area was visited and the situation was assessed based on:

- project potential,
- community cooperation possibilities,
- information availability,
- available facilities,
- forestry sector support.

A literature review was then carried out (chapter 2 & bibliography) including information on:

- Wood
    - Properties
    - Sources
    - Processing techniques
- Forestry
- Timber drying

The opportunity arose to attend a conference[6] in order to get an idea of the current developments in fuel wood utilisation in Scotland, and to get in contact with some of the companies and trusts in the industry.

A second visit to the area was made in order to have interviews with:

- A local community representative,
- Local foresters and contractors representatives,
- A local sawmill manager,
- A representative from Forest Enterprise,
- Possible end users of woodchip fuel.

Along with the interviews, a personal assessment of the distances involved and the road conditions was carried out so that the transportation problems associated with the project could be tackled. The forestry resource was also discussed with the North Highland Forest Trust (NHFT). The particularities of the local forests (pertaining to ground conditions, biodiversity within the forest, local forest management techniques and so on). Furthermore, a timber harvesting operation was viewed first hand and the dangers associated with such operations were discussed.

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[6] Heating up on wood 2, Developing small woodfuel heating systems, 24th, 25th May 2002, Kinlocleven

The costs of harvesting, comminution, drying, transportation and use of woodchips for heating the individual processes involved were then studied separately bearing in mind the information gathered from the interviews.

As drying was identified as one of the most sensitive areas of this type of project it was studied closely. The technical details of the various drying techniques were studied and the end result was the development of a technique that will suit the local needs using the local resources in the most efficient manner. The end product (dry woodchips) should be cheaper than the price of other fuels available in the area. Thus, combinations of the separate processes were studied in order to identify the most *cost effective* approach. Furthermore, a program developed by the NHFT[7] and David Palmer[8] was used to verify the costs calculated by hand.

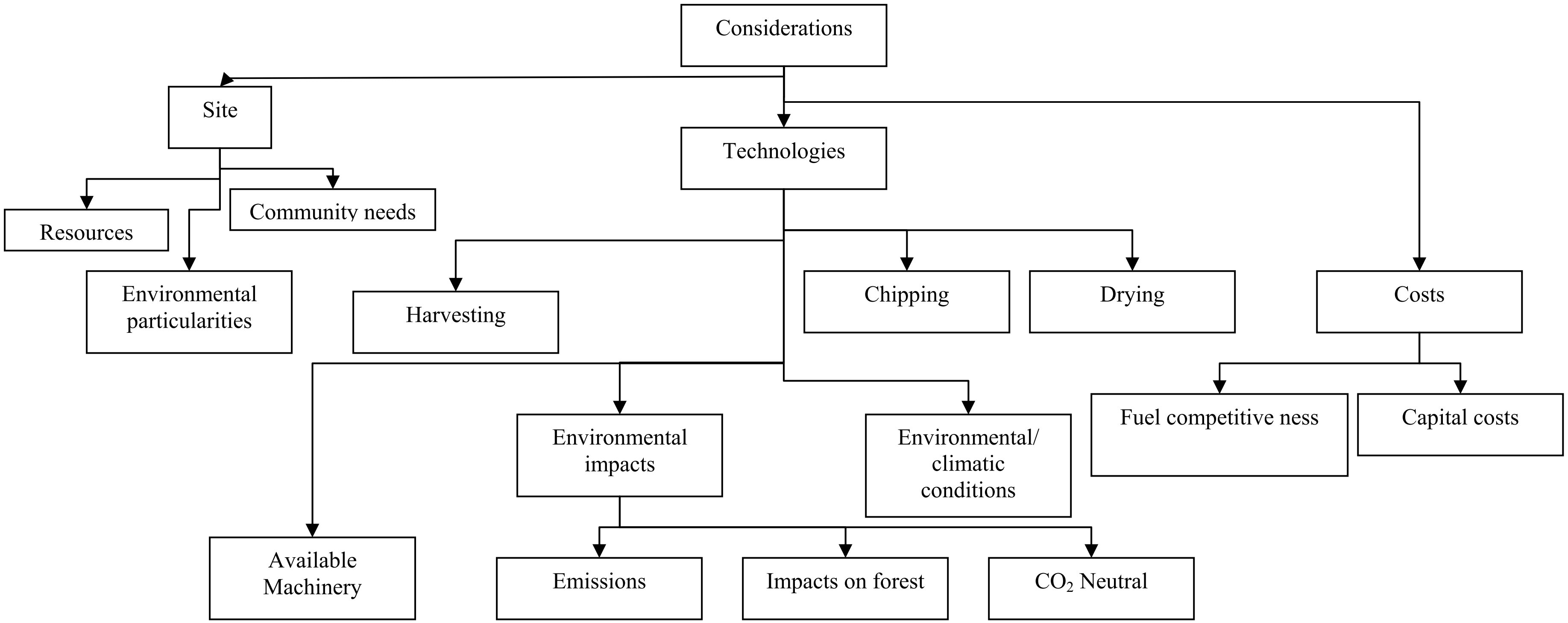
The effect on the communities and their economy was then assessed and the possibility of creating employment opportunities was also be carefully studied.

The environmental impact was also assessed based on the properties of wood, its energy value, and the emissions during its processing and after its complete combustion and the local forestry resource.

A summary of needed considerations for this type of project is shown in figure 3. Although some items need be considered for different topics (for example the costs of individual technologies) this has not been depicted in figure 3 for reasons of simplicity.

[7] North Highland Forest Trust

[8] Director of the Campbell Palmer Partnership LTD




**Flowchart 1: Methodology summary**

# 2. Wood as a fuel

The discovery of the uses of fire marked the beginning of Man's evolution. Thus, one could say that the first fuel ever used was *wood fuel*. Today there are many other uses for wood; some building materials, paper, furniture, railway ties, chemicals and so on are all made of wood and its by-products. Historically the use of wood fuel has never ceased but since the industrial revolution and with the decrease of traditional lifestyles that use wood for heat, it has declined as coal and oil have taken its place. Recent developments have once again warranted the use of wood heating.

## 2.1. Properties of wood

### *2.1.1. Chemical composition*

Wood, as is the case with most living matter, consists of a wide variety of substances. In its dry state, it is of the most value as a fuel. The constituents of dry wood are:

- Cellulose, roughly 50% by weight. Cellulose is a high molecular weight polymer, which, as the tree grows, becomes fibrils, which are then organised into wood fibres.
- Lignin, roughly 23-33% for softwoods and 16-25% for hardwoods. It is a macro-molecular constituent existing as an intercellular material.
- Extractives, depending on the species of wood extractives can range from 5-30%. Extractives determine the colour, odour taste, decay resistance, strength, density and flammability. They are also dependant on growth conditions i.e. climate and soil conditions as well as the season in which the tree is cut. They include:
    - Tannins, polyphenolics, oils, fats, resins, waxes, gums, starches, and metabolic intermediates.
- Ash forming minerals and other constituents make up for 0.1-3%. These include:
    - Silica, phosphate, potassium, calcium.

An observation to be made is that wood and bark contain no sulphur in comparison to fossil fuels like coal, therefore eliminating any problems from sulphur dioxide emissions. Furthermore, wood has a very low ash content compared to coal (with an average content of 5-25%).

### *2.1.2. Structure*

The tree consists of the *crown*, the *stem* and the *roots.* The Crown includes all leaves, twigs and branches. The Stem or trunk supports the crown, transfers water and nutrients and stores food. The Roots support the trunk and absorb water and nutrients. From the outside in the major components of the stem are listed below:

- Outer bark
- Inner bark
- Cambium: Lies dormant until spring and summer when the formation of new cells occurs
- Sapwood
- Annual rings: evidence of seasonal growth through the cambium
- Heartwood: is at the core of the stem and provides mechanical support

(See also figure 4)

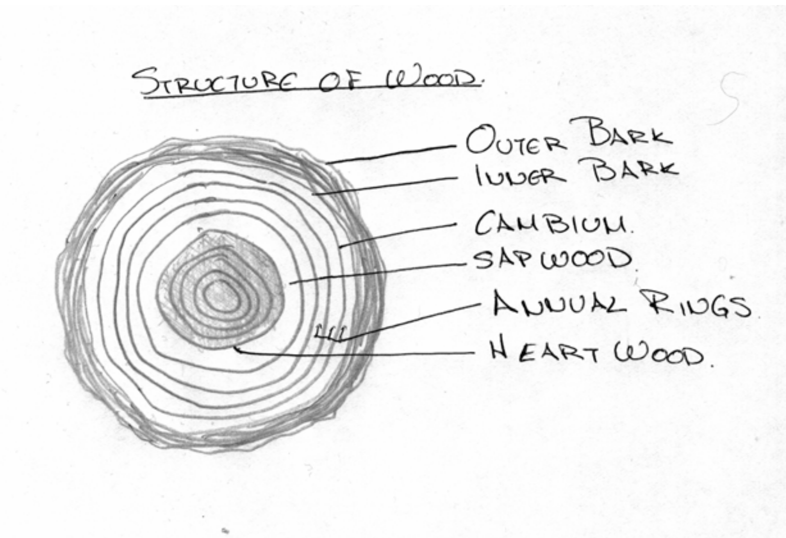



**Figure 3: Structure of Wood**

### *2.1.3. Species*

The two categories trees lie in are hardwood and softwood. The Caithness coast forests comprise of Lodgepole pine (*pinus contorta*), Sitka spruce (*picea sitchensis*) and Larch (*larix occidentalis*). All three species are softwoods (otherwise named conifers or evergreens) and they are commonly used for flooring, ceiling, shingles, cabinets etc.

### *2.1.4. Heating value*

The heating value of wood depends on the species, the amount of infiltration products in the wood and the amount of moisture present. In order for comparisons to be made the concept of oven dry (O.D.) wood is introduced whereby wood is considered O.D. when there is no presence of moisture. Corder[9] has found that different species of **oven-dried wood** have roughly the same average heating value of around:

19.26 GJ/tonne = 4458.3 kcal/kg = 5.35 MWh/tonne

But pine, spruce and larch have significantly high amounts of resin and consequently, have higher heating values compared to resin free species, as **resin** itself has a heating value of about:

39.54 GJ/tonne = 9444 kcal/kg = 10.98 MWh/tonne

Furthermore, bark has a higher heating value than wood and bark from softwoods has a higher heating value than bark from hardwoods. Therefore, for the three individual species mentioned the values of **oven-dried bark** are as follows:

| | |
|---|---|
| Lodgepole Pine: | 23.86 GJ/tonne = 5700 kcal/kg = 6.63 MWh/tonne |
| Sitka spruce: | 19.58 GJ/tonne = 4677 kcal/kg = 5.44 MWh/tonne |
| Larch: | 19.26 GJ/tonne = 4458 kcal/kg = 5.35 MWh/tonne |

### *2.1.5 Moisture content*

[9] Corder, S.E. 'wood and bark as fuel', 1973

Water in wood contributes nothing to its stored energy. On the contrary, it reduces the heating value as it adds to the wood's weight. Furthermore, combustion of the wood can only start taking place after the water contained within is evaporated.
Therefore, useful heat energy is lost as latent heat for the change of state of this water. Generally the higher the moisture content of the wood fuel the more heat is lost through the evaporation process. It is extremely unlikely though, for the wood used for combustion to be oven dried. The moisture content of fresh cut wood can be as high as 70% depending on the season it was cut, the species of wood and the age of the tree. Heartwood has generally lower moisture content than sapwood and the difference can be as high as 20%.Usually the wood fuel used in combustion has a moisture content between 25% and 10%. The average heating value of softwoods at 20% moisture is about:

$$\underline{15\ \text{GJ/tonne} = 3582\ \text{kcal/kg} = 4.17\ \text{MWh/tonne}}$$

The various drying processes with which this moisture content is achieved will be discussed in the following chapters.

## 2.2. Sources of wood

Wood fuel sources are many and varied; they can be however split into the following categories: mill residues, forestry residues, thinning operations, short rotation energy plantations and modified conventional forestry.

### *2.2.1. Mill residues*

Mill residues are the by-product of various processing operations accumulated at primary wood manufacturing plants. These include the Lumber, Plywood, Furniture industries etc. Less than a half of the timber processed into plywood or lumber becomes a finished product. Sawdust, woodchips and offcuts produced during these processes make very good woodfuel. Mill residues are the most readily available of the various source of waste wood. However, a portion of these residues is being used in the pulp industry or in MDF manufacture.

If the remains were to be used, an individual agreement should be made with specific sawmills in the area. Furthermore, most mills are already equipped with their own chippers so a chip size can be agreed along with the quantities available from the sawmill.

### *2.2.2. Forestry residues*

Forest residues include logging residues, intermediate cuttings, understory removal and annual mortality. Logging residues compile the amount of biomass that is usually left behind after commercial logging operations. These include branches, treetops, cull logs, standing live and dead trees, stumps and foliage. In some cases, these residues are left behind in the forest and in others; they are piled and burned on site.
Removal of such remains from the forest help to prevent against forest fires and increase the chances of survival for various plant species on the forest floor as more sunlight is allowed to reach them. The small and or inferior trees removed for stand improvement are referred to as intermediate cuttings. Whereby understory removal refers to the clearing of shrubs and trees that grow beneath the canopy of an older commercial forest.

In some cases, and where the ground is not suited to support heavy machinery, such as the harvester, the residues are used for *"brash mats"*. The term refers to the laying down of the residues on the forest ground in order to re-enforce the soil and provide a suitable support for the harvester. Lodgepole Pine in specific is quite brittle and during harvesting operations in forests with poor soils quality (like the North Sutherland forests) large amounts of branches and gnarled stems are needed for the harvester to manoeuvre efficiently. If the brash mats are not supportive enough harvesters and other machinery move much slower or even get stuck in the ground; this increases harvesting time, manpower is sometimes needed to free the machinery and the cost of harvesting inevitably increases.

### *2.2.3. Thinning operations*

Thinnings operations are undertaken in order to open the forest to sunlight and to promote regrowth. Thinning includes cutting trees and collecting the debris from the forest. The material is sometimes burned in piles or taken to landfill sites. The use of such material as woodfuel would both benefit the environment and make good use of otherwise valueless waste .The windy climate in the northern Sutherlands does not allow for thinning operations within the forests. This is because thinning creates openings for the wind to penetrate the forest. Moreover, it literally will create a hole in the forest which the wind will maker increasingly bigger. The intensity of the winds in the area can then blow a considerable portion of the trees over. This is known as *blow over.* These forests also provide natural wind breaks for the surrounding areas and so any openings for the wind to penetrate the forests will result in a change of climatic conditions for the area. In order to ensure the forests resistance to these winds the trees are harvested approximately every 30-50 years (maximum) as taller trees are also threatened by theses winds. Furthermore, there are access limitations on the North Sutherland sites and the thinning operations (even if blow over is not a factor) becomes increasingly economically unviable. If a market for the thinnings were to be created (through the increasing use of woodchip for example) and the environmental conditions allowed some sites might be thinned in future[10]. For the time being, the operation is not practised.

### *2.2.4. Short rotation energy plantations (SREP)*

These are plantations especially cultivated for use as biomass feedstock. The species selected should be fast growing, easily established, easily regenerated and they should be free from any major disease or pest problem. Some hardwood species such as the Eucalyptus have these properties. Softwoods are not the best suited for his type of plantation. Therefore, such a scheme is not adopted in the northern Sutherlands.

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[10] Referring to forests managed by Forest Enterprise in the North Sutherland area

*2.2.5. Modified Conventional Forestry*

This is based on integrated harvesting techniques developed in Sweden. It involves high-density plantation of softwoods. After a few years, the area is vigorously thinned thus, yielding an early harvest of woodfuel. Again, the windiness of the area does not allow for such operations.

## 2.3. Extraction techniques

In the cases the source of the woodfuel is the forest itself the techniques used to extract the wood have to be investigated. This is done so that all associated processes from forest to boiler can be assessed economically, environmentally and socially[11]. The following are the most common extraction techniques used in forestry today.

*2.3.1. Harvester*

The use of a harvester is the most common practice for extracting wood from a forest. It is used when the forest is on flat ground and all areas are easily accessible by forest roads. It is also the most expensive of the extraction techniques as the machinery is at the top of the range in foresting even if only two people are needed to carry out operations. The harvester cuts the trees and then strips the stem of any braches and thin tops it then loads it on to the back and moves on with the next tree. The branches and tops and any unsuitable round wood is used for brash mats. The harvester technique uses the least amount of manpower in forestry operations as only one person is needed to operate such a machine.

**Figure 4: The harvester**

[11] If the feedstock originates from milling operations extraction is not taken into account.

*2.3.2. Motor manual*

This technique involves the manual cutting and stripping of the trees by trained foresters. The final product is then bundled and loaded on to a forwarder or a skidder. The skidder has the timber tied in bundles and drags it as it moves forward.

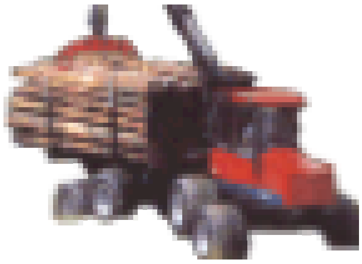


**Figure 5: The forwarder**

*2.3.3. Skyline*

Skylines are used in areas where the ground is unsuitable for machinery. In most cases, the ground is too inclined and machinery cannot get a grip or some times, it is weak to support the machinery even with brash mats. On one end of the forest, a tower is used (usually mounted on a tractor) with a main tower guy to side guys and a back and a front security guy (see figure 7). At the other end of the forest, a main support is mounted on a tree while intermediate supports are mounted on to various other trees mid way.

In conditions where there is not enough height, (i.e. the slope of the forest is not adequate) the other end of the skyline can be fixed to another tower mounted on a trailer, a tractor or even an excavator arm. The timber is harvested manually and put in bundles; these are then tied to the haul-in line. They are then hauled in to the main tower via the carriage. The skyline is moved as soon as an area has been harvested. The extracted trees do not touch the forest ground during this operation. This is an expensive technique as a lot of manpower is required both to set up the skyline and to harvest the timber. Furthermore, as the technique is used mostly in the special ground condition cases stated above, it is not as common as the harvester.

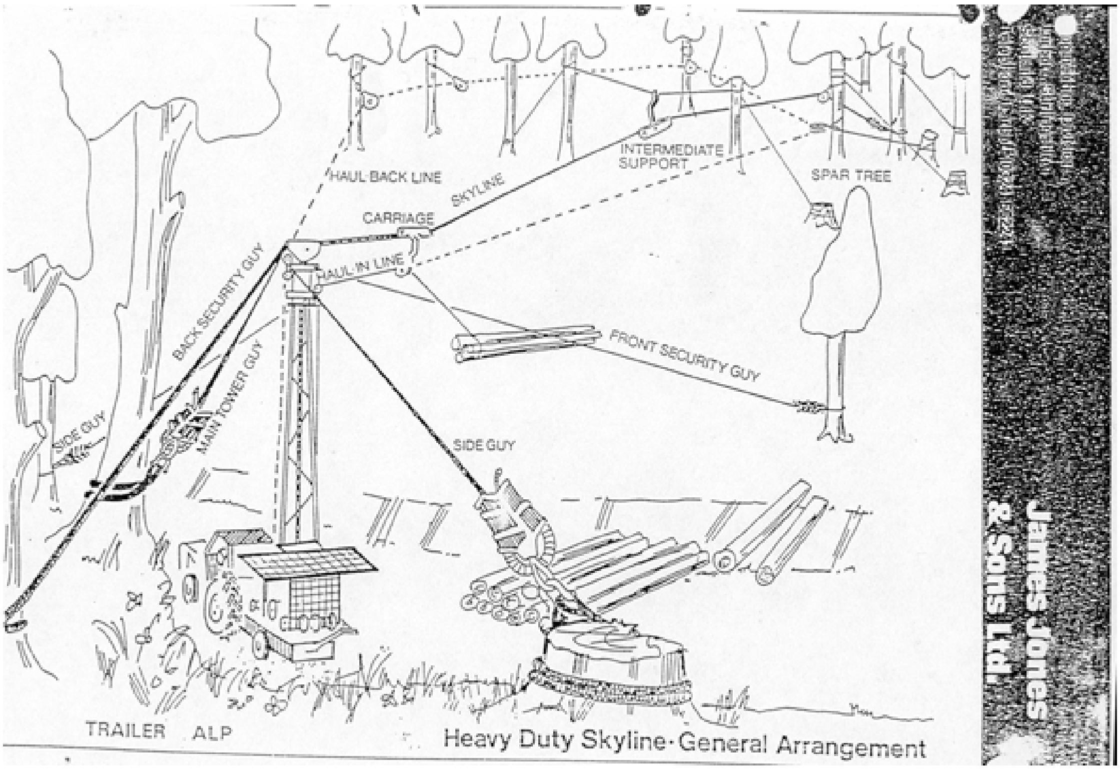


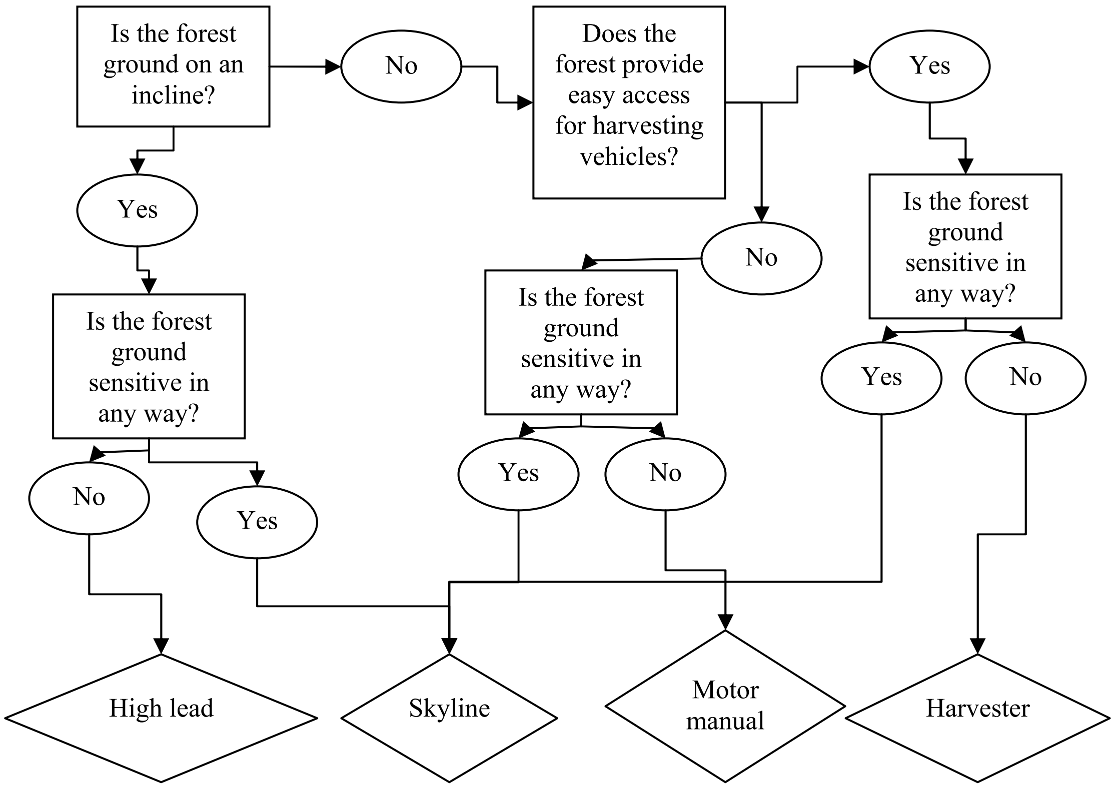

**Figure 6: Skyline arrangement**

### *2.3.4. High lead*

The high lead technique is very similar to the skyline. The difference in this case is that the setup is slightly simpler. In addition, the extracted trees are allowed to touch the forest ground and skid along it as they are being hauled toward the main tower. Again, this technique requires extra manpower compared with the use of a harvester. However, it cannot be used when the forest ground is sensitive as the skidding of the trees might damage it. Or when the trees themselves should not be damaged (for example during Christmas tree harvesting).

When none of the above techniques are viable for any number of reasons timber can be harvested manually and the end product extracted by helicopter off the forest floor. This is obviously a very expensive operation (£500/hr) and is used when the final yield of the timber is high.

Flowchart 2 summarises the harvesting techniques and indicates the main choices available when considering forest ground conditions.




**Flowchart 2: Harvesting techniques.**

## 2.4. Comminution/Chipping

Any flammable material burns more easily when its cut down to smaller pieces, the same goes for wood. Combustion efficiency improves when the wood is chipped as the smaller wood size allows for easier ignition and helps to completely burn of the material therefore, aiding the complete combustion process. Furthermore, drying becomes easier as a larger surface area is exposed to air and consequently, allowing for moisture to escape.

There are two types of chippers. Cone chippers (see figure 9) and disc or knife chippers (see figures 8 a and b ). Both types can be adjusted to produce various chip sizes.

In the case of the disc chipper the timber is fed into the back (as shown in figure 8a) it is chipped in the manner shown on the figure 8b. The woodchips are then blown out of the shoot on top of the machine. The shoot can be directed to blow the chips into the back of a lorry or a hopper or a bag for storing or transporting. The operation ensures that the chips are of uniform size as the entrance angle in relation to the fibre direction is the same irrespective of the thickness of the tree. In the case of the cone chipper the chips produced are not as uniform as the angle of entry depends on the thickness of the tree (see figure 9).

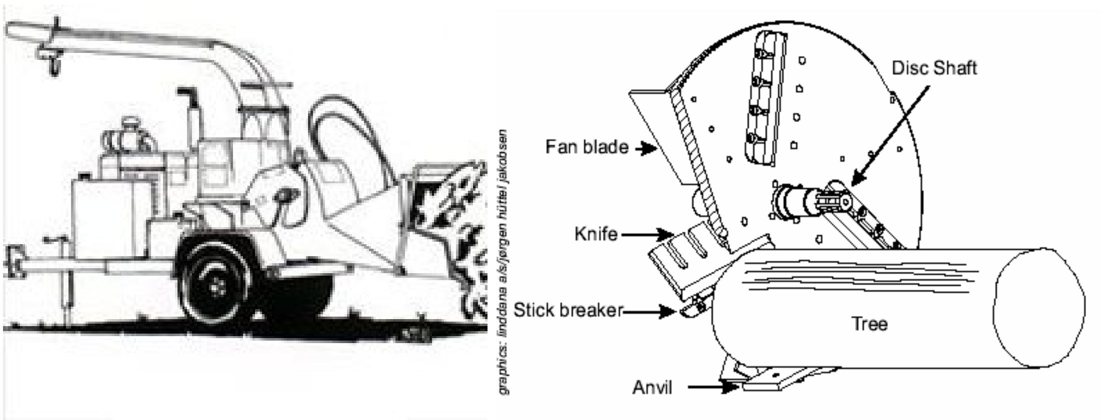



**Figure 7: a. The disc/knife chipper and b. its operation principle**[12]

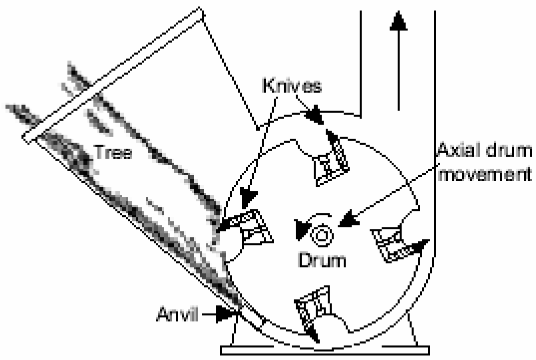


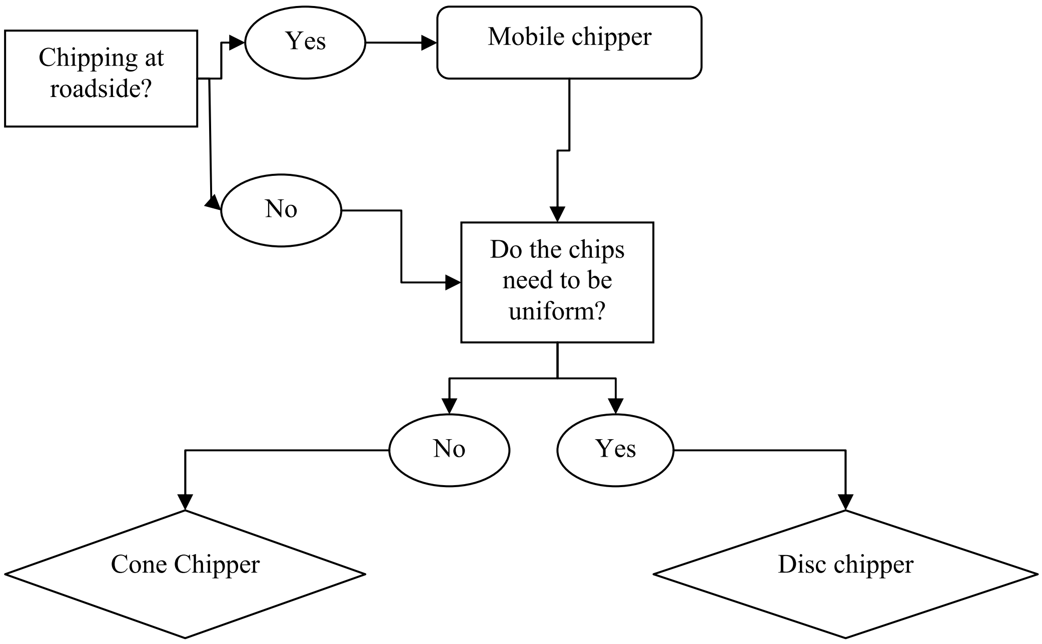

**Figure 8: Operation principles of a drum/cone chipper**

Most chippers can be mounted onto the back of a tractor and some are self-driven (usually the very large whole tree chippers).

[12] http://www.videncenter.dk/uk/index.htm

Furthermore, most chippers run on diesel and should always be operated by trained personnel. Saw mills usually have a chipper on site and forestry contractors usually rent large whole tree chippers to use at the forest roadside depending on the individual needs of the contract.

Flowchart 3 indicates the decision making process followed to chose a chipper type for this project.



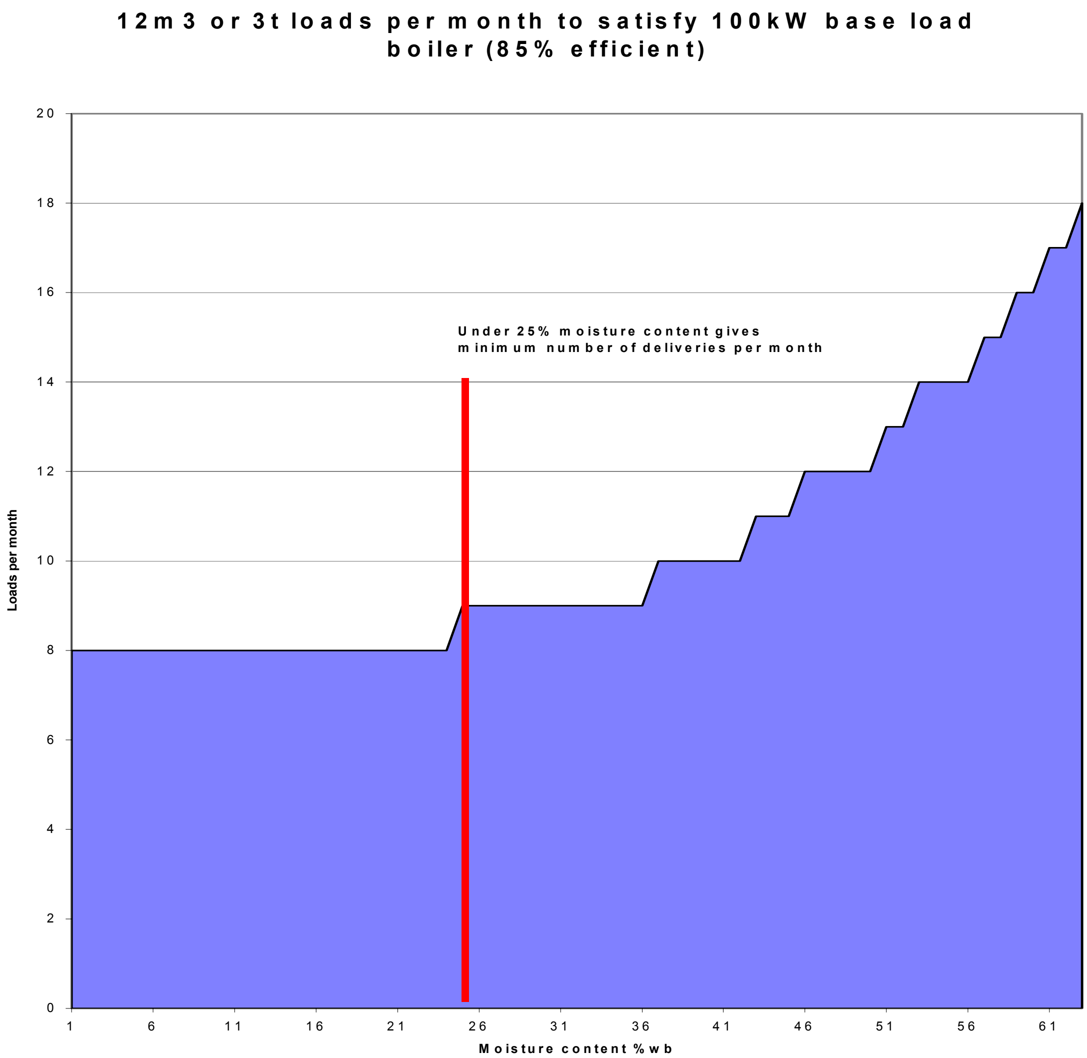

**Flowchart 3: Chipping techniques**

## 2.5. Drying

Harvested timber usually contains about 60% - 50% moisture depending on the age of the tree and the season it has been harvested in. Different end uses require different moisture contents, for combustion, the wood should have around 10 to 15 percent moisture content.

Wood should be dried mainly to improve combustion efficiency. Although wet woodchips can be burnt in boilers a large portion of the energy lost to dry the excess moisture in woodchips before it starts heating the water.

This means that more fuel is needed to produce the required boiler output (see graph 1). Furthermore, wet or damp woodchips are very likely to go out if enough heat is not produced to evaporate the water, they are also more likely to cause a jam in the feed mechanism of the boiler system.




**Graph 1: Effect of moisture content on boiler loads needed.[13]**

[13] Gavin Gulliver Goodall, 3G Energi, Heating up on wood 2, Kinlochleven, May 2002

Timber should be dried for various other reasons as well, these include, transportation, storage and combustion becomes easier. In specific, transporting wet timber essentially is transporting water. The more dry the timber, the smaller the vehicle needed to transport the less, the transport costs. Furthermore, the energy content of wet timber is less then that of dry timber. In addition, wet chips decompose and turn to compost. It is a health danger to handle (due to the spores within the decomposed chips) and combustion produces particulates harmful to the environment and man.

The following chapter will look at the various timber and woodchip drying mechanisms available in an attempt to identify the most effective technique to be used for drying taking into consideration the particularities in circumstance in North Sutherland.

# 3. Drying

In order to choose the most suitable drying technique to be used in North Sutherland for a very small woodchip market (initially), the equipment, drying times and initial capitals needed for the various techniques will now be investigated.

## 3.1. Drying Techniques

There are two main categories of drying that are not mutually exclusive. Natural drying and Forced drying. Natural drying (roadside and open air) allows for the timber to dry slowly and naturally influenced by the surrounding environmental conditions. Forced drying involves the heating, drying and/or circulating of the air throughout the timber to speed up and better control the drying process.

### *3.1.1. Roadside drying*

Harvested timber is usually left at the roadside for some time before it is collected and delivered to a processing area (this might be a sawmill or a storage area etc.). As it is left at the forest roadside the moisture, content drops by about 10 to 15 percent depending on the climatic conditions and the amount of time it stays there. Usually there is need for more drying, therefore one or a combination of the following techniques is used.

### *3.1.2. Open air*

If time is not an object, timber can be further dried in the open air under some sort of cover to protect it from wet weather. This reduces the moisture content to about 20% after 1 to 12 months depending in the climatic conditions (in hot dry conditions the process is much faster than it is in wet and cold conditions). The timber is placed in bales and is more or less tightly packed together this reduces the amount of air circulating through the individual logs; the end result is for the top logs to have lower moisture contents than the bottom logs. Thus, the technique can be further improved if the timber is stacked so that air can circulate within the logs.

This will reduce the drying time (the improvement in time again depends on the sites' individual climatic conditions) and the moisture content will be more uniformly distributed.

### *3.1.3. Air blast*

To reduce drying time with low cost, wood can be dried in sheds. The timber is stored in a grid allowing air to circulate through out. A fan is used to blast air through the grid and remove the excess moisture. The moisture content can reduce to about 15 - 20% from the initial 50 – 60%. The time it takes varies greatly from months to days depending on the amount of timber stored the air velocity and the climatic conditions on site. In addition, if the timber is in woodchip form drying time can be further reduced. But on the whole the process is quite quicker than the open air-drying and the cost is relatively low as the only mechanical help is from a simple fan that can run on mains electricity or even solar power.

### *3.1.4. Hot air blast*

Finally, timber can be dried using hot air. Depending on the temperature of the air that is being circulate in the wood, the climatic conditions and the form the wood is in; the drying can take from hours to days and the final moisture content can be as low as 10%. The operating costs are a bit higher than during simple air blast drying, as a heater needs to be in place to heat he air. The cost of the operation also depends on the air temperature needed. It should be noted that the fan will be running for less and so a combination of air temperature and drying time can be found so that the costs are similar. Kiln drying and HTD are also types of air hot air blasting.

#### 3.1.4.1. Kiln Drying

For large operations usually involving timber for industrial use (furniture manufacturing, building materials etc.) kilns are used for drying. The process takes place in a closed chamber and is quite rapid.

Kiln drying is highly controlled, as timber tends to shrink, break and lose its structural integrity if it is dried in the wrong manner. Temperature can be controlled and increased to the maximum tolerance levels for each wood species. Air speeds can also be controlled in the same manner. Furthermore, there the timber's moisture contents can be closely monitored throughout the process. All in all kiln drying is the most efficient technique but it is also one of the most expensive and is mostly used when the degradation of the wood is an issue. As the woodchips are going to be used for combustion any type of degradation due to drying does not have to be taken into account and so the control provided by kiln drying is not really needed.

#### 3.1.4.2. High temperature drying (HTD)

This is a fairly new technique compared to conventional kiln drying, a kiln is still used to dry timber but the air temperatures are for most of the process above 100 ˚C. The process is even more controlled as the drying times are significantly shorter and uniformity of air temperature, humidity and speed within the kiln are essential. The drying is usually completed in sessions. Typically there is a warming up session (starting from 20 and going to 100˚C), a first drying phase (at 100 ˚C and above), a second drying phase (again at 100˚C and above but slightly lower than the first phase), a cooling down session (at around 60˚C) and a conditioning session at around (75˚C). This is the most expensive technique, but also the most efficient as all available energy is used to dry the wood in the least amount of time with the least amount of losses. Of all the processes involved in preparing small round wood for use as fuel in woodchip-fired boilers, drying is the most diversified one.

#### 3.1.4.3. Solar drying

Solar drying utilises solar energy to heat air much like a greenhouse does. With ample ventilation and sunlight timber drying can be completed in days. The drawback to this technique is that in Scotland drying is only viable during spring and summer; during which there is enough sun. On the other hand, solar drying does allow for considerable control depending on whether or not fans and various measuring devises are installed. Figure 10 indicates one of the possible layouts for a solar dryer.

It also depicts other possible uses for it such as food drying. (quite similar to timber drying as they are both organic and contain larger amounts of water).

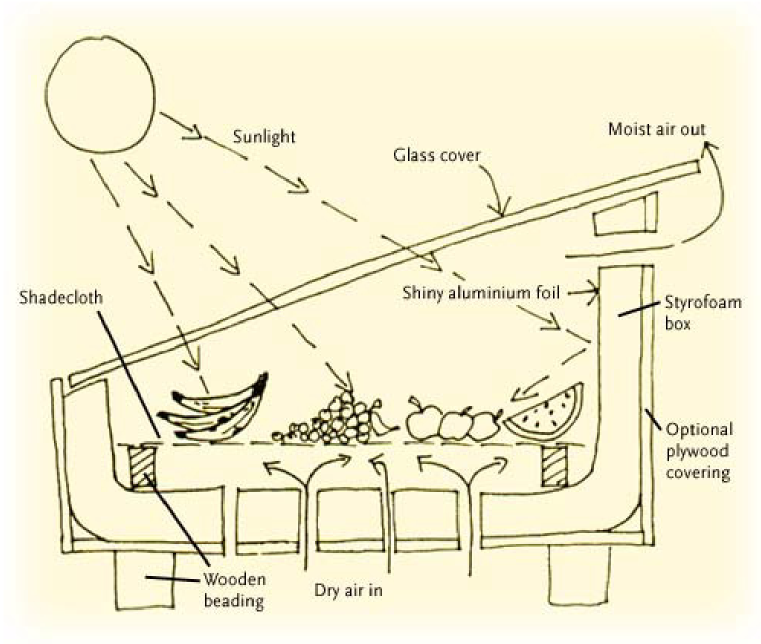



**Figure 9: Simple solar dryer with alternative uses[14]**

## 3.2. Factors affecting drying times and efficiency

As the timber to be dried is chipped and to be used for fuel, the structural integrity of the material is of no importance. Therefore, any effects due to internal stressing like shrinkage or splitting are not taken into account. This gives the advantage of not needing any great degree of control over temperature, relative humidity of air velocity of the hot air used for drying. This being the case the following factors affecting drying times and drying uniformity have to be taken into account.

### *3.2.1. Chip Size*

Chips come in different sizes, if they are to be combusted the chips have to be between 4mm to 1cm thick. The length is also important in combustion for if it is too thick or too long complete combustion might not be achieved.

[14] Australian Greenhouse Office.

In terms of drying though, the length of the chip is not as important (furthermore, a 1cm thick chips tend to come out of the chippers quite short as well). So if the chips are thin enough they should dry uniformly otherwise the surface of the woodchip would seem dry while its centre will have remained wet, consequently more drying will be needed and combustion efficiency will reduce, as more heat will be needed to evaporate the excess water.

### *3.2.2. Woodchip layout*

Any techniques adopted for drying will require the woodchips to be laid out in a certain manner. If only to avoid decomposition, woodchips should not be stored in big piles until they are sufficiently dried. If this is not possible (due maybe to lack of installations) and woodchips *are* going to be piled, someone will be needed to turn the woodchips periodically to ensure uniform drying. Otherwise, woodchips can be spaced so that air can circulate within a specific lot. As with timber drying for furniture manufacturing, or building materials. This can be achieved by placing them on horizontal grates (small enough for the chips not to fall through and big enough to allow air to circulate).

If this is the case, the thickness of the woodchip layers also needs to be considered. If the layer is too thin, too many grates and levels will be needed and even though the drying time will be considerably lower, the installations will have to be very large if a considerable amount of woodchips is to be dried all at once. If the layer is too thick, the installations needed might be smaller but the drying times are going to be long and there still will be a risk of decomposition in the layer's centre. A maximum thickness would be 1m and a minimum would be around 10 to 20cm.

### *3.2.3. Moisture content*

Moisture is "trapped" within wood in the three forms[15] stated below in order of content:

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[15] "Heat and Mass transfer in the drying of wood". M.E. de Paiva Souza and S.A. Nebra

- Water vapour, which migrates through diffusion due to the partial pressure gradients within wood.
- Free water, which migrates through capillary motion (subject to Darcy's Law). It is present in the cell cavities of wood.
- Bound water: which starts evaporating only after all the free water has dried off and migrates through chemical potential gradients between phases and is usually only around 10% to 15% of the total moisture content and can be considered as part of the solid phase without a large margin for error. Furthermore, bound water is the most difficult to evaporate and unless a kiln is used to "oven dry" the wood it stays within the material as it is closely bound to the cell wall constituents of wood.

The initial moisture content, as stated previously, depends on the time of harvesting and the age of the tree, it is safe to assume though, that the moisture content of the softwood coming out of the North Sutherland forests is around 50% to 65%[16]. If bound water only takes up to around 1/10$^{th}$ of the overall moisture and since reducing the initial moisture content to 10% is acceptable; only free water and water vapour have to be considered. In which case the drying process itself becomes simpler to represent mathematically and as there is no need to change the chemical state of the bound water less heat is required than that needed to "oven dry" the wood. It should be noted here that it becomes increasingly difficult for moisture to evaporate as the content decreases during the process.

This is due to the fact that the moisture initially evaporates from the outer surface of the woodchip and the deeper it is the harder it is to migrate to the surface. This could be considered a problem for large pieces of wood but since the woodchips are quite small, this effect can be considered negligible.

[16] Wood, in ECT 1$^{st}$ ed. Vol. 15, pp72 – 102, US. Department of Agriculture

### *3.2.4. Vapour pressure, relative humidity and temperature*

Regardless of the wood's initial moisture content the process of drying is much like the process that takes place when two bodies of different temperature are placed next to each other. The moisture trapped within the wood evaporates (in the form of vapour) into the air immediately surrounding it, this process will continue until the surrounding air takes up as much moisture as possible. In that instant the surrounding air's relative humidity is 100% and the pressure is at what is called saturation vapour pressure (the air is saturated with vapour). Thus, the relative humidity and pressure of the air immediately surrounding the wood is an important factor affecting drying rates. As the higher the relative humidity, the less amount of moisture escaping from the wood is absorbed by this air. The Scottish climate is quite humid; this humidity obviously increases drying time especially when drying in open air as the relative humidity increases. It is worth noting though, that the higher the temperature of the air the higher the saturation vapour pressure. (see figure 11). Therefore, by heating the air used for drying as the vapour pressure difference between the air surrounding the wood and the environment increases and so evaporation takes place more readily and otherwise extended drying times are reduced.

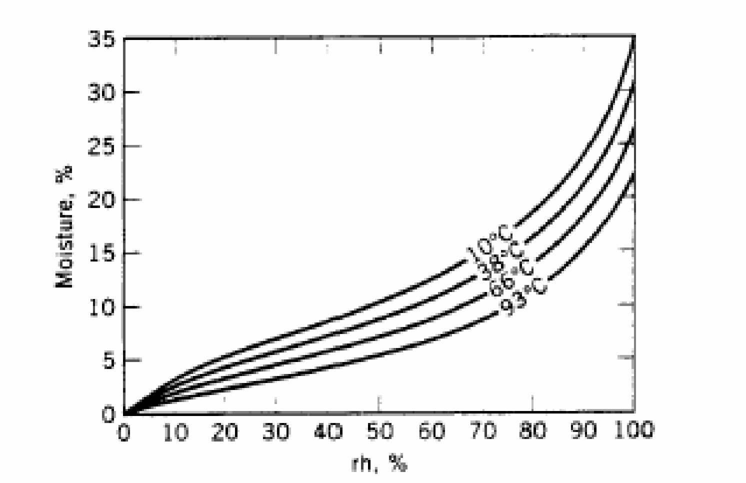



**Figure 10: Relationship between moisture content of wood and relative humidity[17]**

[17] Wood, in ECT 2nd ed. Vol. 25, pp633, US. Department of Agriculture

### *3.2.5. Air movement*

As the affected air directly surrounds the woodchips, it falls to reason that it will need to be circulated and renewed often. Moreover, the overall humidity in the drying area increases as water evaporates. Good ventilation should be provided so as not to impede the process any further. So, in order to ensure uniform and fast drying air should be ventilated through the woodchips. Open air drying is an option but a very slow and inefficient one as the air surrounding the wood remains mostly stagnant. Furthermore, the longer the drying time the more prone to decomposition the chips are. A fan can be used (even if the air is not preheated) to circulate the air and ventilate the overall area and help to speed up the process. The air flow itself should be turbulent as it has been proven to better for this type of circulation rather than laminar flow. As woodchips are quite splintery, this will not be a problem if the air is circulated at speed. This speed though, should be taken into account, as if it is too high it will blow the woodchips off the racks or whatever dividing structures are used to separate them. If a fan is not used and the chips are left to dry in the open air they have to be turned often (even if they are placed in layers) to allow for the stagnant saturated air to escape and be replaced. Furthermore, the drying process will take much longer. If a fan is used drying can take place in a matter of hours whereby if it is not it could be a matter of days with the possibility of decomposition remaining.

## 3.3. Drying times

Bearing in mind the parameters affecting drying times: woodchip size and layout, initial moisture content, vapour pressure and relative humidity and air movement; it is difficult to accurately predict each different drying process takes to dry timber. The aforementioned factors interact with each other during drying changing as time goes by. In the best of cases, kiln drying for example where all measuring devices are available, drying schedule prediction is usually done by computer programs. For the purpose of this thesis and to allow for choice of technique the following can be surmised for 1 tonne of material.

### *3.3.1 Road side drying*

Logs could be left by the forest roadside to dry for a period of several days before collection, thus reducing their weight and initial moisture content. (An amount of moisture will have evaporated from the logs, consequently making them lighter and reducing transport costs). The minimum moisture content that can be achieved through roadside drying of timber is around 20% for softwood. It takes around 40 – 150 days for this to be achieved and it greatly depends on the weather conditions during that period. If however the weather conditions are severely damp (as is usually the case during autumn, winter and the beginning of spring), the possibility of decomposition and mould growth is quite high. Therefore, care should be taken to monitor the condition of the timber. It is better to transport water than to lose a considerable amount of wood to mould.

### *3.3.2. Open air drying*

After transportation from the forest, the timber should be chipped and prepared for drying. If the processing area is sheltered from rain, snow etc. then the chips could be further left to dry for a small period of time. This will further reduce their moisture content. Again, the minimum that can be achieved is 20%. If the timber has been left at roadside, the combined period to leave logs and chips should no exceed 150 days. Furthermore, in chip form wood decomposes quicker than in log form so it should be turned regularly during this period.

### *3.3.3. Air blast*

The chips should now be laid out on grated surfaces to allow for air to circulate throughout their volume. As the air surrounding the chips will be constantly renewed, thus reducing its relative humidity, the moisture content of the chips will decrease at a considerably faster pace. It depending on the environmental conditions again the moisture content of the chips could decrease to as low as 15% in a matter of days, namely from 6 to 20 days depending on it's initial moisture content, the thickness of the layers and so on. As a fan has to be used for this type of an operation, its energy consumption would be around 90kWh[18] per dried tonne.

### *3.3.4. Hot air blast*

Using the same basic configuration for woodchip layering as for the air blast but using hot air rather than ambient air the hot air blast technique takes considerably less time to dry the chips. For air temperatures between 70˚C and 150˚C the drying times could be reduced to a matter of hours. Furthermore, the final moisture content can become as low as 10% in a matter of 10 hours[19]. The energy consumption for this type of operation is significantly higher than for the ambient air blast and can be as high as 450kWh per dry tonne, but the source of this energy can easily be previously dried wood and so the cost will still be quite low.

### *3.3.5. Kiln drying and HTD*

These drying techniques allow for a very high control over the drying conditions within the drying chambers. All the aforementioned factors affecting drying times can be closely monitored and adjusted to reduce drying times to a matter of 2 to 3 hours. But these techniques are used for very large amounts of material and very rarely used for woodchips. They very expensive and the energy needed for the drying comes primarily from fossil fuels (kilns emit greenhouse gases, if the woodchips are dried in kilns they are no longer $CO_2$ neutral and, thus not considered a renewable source of energy).

[18] see bibliography reference 12, pp148

[19] 3G Energi, Gavin Gulliver Goodall, 3rd July 2002

### *3.3.6. Solar drying*

Again the woodchips should be laid out in a manner that allows for air to circulate throughout their volume. Air in the solar dryers circulates either because of temperature differences (figure 10) or due to fan operations (figure 12).

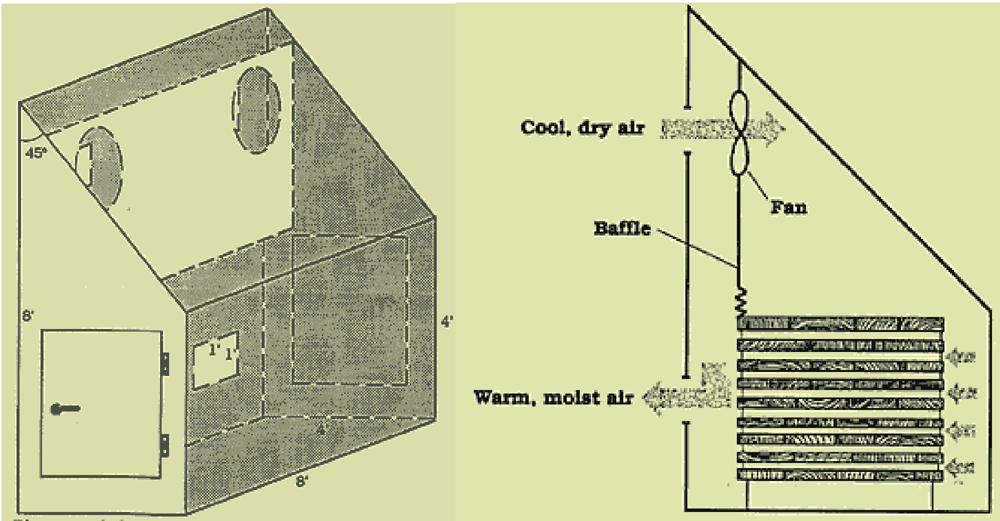



**Figure 11: Solar kiln design**[20]

Drying times depend on ambient air temperature and solar radiation levels. In summer drying can take place in as little as 2 to 3 days. The moisture content can become as low as 10%. Further control can be added by installing a hygrometer and measuring the air moisture content. Solar kilns cannot be used with any success during the winter in the North Highlands as there is not enough sunlight during the short days. But the design is versatile and a heater can be installed to act warm the air during those periods of low to zero solar radiation. Such installations though will emit greenhouse gasses due to their operations and so negate the environmentally friendly and renewably powered characteristics of the solar dryer.

[20] Processing Trees to Lumber for the Hobbyist and Small Business, by Eugene M. Wengert and Dan A. Meyer, Oregon State University

### 3.4. Installations needed, energy sources and emissions

In order for woodfuel to be truly $CO_2$ emissions neutral, the emissions during processing need to be considered. Emission levels from harvesting and chipping cannot be avoided as the techniques used do not vary according to their energy source. Drying on the other hand, can be undertaken with many techniques whose energy sources vary. Table 1 indicates the installations needed to dry woodchips depending on the technique adopted, the energy source needed to accomplish this and the emission levels of the fuels.

| Technique | Installations | Energy source | Emissions (per tonne of dried woodchips) |
|---|---|---|---|
| **Roadside** | - None | -Environment | **None** |
| **Open air** | - Shelter from rain etc.<br>- Packing area | -Environment | **None** |
| **Air blast** | - Shed or other enclosure<br>- Fan<br>- Grated levels/ Drying bay<br>- Sheltered storage area and/or packing area | -Electricity for fan | Small amount[21]<br>**125 – 413 kg of $CO_2$** |
| **Hot air blast** | - Enclosure<br>- Fan<br>- Burner<br>- Grated levels / Drying bay<br>- Sheltered storage and/or packing area | -Electricity for fan<br>-Electricity, oil, or wood for burner | Can be considerably small if wood is used for the burner<br>**18 – 450 kg of $CO_2$** |
| **Kiln type drying** | - Kiln | -Electricity and/or<br>-Oil or gas | Large[22]<br>**Over 5000 kg of $CO_2$** |
| **Solar Dying** | - Enclosure + black paint<br>- Glass façade (south facing)<br>- Grated levels/Drying bay<br>- Fans optional | -Sun<br>-Electricity for fans (optional) | - **None** (no fans)<br>- Small[19] (with fans)<br>**120 – 310 kg of $CO_2$** |

**Table 1: Drying technique comparison based on installations needed and emissions**

[21] Emissions from power station due to electricity consumption about 0.43 kg/kWh

[22] Oil (0.27 kg/kWh) or gas (0.19 kg/kWh) has to be used in most cases, and when only electricity is used again the emissions are quite larger than other techniques as much more energy is required

It is obvious that if solar drying is to be used as a technique it is preferable for there not to be any electricity used so that the process remains as low cost as possible and environmentally friendly.

### 3.5. Costs

Again in calculating costs a major variable is drying as the technique used is not site specific (as harvesting techniques are). Drying costs depend on the installations and equipment needed, the man power required and the energy consumption. Table 2 compares drying techniques based on the cost and drying times.

| Technique | Installation costs[23] | Running costs per dry tonne | Drying times |
|---|---|---|---|
| **Roadside** | None | **None** | **40 to 150 days** |
| **Open air** | Cost of shelter - £1,000 max | **None** | **40 to 150 days** |
| **Air blast** | Cost of equipment and installations stated in table 1 - £25,000 max + cost of enclosure acquisition[24] | Around **£5.40** | **6 to 20 days** |
| **Hot air blast** | Up to 30,000 ready made dryer is acquired | - **£7** + cost of wood* <br> - Around **£23** if oil or gas are used for burner | **Up to 10 hours** |
| **Kiln type drying** | Over £50,000 | Over **£25** per dry tonne | **3 to 5 hours** |
| **Solar Drying** | Cost of equipment and installations indicated in table 1 - £2,000 max. + cost of enclosure | - none (without fans) <br> - Around **£7** (with fans) | **6 to 15 days** |

**Table 2: Drying technique comparison based on costs and drying times**

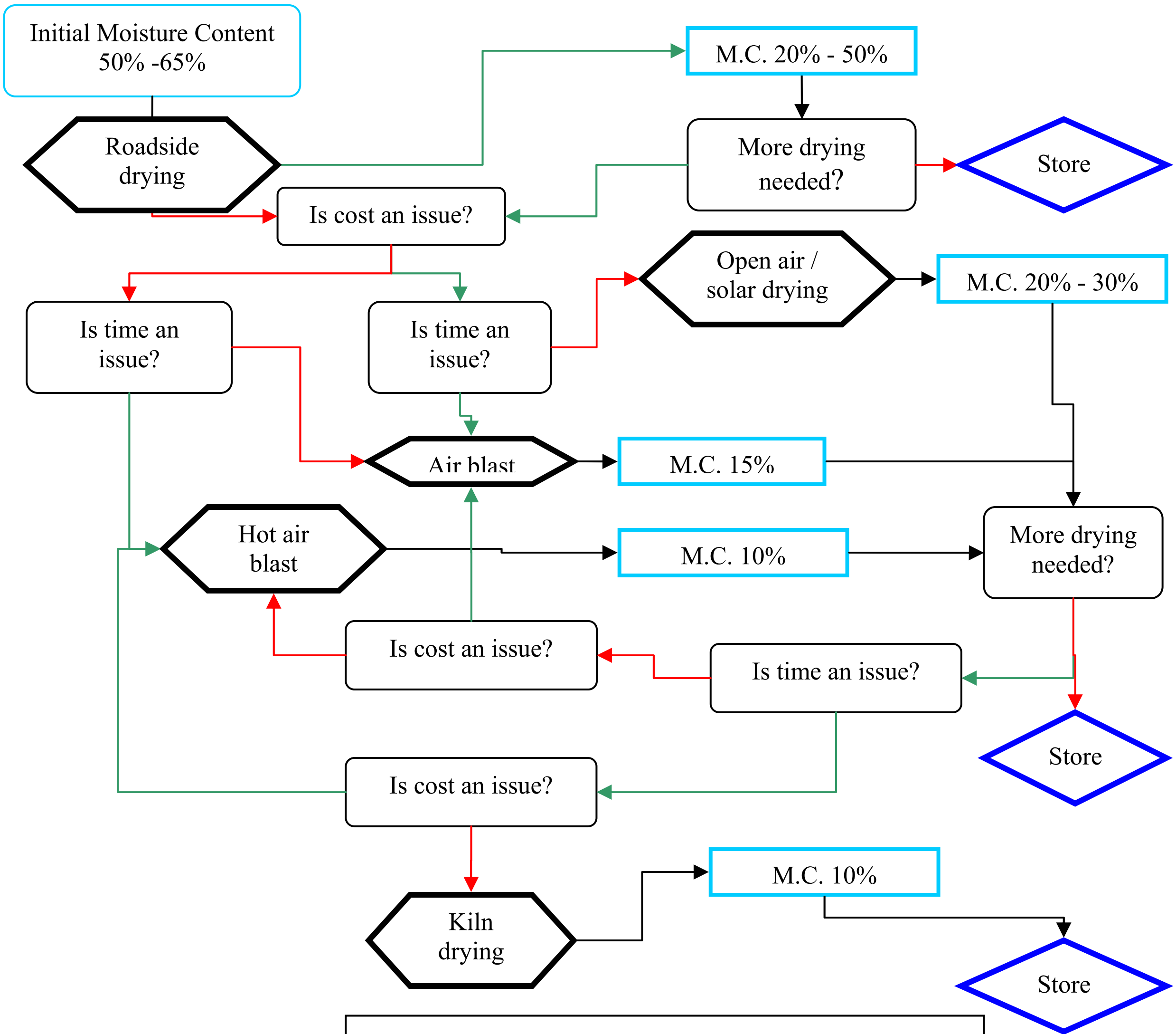
[23] Cost information was acquired through interviews of the various industry representatives at North Sutherland and Conference unless otherwise stated

[24] 3G Energi, Gavin Gulliver Goodall, 3rd July 2002

* if a portion of the woodchips themselves are used to fuel the burner, then this costs is next to nothing, as their use can be reflected on the end user price.

### 3.6. Drying technique proposal

Flowchart 4 will help to choose a drying technique to suit the amount of capital available, the required moisture content (minimum of 10%) and the drying time needs. As solar drying has roughly the same installation and cost requirements as open air drying (solar kiln without fans) or air blast drying (solar kilns with fans) it has been incorporated into these two rather than be denoted separately).




**Flowchart 4: Drying technique for cold climates with low solar radiation**

Key: A green line denotes "Yes", and a red line denotes "No". Light blue boxes denote moisture content. Bold black boxes denote **drying techniques**

# 4. Process costs

## 4.1. The cost calculator

A CD produced by the North Highland Forest Trust and The Campbell Palmer Partnership Ltd. incorporates the Woodchip Fuel Cost Calculator[25]. This program enables end users to calculate and compare the cost of wood fuel with the other conventional fuels available for heating. The calculations are based on the input values entered by the user. If certain values are not known, the default parameters in the program would suffice and produce good ballpark figures. The parameters the user has to input into the programme are as follows:

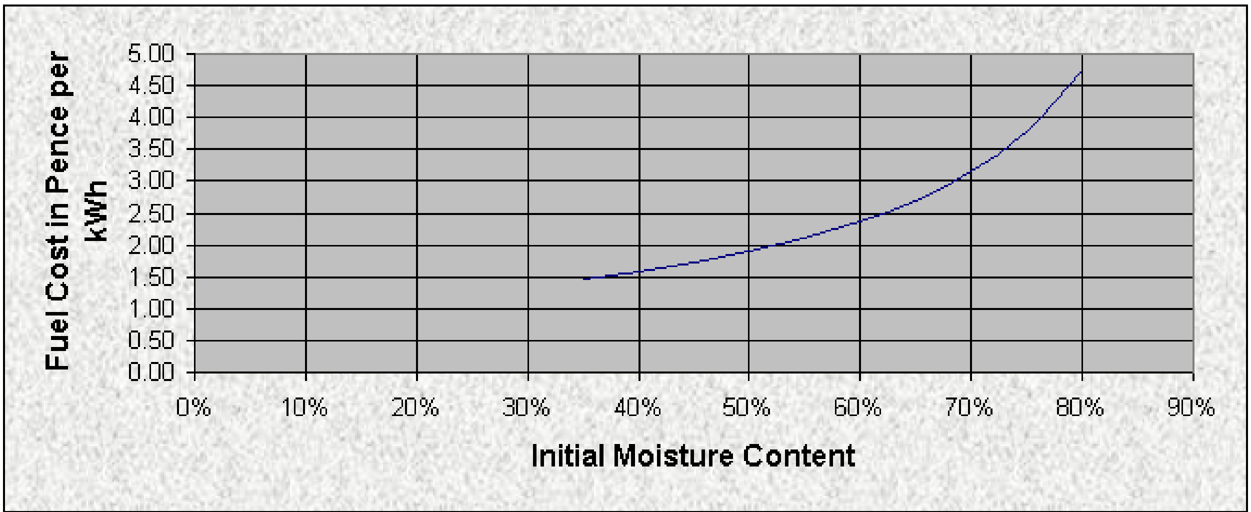
- Acquisition:
    - Bought standing plus
        - Extraction costs to roadside
    - Bought at roadside
- Chipping cost
- Drying cost
- Total transported distance
- Transport cost
- Target moisture content when "dry"

The end result is a graph indicating different prices for different initial moisture contents ranging from 35% to 80%. An indicative calculation was made so that general ball park figures can be obtained; table 4 contains the parameters used. Graph 5 shows the program's output; it indicates the cost range of the woodchip fuel depending on the timber's initial moisture content.

[25] © CPp Ltd. 2002

| **Parameter** | **Price** |
|---|---|
| Bought standing | 2 (£ per tonne) |
| Extraction | 14 (£ per tonne) |
| Chipping | 6 (£ per tonne) |
| Drying | 7 (£ per tonne) |
| Transported distance | 50 (miles) |
| Transport price | 0.2 per tonne per mile |
| Target moisture content | 15 % |

**Table 3: Input parameters into the Cost calculator**




**Graph 2: Woodchip end user fuel cost calculated by "Woodchip Fuel Cost Calculator"**

## 4.2 Additions needed

The cost calculator used above allows for some flexibility but the input parameters are not extensive enough to cover site specific situations. Taking the calculator as a point of reference for the type of output values required some additions have been made and new cost calculations undertaken.

The additions have to do with the

- added expenses of the manual labour needed for deliveries and processing
- delivery transport costs (different from timber transport costs as during delivery, woodchips are dryer, therefore lighter and transportation is less expensive
- differences in cost due to different drying techniques.

The differences in price depending on acquisition type were large (graphs 2 and 4) and so all results are shown together for comparison purposes. The cost calculator did not provide this facility and so the results obtained from the additional cost calculations have been displayed in graphs with drying technique and acquisition types depicted.

## 4.3. Further cost calculations

In order to verify the economic viability of using woodchips for fuel the costs involved were studied.

### *4.3.1. Acquisition*

If the timber is bought standing (i.e. the owner of the afforested land (private or the forestry commission) the cost of acquisition (usually during bidding) depends on quality (species, age of trees, straightness of stems etc.), size and ease of extraction (accessibility, distance from forest road and so on) the timber. Furthermore, the transport costs after extraction also play a part in forming the price of the standing lot up for bids. All in all, it is quite difficult to quote a specific price; a rough ballpark figure though would be around:

- £2 per tonne.

In some cases, the timber might be bought at roadside from any contractors working on the local forests. If this is the case, the timber would cost about:

- £18 per tonne.

### *4.3.2. Harvesting and extraction*

The costs involved in harvesting and extraction vary slightly depending on the acquisition price, the ease with which they are extracted and the extraction technique used. For example, it is obvious that a two-man operation will costs less than a ten-man operation. On the other hand, if the equipment used are to be taken into account then it becomes difficult to ascertain which is more cost effective. In North Sutherland (as is the case for small rural communities), there are skilled foresters but there is a definite lack of machinery such as harvesters.

Anyone wanting to carry out timber extraction operations need to use motor manual techniques such as the forwarder or skidder, skyline or highlead. If a harvester is to be used than the capital costs and pay back periods have to be taken into account, will it be a new machine or a used one, will there be some sort of subsidy for the acquisition of it, these questions have to answered before a final price for extraction is to be estimated. Through interviews with the forestry commission and local foresters, it has been ascertained that as a general rule of thumb extraction costs in North Sutherland are round about:

- £13 to £14 per tonne for poor quality 7-14cm timber and £
- 6 to £7 per tonne of good quality roundwood (14cm and above).

The difference in cost between small roundwood and larger roundwood has to do with the shape of the timber and the amount of motions needed by a harvester (most widely used technique) to harvest equal weights of both types. I.e. the harvester needs to make more motions and trips to the forest road in order to harvest 1 tonne of small roundwood as more stems need to be striped of their branches and stored than 1 tonne of larger roundwood, as it is bigger and subsequently heavier. Even if a harvester is not the technique used the difference in cost will still be valid as the motions of striping and transporting to the roadside still need to be made by the foresters the forwarders or skylines.

### *4.3.3. Transportation*

There are parts of rural Scotland with poorly maintained public roads. There are single and dual carriageways but they are on the coastline. The roads leading to and from forests and many villages and homes are mainly single-track roads that cannot handle very heavy loads. This introduces a problem for transportation, as lorries that carry timber have to take the main carriageways, something that adds quite a bit of distance to any haul. For North Sutherland for example, at present, this is a major problem as the extracted timber is hauled to Aberdeen or Inverness using the A9.

If woodchips and timber are to be transported to storage areas or the end users, the state of the road system and the extra costs should be taken into consideration. Another point to consider is whether logs or chips are going to be transported in bulk. Logs weigh more than chips but woodchips are much bulkier and for the same weight, many more trips are needed. It is therefore advisable, that logs be transported from the forest road to a central processing area whereby chipping and drying take place and then the dry (and therefore lighter) woodchips are delivered to the end user. This way the bulk weight from the forest roadside is transported as effectively as possible and processed while any subsequent trips are made for the end user and can be incorporated into the end user price for woodchips.

The cost for transporting varies from

- 10 to 40 pence per tonne per mile

depending on the company and road system (some companies charge extra if the roads on the prearranged route are known to be un-kept or in bad condition).

### *4.3.4. Processing*

As stated above it is more effective to transport logs from the forest roadside rather than woodchips.

If however, the latter were to be chosen, a mobile chipper could be rented for the job. As soon as the extraction of the 7-14cm small roundwood began, a chipper could chip it at the roadside where the larger roundwood is piled.

In some cases, roundwood is left behind at roadside at the end of harvests if it does not make up a full load awaiting the next harvesting operation. The woodchip on the other hand would all have to transported away for drying as decomposition sets in quickly (especially in the environmental conditions present in the forest). This in turn means that half loads (not cost effective) would have to be transported so that no material is wasted.

If a processing unit exists for preparing the woodchips for the market, again, a mobile chipper can be rented and the bulk of the small roundwood can be chipped on site at the unit. The rental option is one of the most viable ones as a new or even used chipper is quite expensive; and at least for the initial period when the demand for dry woodchips would be small, a large capital for purchases might not be available. Table 3 indicates prices for purchase or rental of some of the chippers available on the market[26].

| **Chipper** | **Gravely Pro-Chip 395** | **Greenmech MT 252** | **Gandini 007 TPS** |
|---|---|---|---|
| **Capital cost (£)** | 14,950 | 19,300 | 13,600 |
| **Rental cost (£/hr)** | 5.13 – 5.90 | 5.79 – 6.77 | 10.30 – 10.99 |

**Table 4: Chipping costs**

Chipping trials carried out in Sutherland[27] indicated that chipper output is around 5 tonne per hr allowing for manual loading of stems onto chipper and direct packaging after discharge.

[26] Woodfuel chipping: Field trials, Technical note 9/98, Forest Research – technical development branch

[27] Roddy Laing, Dunrobin Sawmill, Backies, Golspie, Sutherland

Therefore, if renting a chipper the costs will average to around:

- £6 per tonne

This price allows for VAT, the manual labour needed (1 or 2 people depending on operations) the rental of the most expensive chipper.
Large mobile chippers cost much more to rent (around 48£/hr) but they would not be suitable as the load is small in this case. Drying costs have been already calculated, and can be found in chapter 3 table 2.

### *4.3.5. Calculations*

The overall costs were calculated for 1 tonne of timber extracted (or bought at roadside) from the forest floor. The formulae used were:

$$\text{Acquisition} + \text{Chipping} + \text{Drying} + \text{Transport}_{dry} + \text{Handling} + \text{Packaging} = \text{Total cost}$$

Where:

$$\text{Acquisition} = \text{cost Standing} + \text{Harvesting} + \text{Transport}_{wet}$$

Or

$$\text{Acquisition} = \text{cost at Roadside} + \text{Transport}_{wet}$$

And:

$$\text{Transport} = \text{£/tonne per mile} \times \text{miles transported}$$

Initially, the timber transported from the forest is heavier than the dried woodchips, hence the transport cost is multiplied by a correction factor to reflect this difference. Effectively this correction factor is the weight of the tonne of wet woodchips after drying.

This can be calculated using the formula below:

$$Weight_{afterdrying} = \frac{WetWeight}{MoistureContent + 1} \times (MostureContent_{afterdrying} + 1)$$

This "weight after drying" is always less than the wet weight (or weight before drying), in this case, 1 tonne of wet timber is being used as a reference and so the "weight after drying" is going to be a number less than 1; consequently it can be used as a correction factor for the transportation costs incurred after drying.

Handling and Packaging costs have also been added. After consultations with local representatives, the following have been quoted:

- Handling costs: £3 per tonne
- Packaging: £15 per agricultural Barley Bags
- Each bag can hold 1.5 $m^3$ of woodchips[28].

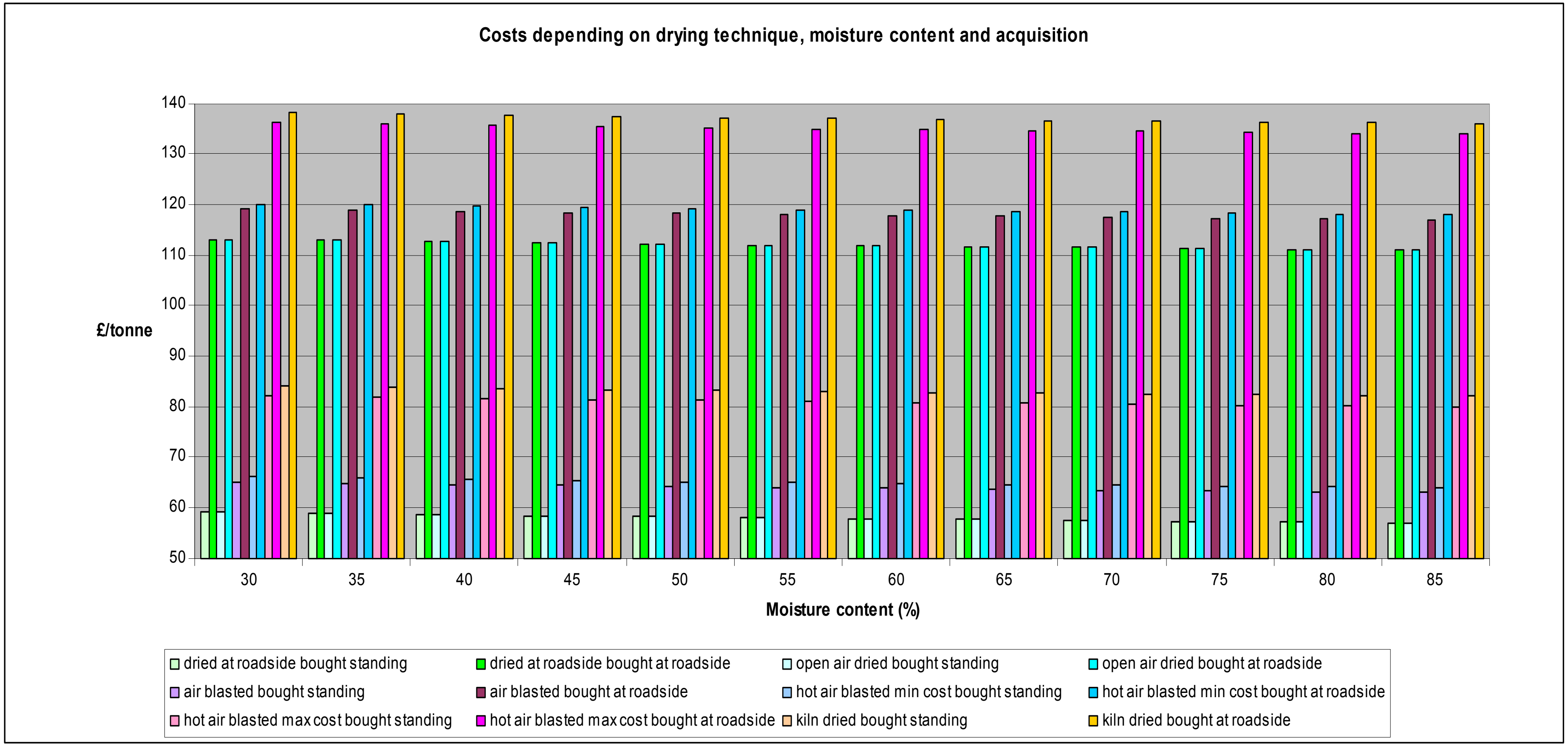
The weight of each of these bags can be calculated by using the density of the woodchips in the following formula:

$$V \times \rho = W$$
$$1.5m^3 \times 400kg / m^3 = 600kg$$

The density of the woodchips has been taken from tables supplied by The U.S. Department of Agriculture, Forest Service, Forest Products Laboratory in it's technical report "Specific Gravity, Moisture Content and Density relationship for Wood" numbered FLP-GTR-76 and is a function of the woods specific gravity at a moisture content of 15%.

[28]Roddy Laing, Dunrobin Sawmill, Backies, Golspie, Sutherland

Graph 2 indicates the costs calculated using the formulae in this section for the various drying techniques identified in chapter 3 and different initial moisture contents. Solar drying without fans has the same running costs as open air drying (zero), while solar drying with fans has the same running costs as ambient air blast drying.




**Graph 3: Calculated cost reflecting drying technique, initial moisture content and acquisition type (standing or roadside)**

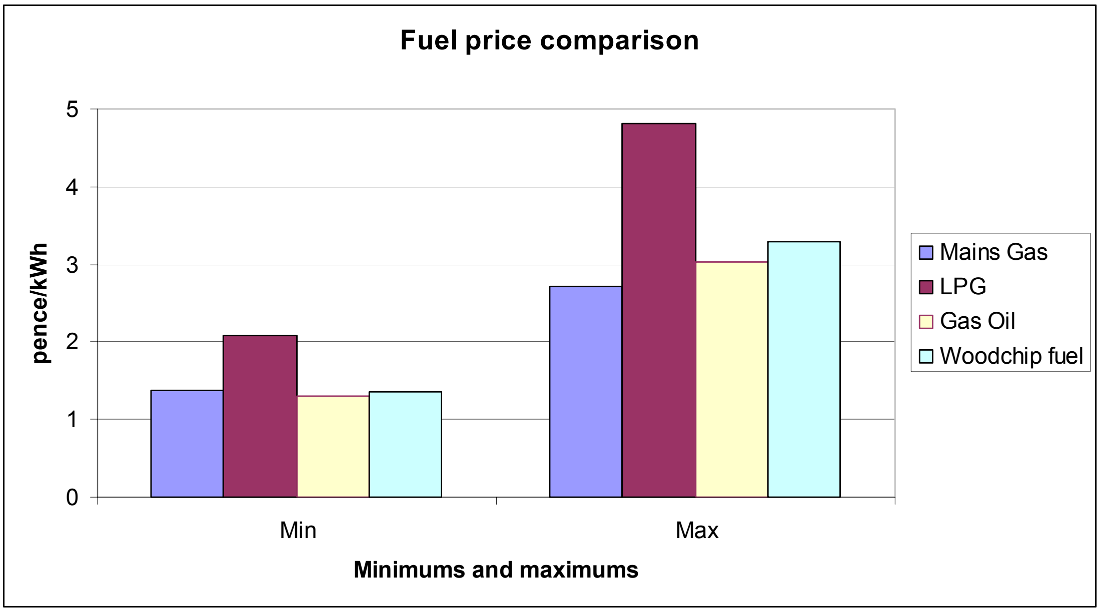
In order to compare this price to other fuels available on the market the price in pence per kWh was also calculated bearing in mind the calorific value of the dried woodchips:

4200kWh/tonne

This value is an approximation as the woodchips comprise of different parts of the tree (stem, bark, leaves etc.) and of different tree species (Lodgepole Pine, Sitka Spruce and Larch) and it is impossible to accurately evaluate it. The following formula was used:

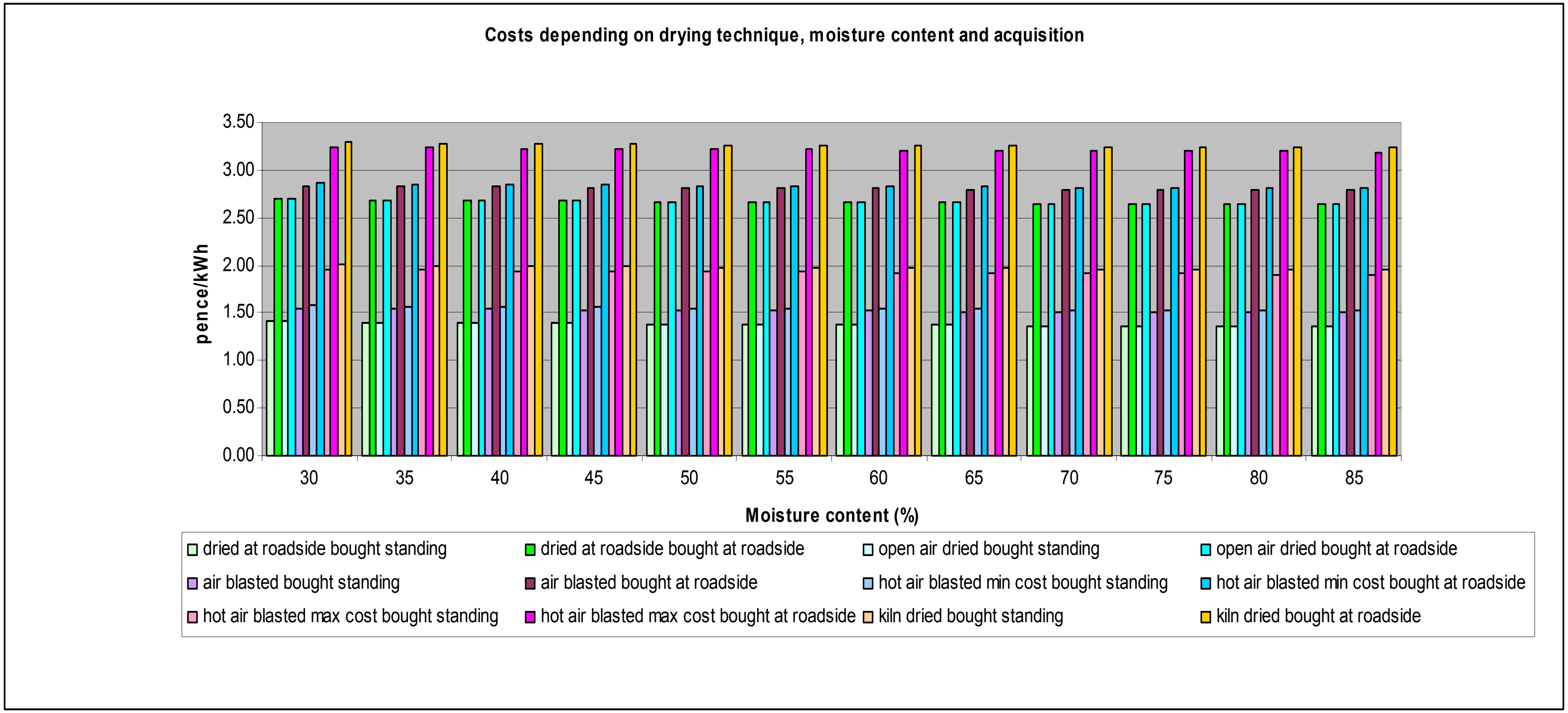
$$\frac{\pounds / tonne \times 100}{Calorific Value} = pence / kWh$$

This was done so that the overall cost of the woodchips could be compared with the cost of other fuels on the same plane. Graph 2 illustrates the minimum and maximum occurring prices in pence per kWh for Gas oil, LPG[29], Mains Gas and Woodchips for comparison. The figure quoted for woodchips are the minimums and maximums from graph 3.



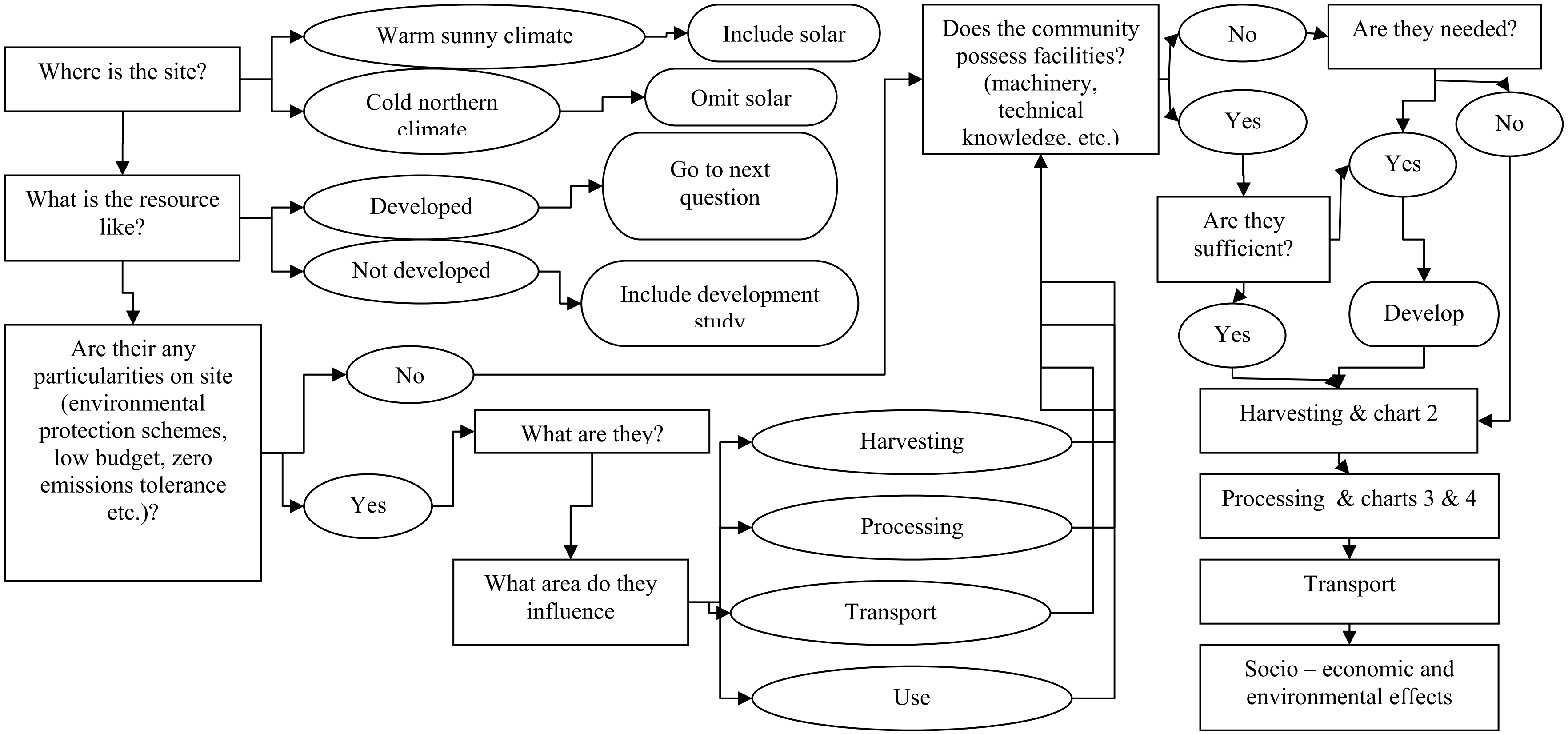

**Graph 4: Comparison of maximum and minimum fuel prices**

[29] Gas oil and LPG prices taken from "cost calculator" mains gas prices taken from Energy watch UK




**Graph 5: Calculated cost reflecting drying technique, initial moisture content and acquisition type (standing or roadside) in pence per kWh**

Having identified the available process techniques, their subsequent costs and environmental impacts a combination of processes can now be selected depending on the individual characteristics and requirements of an area or community. Flowchart 5 indicates the methodology used.




**Flowchart 5: Decision making process**

# 5. Case study: North Sutherland woodchip fuel supply chain

North Sutherland comprises a vast area of forests and various glens and mountains with a few scattered towns and villages along the northern coast of Scotland. Distances are quite vast and the population is quite small and relatively far apart. Tourism is one of the sources of income for the communities while the rest comprise of farming and crofters products. The road systems are mostly single track, except for the main single and dual carriageway along the coastline. Most of the roads also have restriction on the vehicle weight that uses them, therefore transporting of heavy goods has to be kept to well maintained roads. In order to establish a reliable picture of the Sutherland market interviews with representatives of the local communities, foresters and a representative from the Forestry Commission (otherwise known as Forest Enterprise) were undertaken. Many facts and cost data quoted are sourced from those interviews (appendix iv).

## 5.1. Fuel of choice

The winters in Scotland are quite harsh and heating is needed for about eight and a half to nine months a year. Generally, heating with electricity is an option, but it is deemed the most expensive option, even if storage heaters are used. Large establishments like schools and hotels do not usually consider electricity as an option at all, unless the source is local and the price per kWh is fairly low. The next available option is oil. Oil fired boilers are used along with oil fired generators in some of the remotest areas where the electricity grid has not yet been established. These boilers are seen as cheap to run as both hot water and heating is provided at a relatively low price (18p/lt). The cost effectiveness is difficult to ascertain as it depends on the individual boilers and there use. Furthermore, in the areas that an centralised gas supply has been established gas boilers are used. The ease of a constant supply and a regular quarterly or monthly bill in addition, to the low price of gas makes this the most preferred source of heating fuel. If woodchip boilers are to be introduced into this market, the target consumers would be people who use oil-burning boilers. Furthermore, the ease of maintenance and running along with the fuel price should be highly competitive against that of the oil-fuel option.

The following chapters will deal with the economics of using woodchip boilers burning fuel from the local forests. The main consideration would be the price of the woodchip for the end user.

## 5.2. Available outlets for woodchip boilers

The North Sutherland population does not use woodchip boilers at present. The North Coast leisure pool[30] at Bettyhill will be the first installation and use of such a boiler when it is finished. Consequently, any other woodchip boiler installation would depend on the success of that subsidised pilot programme. The initial installation costs are also a concern, so the first to uptake the use of woodchip boilers would be organisations such as schools, community centres, hotels, stately homes open to the public and so on. As soon as these establishments prove that, the use of woodchips is viable for the general public it is most likely that private homeowners will start using this renewable resource for their heating needs as well.

## 5.3. The area's resource

### *5.3.1 Forestry resources*

The forests in North Sutherland comprise mainly of Lodgepole pine, Sitka spruce and some Larch. The pine acts as a nurse tree for the spruce and larch (it helps the spruce grow in a straight line) but does not produce particularly gone timber. It is quite brittle and often grows very gnarled. On the other hand Lodgepole pine is quite suitable for both chipping and burning, its lower market value though means that foresters will prefer to use it for brash mats needed during harvesting operations as Spruce and Larch will yield considerably more in the market and as less as possible is wasted. The tops and gnarled stems are primarily used for the mats, but it brittleness means that comparatively more material is needed so less of the tree is available for marketing or chipping.

[30] Run by: Tongue and Farr Sports Association, Contact: Jim Johnston

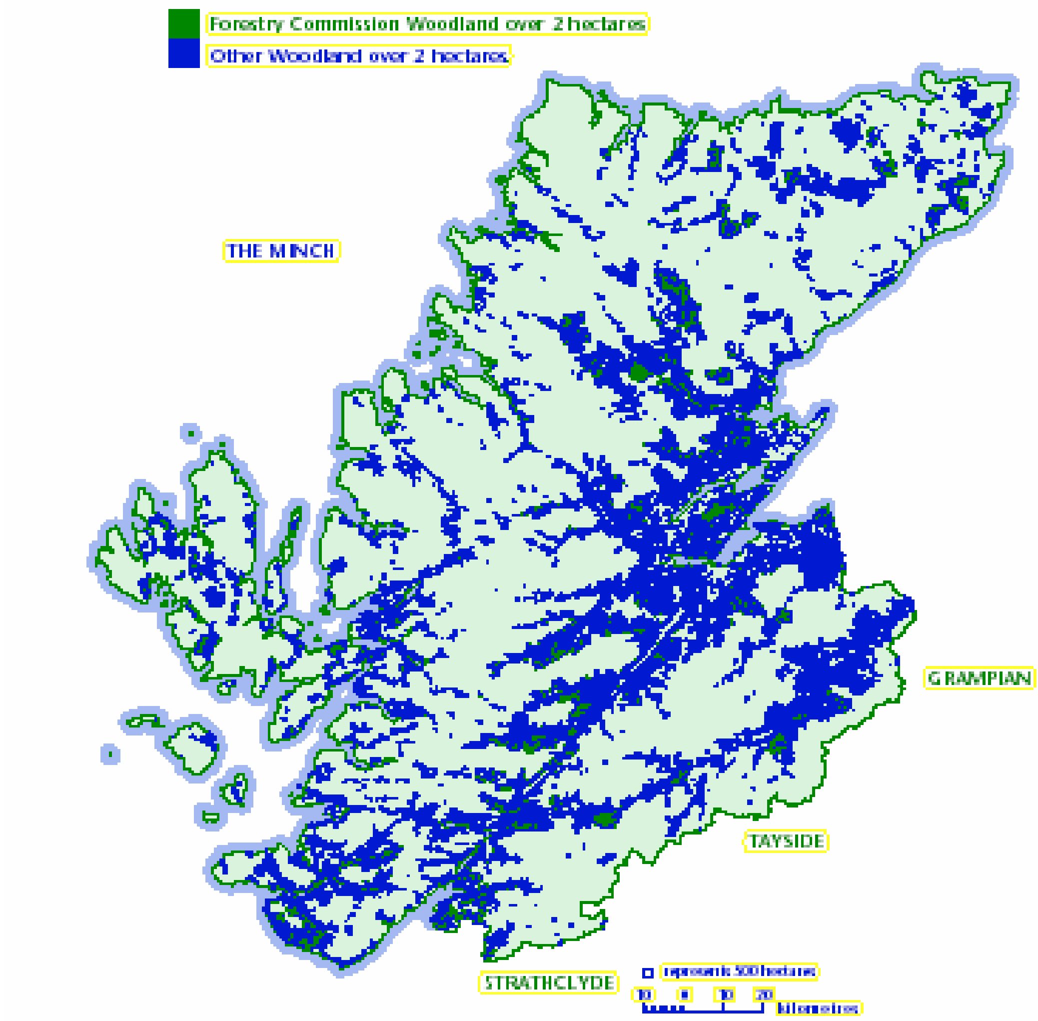



**Figure 12: Forest cover in the Highlands**[31]

If a market for woodchip were to be developed, foresters would try to conserve more of the pine that is "wasted", but the percentage would still be small as the need for brash mats is a very practical one. As stated before they are used to create easily navigatable routes through the area being harvested; the weaker the brash mats the more time needed for harvesting the more expensive it becomes. Furthermore, the forests have to be harvested every 30 to 50 years maximum, this means that the wood does not have a very long time to grow (compared with forests in other areas where trees are allowed to grow to suitable heights and widths). The result is that the yield from these forests has a greater percentage of lower quality timber.

[31] Forestry Commission, National Inventory of woodland and trees, Scotland- Highland Region, Part 1 Woodlands of 2 hectares and over, ISBN 0 85535 532 4, 2001

The small roundwood (from 7 to 14cm in diameter) is extracted from the forest at he same price as the larger roundwood (from 14cm and upwards) but yields less in the timber market. In particular, the £18/tonne[32] that small roundwood is sold at, does not always cover the extraction and transportation costs (discussed in following chapters) to harvest and deliver it. At the moment, it is subsidised by the yields form larger roundwood, which sells at about £29/tonne. This lower quality timber (acquired from all species) is what could be locally used for chipping. The transport costs would be considerably lower and thus, a loss on the end product could be avoided. Along with the 7-14cm timber, blow-overs and trees that have been "felled to waste" (cut down and left on site) could also be used. Trees that have been blown over usually die quite quickly as their roots become exposed to air and light these trees could be salvaged for marketing.

#### 5.3.1.1. Blown over timber

Usually private forest owners allow foresters to keep any blown over timber so long as they harvest the rest of the timber without pay. The blown over timber is particularly hard to extract as the tops and branches have to be cut off manually and the tangled piles of trees are very dangerous to navigate and work through. This is primarily why many forestland owners allow for the timber to be kept by the contractors. On the other hand, if someone is willing to take the risk of extracting such timber the end product is free and extraction costs are no issue. There are about 1450 ha of windblown trees in all the Highlands at present[33] that amount to about 0.4% of the total woodlands in the area. These windblown trees have not been recovered from the forests and are a possible resource for chipping.

[32] Prices acquired from Forest Enterprise

[33] Forestry Commissions National Inventory of woodland and trees, Scotland- Highland Region, Part 1 Woodlands of 2 hectares and over, ISBN 0 85535 532 4, 2001

#### 5.3.1.2. Caithness and Sutherland peatlands

The RSPB (Royal Society for the Protection of Birds) is actively involved in the restoration of damaged blanket bog in Caithness and Sutherland. Between 1994 and 1998, the RSPB led a project[34] focused on the peatlands of Caithness and Sutherland[35]. As part of that project, restoration work was carried out in order to restore specimen areas of damaged blanket bog and in an attempt to protect areas of adjacent intact blanket bog. Restoration work was carried out on seven areas of afforested peatland. Work was also carried out to aid the recovery of an area of peatland damaged by All Terrain Vehicles (e.g. Harvesters). By the end of September 1998, trees had been removed from 202 hectares of afforested peatland. Past planting activity was responsible for a high proportion of peatland habitat losses and today the felling of trees, which are damaging bog systems, is a key issue. Work at RSPB Forsinard Reserve in Sutherland, is being undertaken to illustrate the practical benefits, which can be achieved for wildlife where trees are removed from peatland. The trees in this area are to be felled to waste as extracting them with heavy machinery (e.g. a harvester) will destroy the ground and because it is quite boggy in itself is also very difficult from the onset. The trees in question are quite large though (in some areas they are 27 years old) and leaving them on site to rot will impede the regeneration process rather than help it as the shear mass of the trees does not allow for air and light to reach the blanket bog.

Some material should be left behind but a large portion (comparatively large trunks, chunky branches and so on, see figure 14) should be extracted. The removal of this material should be done in a manner that does not in any way harm the sensitive ground this means that heavy machinery or skidding of the timber should be avoided. Hence, the only technique that would be "peatland friendly" is to fell and trim the trees manually and to extract them either by helicopter or by using a mobile skyline.

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[34] Funded by EU LIFE - Nature

[35] Conservation of Active Blanket Bog in Scotland and Northern Ireland

**Figure 13: 25ha of felled area of 27yr old Lodgepole pine in Borgie Forest[36]**

Both techniques have problems associated with them. Helicopters are too expensive and without some sort of subsidy are economically unviable. Skylines on the other hand are economically viable but are more effective on sloped ground. This problem can be tackled though, if an excavator acts as the tower for the other end of the skyline.

Any other options (low ground pressure vehicles, highlead, forwarders and so on) will inevitably cause some amount of damage to the already damaged blanket bog and consequently, further impede the restoration process. Furthermore, the authorities will not produce the necessary permits for extraction if there is a possibility of damaging the recovering ecosystem.

### *5.3.2. Contractors & the forestry commission*

Sutherlands Forests are owned either by the Forestry Commission (Forest Enterprise) or by private landowners. In most cases the trees are sold standing, i.e. they are auctioned as is on the forest floor. The highest bidder undertakes the harvesting, extraction and transportation of the timber acquired. This means that contractors have to reduce harvesting cost as much as possible and increase the economic yields from the timber. Therefore, they extract all marketable timber and leave behind only what is absolutely necessary this way nothing is wasted. Most of the contractors undertaking such projects are from outside the Sutherland community and the timber that is extracted is transported outside the community as well.

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[36] Forest owned by Forest Enterprise

Consequently, it is in the interest of the local population to create a market within Sutherland whereby a portion of the timber stays in the area. Therefore, if timber were to be used locally it could be bought from the forest roadside in which case the contractors' transport costs would be greatly reduced as only a portion of timber would have to be transported to the Aberdeen or Inverness market. Alternatively it could be delivered to a near by sawmill or storage area for further processing transporting costs will still be reduced in both cases. In some instances of private ownership (small area of woodland, heavily windblown areas and so on), the owner undertakes the extracting of the timber. If the transportation costs are too high, the small roundwood is sold at very low prices or even given away at the forest roadside so as to cut the losses of transportation.

#### 5.3.2.1. Current outlet for forestry products

Sutherland does not have any large timber processing units at present. This is the reason why any timber from the Sutherland forests is transported to sawmills in Inverness or Aberdeen where large saw and paper mills are located and can handle that sort of bulk of material. A number of small community projects are being developed[37] to allow for more of the local timber to stay in the area and thus, help regenerate the economy but none are very large and so only a small portion of timber will stay. The use woodchip is already being piloted on a small scale for Cattle Corrals in order to provide over winter accommodation for cattle[38]. The further use of woodchips and the generation of a woodfuel market for North Sutherland will greatly increase the amount of timber that is produced and used locally.

#### 5.3.2.2. Wood of choice for chipping

As stated above the wood of choice for chipping would be the small round wood (7 to 14cm in diameter). Other possible material to use could have been treetops, branches, shrubs on the forest floor and underdeveloped tree stems.

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[37] e.g. Strathy Log Building Course : November 12-16th 2001, (http://www.nhft.org.uk/)

[38] see North Highland Forest Trust at: http://www.nhft.org.uk/

These options are not viable in Sutherland as the forest ground is weak and foresters use all of the above to reinforce the ground (brash mats). Furthermore, as everything else is extracted from the forest floor the material used for the brash mats also helps rejuvenate the soil.

### *5.3.3. Sawmill residues*

There aren't many sawmills in North Sutherland and certainly there aren't any large ones. Any residues acquired from these sawmills will comprise of bark cuttings and various unusable logs. They will be drier than freshly cut timber but drying will be required. As the amount of possible sawmill residues is quite small the consideration has been incorporated along with timber bought at roadside. The price of the residues will be definitely lower but the amount does not warranty an extensive study. Larger sawmills are found in Aberdeen and Inverness but transporting costs and emissions do not make this a viable option for pursuit.

## 5.4. Other considerations

If this project to generate a market for woodchip fuel in North Sutherland is undertaken some facts have to be considered. The market will be completely new and for the moment the only possible end user is the North Coast Leisure Pool in Bettyhill. The generation of this market depends on the success of the Bettyhill pilot programme. If it is found that the use of woodchips for fuel is cost effective and a better option then the use of conventional fuels then establishments like the nearby hotel and various community centres in the area will consider the option of woodchip fuel. This is the first hurdle for the area to overcome.

Once the businesses have taken the woodchip fuel option under consideration decision for brand new boiler installations have to be made. As this is quit an expense for any business it is more likely that establishments that are big enough and successful enough and need a new boiler to be installed (or were maybe already considering installing new wet systems and so on) are going to be the first to uptake the option.

These two points suggest that the various possible end users will develop very gradually. In most probability this rate of uptake will increase as more and more establishments and businesses use start using woodchip boilers. It is most probable that after a period of time homeowners due to renew their boiler and heating installations might take up the woodchip option as well.

All in all the market will be grow slowly to begin with and gradually start to expand more rapidly. This should be taken into account when selecting the process techniques to the production of woodchips. As the initial capital is small and the installations are not very wide spread to begin with the approach should be to use the most cost effective methods available without much consideration on the time it will take to produce the woodchips for the market. When the profits allow and the market is large enough then new processes should be looked into to improve production so that it corresponds with new market needs. Hence, any short term decisions have to be made with the future of a larger market in mind.

### 5.5. The available resource

The candidate forest from which to extract the timber for chipping is Borgie Forest. It is situated in the heart of North Sutherland and so is quite near to the possible market that will develop. As stated in previous chapters the soil in this forest is poor. Trees do not root deep enough and so are prone to being blown over by the severe wind conditions present in the area. Furthermore, the quality of the soil demands that a large portion of otherwise recoverable[39] timber needs to be used for brash so that operations in the forest continue efficiently[40]. Consequently, the available timber for chipping is the low quality and subsequently cheaper 7cm to 14cm small round wood. This timber is delivered at a loss to Inverness and Aberdeen sawmills.

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[39] For use as material for chipping. This material includes branches, shrubs, treetops, leaves, gnarled tree stems etc.

[40] As these brash mats help to reinforce the soil and allow for easier access in later operations they cannot be recovered even after they are first laid down and used.

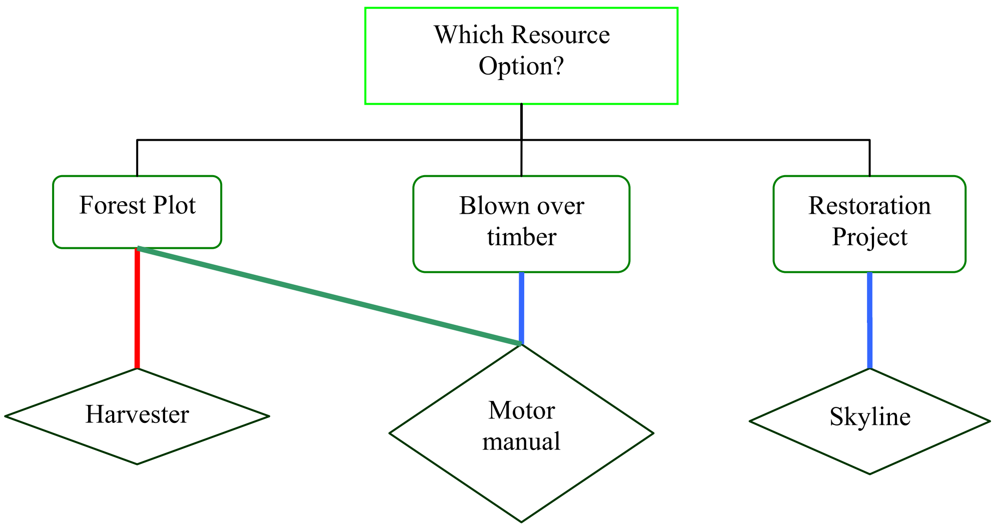
Contractors, private forest owners and the forestry commission alike will be willing to sell this roundwood at roadside at a price lower than usual and cut the transportation losses incurred. Therefore, whether extracted by the community or bought at roadside this would be the timber of choice for chipping.

Another possible resource would be timber recovered from the RSPB's peatland regeneration projects. Again there are certain particularities that should be considered. Firstly the trees on most of these sites are only suitable for chipping; this means that there would be no profit made other than that from marketing the woodchips. As always an amount of timber should be left behind in order to help the regenerative process. In order to allow for restoration No machinery can be allowed to operate on these sites and so the most common harvesting technique (harvester etc.) cannot be used to extract the timber. When felling and when leaving material behind care should be taken to follow the RSPB's guidelines for such operations in these areas.

An additional source could be blown over timber from small plots of privately owned forests. The availability of such an option is quite variable though and in no way should any feedstock and resource planning be based on it. As it depends on the weather, the forest management, plots owner and the contractors undertaking the harvesting.

### 5.6. The applicable harvesting techniques

Flowchart 6 indicates the harvesting technique options available depending on the type of timber resource available after taking into account the particularities associated with each option. When considering a forest plot there are two available techniques. The harvester option is the most expensive one but it is the fastest of the two and what might be lost in capital may be recovered in extraction time. This market development though aims to be sustainable, thus, it is preferred that extraction be undertaken by local foresters. It might also be the case that local foresters do not own harvesters and, as it is unlikely - in the beginning of this development - that they acquire such machinery, the motor manual option can be chosen as a first option, again bearing in mind that later down the line market developments might allow for more expensive machinery to be used.




**Flowchart 6: Harvesting techniques available**

## 5.7. Processing

As has been discussed in previous chapters, It will in the best interest of all involved to process the timber in some sort of a processing unit. The unit would serve many purposes:

- A chipping area whereby timber can be chipped on demand
- A drying area ,
- Whichever drying technique is used a sheltered area for storage will be needed
- A processing area for the ash[41] collected from the end users
- A packaging area
- A centre of operations from which all deliveries (to and from the sheds) could be arranged

[41] See also Appendix III

The North Sutherland Community Trust, chaired by Mr. Sandy Murray, has been awarded funds to acquire the Forsinain Sheds. These are two very large sheds off to one side of the Forsinain forest. They have been connected to the grid and the water supply and therefore, can be developed straight away. These would be very suitable to act as a processing centre for the woodchips, although that will not be their only operation, various other activities involving timber processing will be undergone as well. The sheds are on the southern side of Borgie forest while the initial demand for woodchips would be on the northern side. But again the future expansion of the woodchip market should be taken into account. The sheds are close to Borgie Forest, the initial candidate for the feedstock and to the Forsinain Forest a *likely* candidate for suitable timber later on in the markets development. Additionally, the sheds allow for expansion of operations if the woodchip "production line" needs to grow, due to their size.

The sheds can act as a chipping area. As stated in previous chapters the timber can be initially chipped by renting a chipper. The chipper itself does not have to be mobile but can be attached to a tractor or other farming or forestry vehicle.

Mobile chippers (see figure 15 ) tend to be more expensive and better suited for large job loads. The attachable chipper (see figure 8a) option is suitable for initial operations as the demand will be small and periodic (during parts of the heating season). When operations expand and woodchips are needed all year round, a chipper can be bought and installed on the premises.

Figure 14: Mobile chipper in operation at forest the roadside in Norway[42]

The sheds can also be used as a drying area. Initially and as drying time is not an issue (see flowchart 4) the ambient air blast technique can be used as a temporary measure. It would be prudent though to invest in a hot air blast drying technique in the beginnings as the facility will be needed in future. A dryer of the type developed by 3G Energi[43] would be the optimum choice. If there is a rental option for the initial period of the market generation it would be advisable, otherwise it can be bought. The initial capital is larger than that needed for ambient air blasting (around £30,000 compared to around £20,000) but for an operation of this type it is essential to have a drying option that is flexible enough to expand with the market. As a kiln drying operation is out of the question (the initial capital needed is too high and the type of control available does not correspond with the limited needs of drying woodchips) this hot air blast option is optimal. The waste heat of the dryer can be further used to pre dry the woodchips before they are fed into the dryer to further reduce their moisture content.

[42] http://www.videncenter.dk/uk/index.htm

[43] 3G Energi, Allesudden, Charlesfield, St. Boswells, Melrose


**Figure 15: Prototype 3G Dryer on trial at Longnewton Sawmill, Scottish Borders[44]**

This type of drying also provides all the control needed for uniform drying. In addition, if the target moisture content changes for any reason (other uses for woodchips, developments in woodchip boilers etc.), this can be easily accommodated. This type of dryer is quite small and compact furthermore, it is mobile and consequently, can be moved straight to the packaging area reducing the amount of handling needed. It also allows for woodchips to be used as fuel and therefore, the running costs can be quite low. Finally, as opposed to kiln drying, drying can take place as and when required thus, accommodating for the seasonal nature of woodchip fuel.

The sheds are a shelter for the dried woodchips and can be used as storage after packaging. Agricultural Barley bags can be used to store and transport the woodchips. They can be filled as soon as the chips are dry and be easily stacked for deliveries. Some of these bags are equipped with drawstrings on the bottom for easy discharge into the hoppers[45] at the other end.

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[44] Courtesy of 3G Energi

[45] Woodchip boilers require hoppers to store the woodchips. Some automatically feed woodchips into the combustion chamber and others have a manual feed system of levers. See also appendix III

After the woodchips combust in the boilers an amount of ash is formed (between 1.5% and 2%) This ash should be collected from the end users. It can be used as compost material for the forests soil or it can be sold as composting material to the general public. Either way the shed can act as the necessary centre for collecting and processing this ash.

Finally the sheds can be used as a centre *from* which deliveries can be made to the end users and *to* which the timber extracted from the forests can be delivered. As the sheds are situated near forest roads these can be used for deliveries from the forests without the need to use main carriageways therefore, helping reduce the amount of heavy machinery on the public road systems. Further more, these forest roads can be used for part of the route to the end user.

**5.8. Delivery**

As the need for woodchips is seasonal and usually is mainly limited to the heating season (with usually one delivery during non heating seasons to accommodate for the use of hot water) the deliveries will reflect this.

The frequency of these deliveries greatly depend on the size of the hoppers used by the end users and the use of their boilers. As the road systems that are going to be used are minor public roads, which were initially farm tracks coated with a thin covering of bitumen and chips they were not designed to cope with lorries weighing up to 40 odd tonnes. Hence, the state of the roads should be taken into consideration and loads should be small so as to avoid further damaging these roads.

Woodchips are bulky, but not heavy it is therefore advised, to use smaller vehicles. It should be noted though that when more and more end users of woodchip become available that the deliveries should be programmed so that a large amount of end users can be served. If the weight of the loads is closely monitored this should not pose a problem. The delivery vehicle need not return to the processing centre empty.

Timber from the forest roadside can be picked up on the interim when the vehicle is empty or the ash produced by the woodchip combustion can be collected from the end users and delivered back to the processing unit. In this way an otherwise empty journey would become useful, saving time, money and hassle.

## 5.9. Summary of proposals.

### *5.9.1. Expanding market proposal*

Initially, the market for woodchip fuel is going to be very small, but will gradually increase in size. This needs to be reflected in the choice of processes adopted to produce the woodchips. The processes proposed are the most cost effective and environmental sound techniques available and can accommodate market expansion.

Bearing this in mind, it is proposed that if timber is extracted from the forest floor (rather than bought at roadside) it should be initially done using one of the motor manual techniques.

If this extraction takes place on grounds being regenerated through one of the RSPB regeneration projects, the technique to adopt should be a skyline so as not to further damage the sensitive peatlands. The sheds at Forsinain forest should be used as a processing unit and a base of operations. To chip the timber, it is advised to use a rented chipper until it is deemed necessary to acquire one due to work load (later on in the markets development). A dryer like the type developed by 3G Energi should be acquired to dry the woodchips as it's flexibility and quality of drying reflects the needs of this type of continually developing project. Deliveries should be organised so that the vehicles do not run empty by way of arranging for timber to be collected from the forest roadside before or after delivering woodchips to end users.

### *5.9.2. Single end user proposal*

In the eventuality that the woodchip fuel supply chain is not developed with market expansion in mind but just for the one end user; than there should be some alterations to the techniques developed in order to assure cost effectiveness and an environmental sound approach. Timber should be bought at roadside to avoid large harvesting costs. Moreover, it should be left to dry for a period of a bout a month before chipping to reduce the high moisture content. Chipping should be carried out using a small rented chipper that can be attached to an available farming vehicle. The woodchips can then be dried using solar drier during the summer months. Solar driers are easy to construct as only a glass façade and black paint. If however this is not possible to acquire then a fan can be used to air blast the chips. Packaging and delivery should be carried out at minimal cost. As with the proposal for the expanding market the barley bags used to transport and deliver the fuel should be recovered.

Bearing in mind that the Bettyhill swimming pool is at the north side of Borgie forest whereas the Forsinain sheds are at the south side, processing can be carried out within Bettyhill. Any disused farm buildings will be adequate providing that they offer shelter from the elements. As the amount to be processed will be quite small there is no need for large storage areas. In addition, a processing centre within Bettyhill will further reduce the amount of transport needed for delivery, thus allowing for a cheaper fuel. However, the processing operations needed are quite substantial and so if there is no evidence of possible market growth, than an external fuel provider such as Torren energy will be a better option.

The following chapters will look into the impacts such developments would have on the environment, the community and the local economy.

# 6. Environmental Impacts

## 6.1. Disadvantages of the scheme

The adverse effects of using woodchips as fuel and biomass in general are easily identified and just as easily avoided with sustainable management. What's more, they are localised as opposed to the adverse effects of using fossil fuel which can affect people and environments thousands of miles away. These effects and their subsequent prevention measures are stated below.

As the new market for the timber extracted from Borgie forest expands, more pressure might be put on contractors and forest managers to harvest larger amounts. It is widely known that any use of wood from forests such be done in a sustainable manner. This means that wood extracted from the forest should be subsequently re-planted. It falls on the forest mangers to ensure that this is the case, otherwise the result is deforestation. Deforestation can then lead to desertification a major problem in underdeveloped countries that do not have forest management schemes. The effects of deforestation can be seen in some of the glens in North Sutherland; in this case deforestation was caused by overgrazing. The effect was that the indigenous forests have given their place over to near barren landscapes with clear evidence of water erosion. The forests in question, in North Sutherland, are already managed sustainably by Forest Enterprise and thus, this problem is unlikely to materialise itself. In addition, the timber extracted for fuel use will not add to the amounts of timber already harvested. This is because the woodchips will be sourced from already extracted wood that would otherwise be sold on other markets.

In the case of the RSPB peatland restoration project the timber extracted from the area will not be replenished. This is a studied approach though, and is being undertaken specifically for the purpose of restoring previously damaged land due to *afforestation*.

The opposite of deforestation, afforestation can also take its toll on the environment. If a large plot of land is planted with specific tree species and care is not taken, then the lack of biodiversity may lead to loss of genetic resources, soil and water erosion.

Soil damage is caused by the imbalance of nutrients; this can make the soil acidic which in turn can enter into the water supply and disrupt corresponding balances for marine life. An further example of these effects is the destruction of the peatlands (now being restored by the RSBP) and the loss of a rare birdlife habitat. Forest Enterprise and local councils and trusts are currently looking into expanding the range of tree species being replanted in the forests in North Sutherland. This will be done to restore the indigenous tree species in the area. Such a project will restore the balance of nutrients absorbed by the already damaged soil, consequently helping to restore it to its natural levels. The diversity of the species will not affect the woodchip production in any way as their source is in wood not suitable enough to market and is effectively independent of species. Small differences in drying times and calorific values might be apparent, but the resulting woodchip fuel will be mostly unaffected.

The emissions from burning woodchip fuel are an issue, as apposed to other renewable energy sources (like wind, wave and solar power) the combustion of woodchips emits $CO_2$ and a very low levels of $SO_x$ and $NO_x$. The $CO_2$ emissions need not be taken into account if the woodfuel has been produced in a sustainable manner. Trees act as a sink for $CO_2$. If their extraction, processing and transportation has been done in an “emissions conscious” manner than the $CO_2$ emitted by the woodchips’ combustion will equal the $CO_2$ absorbed by the trees they came from during their lifetime. What’s more as the forests are sustainably managed more trees will be planted to act as a sink once more. In order to ensure this “neutrality”, transportation should be as efficient as possible; i.e. loads transported should be full and the distances as small as possible. Moreover, the vehicles used should be regularly serviced and checked so that they run on maximum efficiency and with minimum emissions. During chipping the machinery capacity should match the production needs; for example a large chipper that burns a large amount of diesel should be used for larger loads. Where possible during the drying process it is also advised to allow for the woodchips to dry naturally for as long as possible, therefore reducing the need to use electrical or fossil fuelled energy. If a dryer is used then the woodchips themselves could be used to fuel the burner, thus reducing emissions further and offsetting an amount of fossil fuel use.

Another possible disadvantage of using woodchips for fuelling boilers is the aesthetic appearance of the hoppers containing the fuel. The hoppers can be quite large and they are usually directly outside of the boiler room to allow for easy filling from a delivery vehicle. However, as boiler rooms are usually situated in the back of buildings the hoppers will not be visible from most angles. If the occupiers and neighbours agree to their installation this need not be a problem.

To offset these avoidable disadvantages of using woodchips the plethora of environmental advantages are stated below.

### 6.2. Advantages of the scheme

Maybe the most beneficial of indirect environmental effects of the use of the creation of a woodchip fuel market, is the fact that the use of fossil fuels is offset. Establishments opting for using woodchip boilers will not be using fossil fuels, therefore, they will not be adding new amounts of $CO_2$ to the environment and they will be helping to mitigate global warming effects. Wood fuels (as stated above) are Carbon Neutral and although woodchip combustion produces a small amount of $SO_x$ and $NO_x$, this quite less than that emitted by fossil fuel fired boilers. Table 5 indicates:

| Emissions | Coal Boiler Average values[46] | Fossil Fuel Boiler Average values[47] | Woodchip Boiler Average values[48] |
|---|---|---|---|
| $CO_2$ (g/kWh) | $959.34 \times 10^6$ | $921.24 \times 10^6$ | $638.65 \times 10^6$ |
| $NO_x$ (g/kWh) | $2.54 \times 10^6$ | $2.295 \times 10^6$ | 0.324 |
| $SO_x$ (g/kWh) | $6.078 \times 10^6$ | $5.262 \times 10^6$ | 0.054 |

**Table 5: Emission rates comparison**

[46] NREL/RAP DR Emissions Collaborative.
[47] NREL/RAP DR Emissions Collaborative.
[48] Dr H. McKay, Policy and practice division. Forestry Commission

On the local scale with the use of woodchips the regional pollution levels will be reduced as the more and more establishments and business uptake the scheme. Acid rain in particular that is caused by the use of fossil fuels can be ameliorated by the use of woodchip fuel.

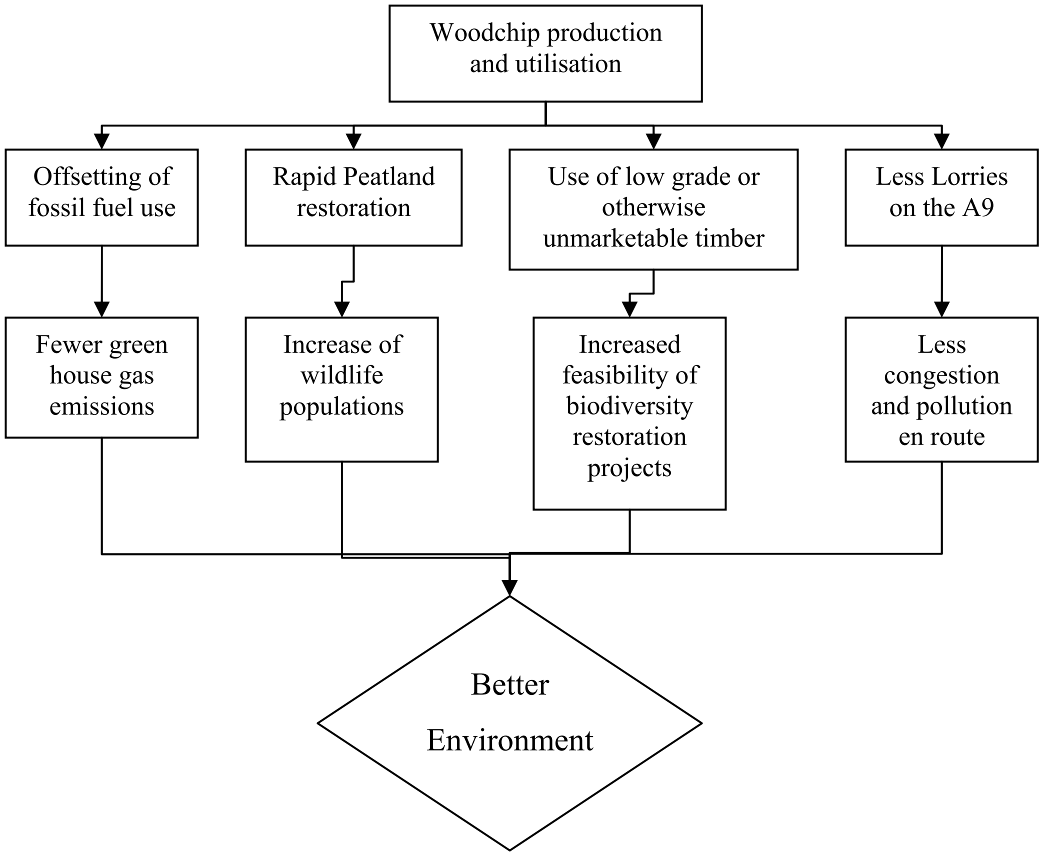
Furthermore, the ash produced by the boilers can be used to replenish the soil. This in conjunction with the sustainable management of the local forests can help restore fertility and stability to the land, thus helping in soil and water conservation.

In North Sutherland the use of the timber from the peatlands will help the rapidity of the restoration process of the area. This is because the excess timber left to waste on the peatlands can sometimes impede the process of restoration as the mass of the materials left behind do not allow for the appropriate amounts of air and light to penetrate down to the ground. With the removal of this excess material the process will develop quicker.

Because woodchips have no specific timber species specifications, as far as heat output is concerned, their use will allow for an increase in much needed biodiversity in the local forests. To date Lodgepole pine (as a nurse tree) and Sitka spruce had been planted in the forest areas as there had been no other market demand. In the interest of profit (without which even basic forest management would not be possible) it had been hard to allow for other species to grow. The use of woodchips would create a market for timber that might not be marketable elsewhere, therefore allowing for non-marketable tree species to be planted.

With the use of wood that would otherwise be transported to Aberdeen or Inverness the amount of lorries on that route will decrease helping to reduce traffic and accident problems on that route. Moreover, the actual haulage distances will be quite shorter, consequently helping to reduce emission due to transportation. In particular timber will be transported for at least 55 less miles this saves an average of 20kg of $CO_2$ emissions per lorry load. Road damage will be reduced as well as the amount of heavy loads (can be up to 40 tonnes) on the major public roads will be reduced.

Flowchart 7 lists the environmental benefits associated with the use and production of woodchips in North Sutherland.




**Flowchart 7: Environmental benefits**

# 7. Socio- Economic impacts

## 7.1. Sustainable development

There have been many debates on the state of the planet. But the environmental and economical changes in circumstance are evident worldwide. The population is growing and the resources dwindling. The earth and its inhabitants have all proven to be very resilient but for how long. The need for *sustainable development* is unmistakable. Sustainability has been termed as the economic and social development that is:

- continuous and permanent
- durable and reliable
- proactive and just
- enterprising and sharing

The market development proposed satisfies these terms and it also follows the local Agenda 21 commitments towards community based approaches in the following ways:

- Wood that is produced locally and currently is extracted by external operators and delivered to external markets will now stay within the local community.
- In some cases the development will also allow for local contractors to extract it (in situations where the skills, equipment and resources needed are available).
- Local contractors will be transporting to local users.
- And finally the local population will be processing the timber and reaping the rewards.

Many would argue that one person or one community cannot make a difference. These people cannot be more wrong. The differences are made through the exemplary actions of an initial few taken up by their “cautious” neighbours after proven successes. This is the case with this project proposal.

As stated in chapter 5, there is only one woodchip boiler user in Sutherland namely the Bettyhill swimming pool. Hardly a cause to create a local woodchip supply chain bearing in mind the amount of processes involved. The success of this pilot project though, is guaranteed to attract more interested parties. The reasons being both economical and environmental. For example:

- All business consumers of fossil fuels attract the Climate Change Levy, undoubtedly this levy will continue to be increased by the government with time. Woodchip energy production does not attract this levy.
- The fuel itself competes in price with the available fossil fuels.
- The environmental benefits, such as emission reduction, are many.

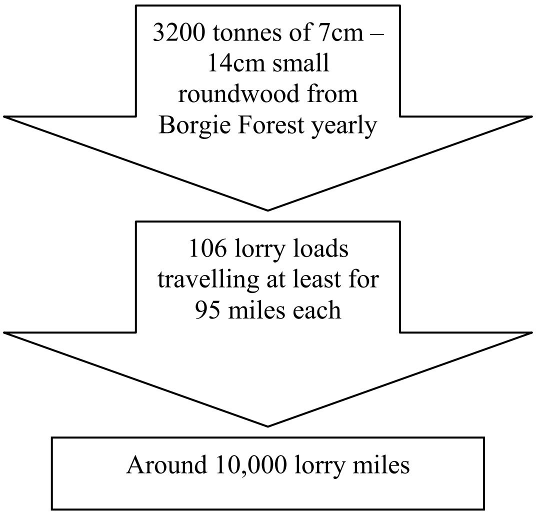
Hence, the need for the supply chain becomes evident. The creation of this supply chain and the subsequent market is in many ways sustainable as is the use of woodchips itself.

**7.2 The new opportunities**

As supply chain is a new development, new opportunities will also be created. To date wood has been extracted from Borgie forest mainly by contractors not based in Sutherland this is because there had been no outlet for the timber in the region. With the creation of a market for woodchips and subsequently timber in the area, local contractors will be more willing to bid for plots of forested land for harvesting. Therefore, new opportunities for local community involvement in Borgie forest will be created.

The need for delivery of the woodchips to end users will create new opportunity for local transport companies. This also corresponds with the Scottish Executive's plans to remove 18 million lorry miles from the nation's roads each year from 2002. The distance from Borgie forest to Inverness (closest port of call for the timber presently) is around 95 miles. The maximum transport distance for the timber and the delivered woodchips combined will now be around 40 miles. Thus, saving at least 55 miles per load.

Yearly figures from Forest Enterprise for 7cm to 14cm small roundwood from Borgie forest (2002 - 2006) is around 3200 tonnes. Flowchart 8 indicates the impacts this current practice has:

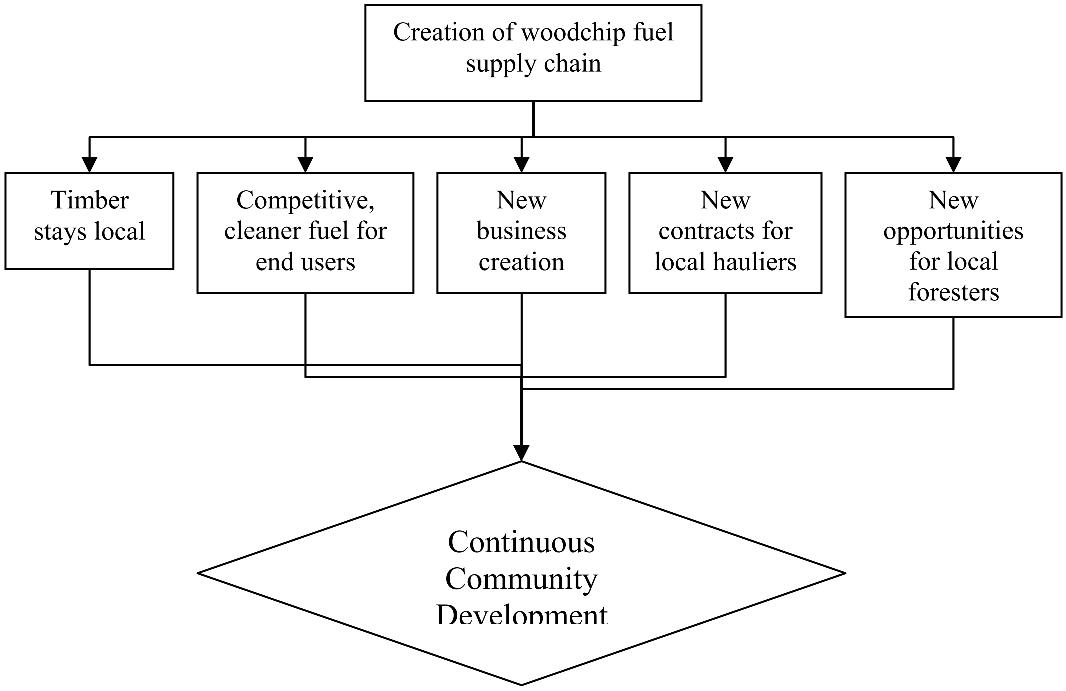



**Flowchart 8: Lorry miles made with current timber marketing practice**

With the development of the woodchip market, 5900 (more than half) lorry miles will be removed from the nation's roads accounting for at least 0.03% of the Scottish Executive's quota.

The need for processing the timber and woodchips creates the need for the development of a new local enterprise to manage the processes, oversee operations and ensure customer satisfaction. Consequently, new employment opportunities arise for at least one manager and one handler. Already existing businesses will also have the opportunity to undertake new projects such as the manual extraction of timber from the peatland areas and chipper rental.

Flowchart 9 illustrates all the new opportunities arising with the development of a supply chain for woodchip fuel.




**Flowchart 9: New opportunities**

## 7.3. The drawbacks

The main drawback in this development is that initial uptake will be slow and so profits will take some time before they materialise. This means that the payback period for any investments is quite long. For many investors that is bad news. In other words any in wishing to invest in such a project from its onset will have to take it on faith that the woodchip market will expand with time. There is no evidence for the contrary though as end users will eventually pay less for their fuel and will be helping the environment both good reasons to take up new options for heating.

Another drawback is that there is need for a large initial capital. This is needed to acquire the sheds, drying machinery, packaging etc. Furthermore, the persons employed to chip and generally process the timber and woodchips will have to be paid. One way of overcoming this problem is by applying for funding to one of the local development authorities.

As the development will help protect the environment, develop the community and reduce lorry miles on the roads, funding should be available.

# 8. Conclusions

Following the Kyoto protocol and Agenda 21 many governments have passed laws pertaining to urban development and green house gas emissions. Sustainable development is the economic and social growth that is continuous, permanent, reliable, proactive, enterprising and sharing. It is a reflection of the intricate ways with which the environment and nature operate, it is a reflection of the effects our interactions have on such a complex system. The first step has been taken through the realisation of the adverse effects of centuries of western world "development". The second is to realise that everyone and anyone can harm or protect the environment. In both cases one action can lead to a multitude of reactions or implications or small impacts. Some of the harmful effects are unavoidable such as the emissions from boilers, but the *amount* of harm done can be greatly influenced; using woodchip boilers greatly reduces $SO_x$ and $NO_x$ emissions.

The future of such sustainable development relies on profit margins these in turn rely on the public. In order for the woodchip boiler concept to catch on, the woodchips have to become a competitive fuel. To achieve a competitive woodchip price without the existence of a woodchip market the supply chain has to be as cost effective as possible. And so, influenced by an already existing cost calculator developed by NHFT and David Palmer, a generalised approach to costing the processes involved in the supply chain was developed. The costing was based on the initial moisture content of the timber, the drying techniques applied, and the timber acquisition type. The results, presented in a graph allow for a quick comparison of prices and an overview of fuel competitiveness.

The supply chain consists of the timber harvesting, its comminution, the woodchip drying, the packaging and the delivery. Flowcharts have been developed throughout this thesis to allow for easier identification of the available possibilities in development. The most common technologies are many and varied. There are also many parameters to consider such as the condition of the forest soil, the accessibility into the forest, the surrounding road structure and state of repair and so on.

These parameters influence the choice of technology as much as available capital and running costs do.

Harvesting greatly depends on the forest ground and type. In most cases the costs are unavoidable and necessary for safety reasons. Certain possibilities to cut costs exist for chipping as machinery can be rented as and when it is needed, therefore reducing capital costs. But the choice of chipper itself depends on whether or not a uniform woodchip size is required. Drying is most probably the most important of processing operations as it determines the calorific value of the woodchips (the dryer they are the higher their calorific value the better they combust). There are many drying techniques, the most inexpensive one would be open air drying as no equipment is needed, apart from a shelter from the rain. It is the other hand a very slow process and it heavily depends on local climatic conditions. A comparison of drying techniques was made based on approximate drying times, installations needed, costs and process emissions. This was done in order to generalise the decision making process for choosing a drying technique. In the case of an expanding North Sutherland woodfuel market for example, the cheapest option isn't necessarily the best. A hot air dryer would be a very good investment that would prove invaluable as the market expands and production times become an issue affecting end user satisfaction. Solar drying, in this instance, although cheap and environmentally friendly is not suited to the weather conditions in the North Highlands.

Transport is also a large factor affecting the woodfuel price. Lower transportation costs can be achieved by drying which reduces the woodchip's weight. Distances also have to be looked into and made as small as possible cutting costs and pollution levels.

Timber is extracted all year round but woodchips are mostly needed during the heating season as operations will follow the harvesting schedule and not the end user needs; a storage area is vital as even dry chips decompose if left to the elements for long. Therefore. in order for the supply chain to function properly there should be a centre of operations. The sheds, recently up for bid near Forsinain Forest for example, seem to be the ideal place for this centre.

Most processes can be carried out within those sheds and most importantly storage. Along with the woodchip processing operations the Sheds can be used for other community operations as well such as log cabin assembly and so on.

The effects of developing a woodchip fuel supply chain, on the community are varied but most importantly new opportunities for business development and employment will become available. In addition, to community development the developments can help mitigate global warming by using a renewable and carbon friendly source of energy. For example, a new timber market will also indirectly allow for greater biodiversity within the North Highland's forests.

The case study made for North Sutherland proves the effectiveness of the methodology developed especially as it allows for different scenarios to be studied (market expansion scenario and single end user scenario). These different scenarios were developed because the proposed drying and acquisition solutions were not universally cost effective. Transport, harvesting and chipping solutions were dictated by site specific particularities but drying and acquisition have to do with available resources and market expansion. In particular the expanding market scenario incorporates hot air blast drying of timber bought standing, whereas the single end user scenario open air drying of timber bought on roadside as the most cost effective solution.

The flowcharts and cost calculations are useful tools that allow for initial decisions to be made at a glance, thus saving time and leaving room for further work to be done in other areas of development.

Future work on this type of project should be done on drying time prediction. The processes and affecting parameters are quite intricate but the end result would be a much needed tool for developers.

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## Appendix I: Photosynthesis

Photosynthesis is the synthesis of organic structures and chemical energy stores by the action of solar radiation. The overall process can be depicted by the following reaction (neglecting a large number of intermediate steps):

$$CO_2 + 2H_2O \rightarrow O_2 + [CH_2O] + H_2O$$

The figure below lays out the photosynthetic process in more detail:

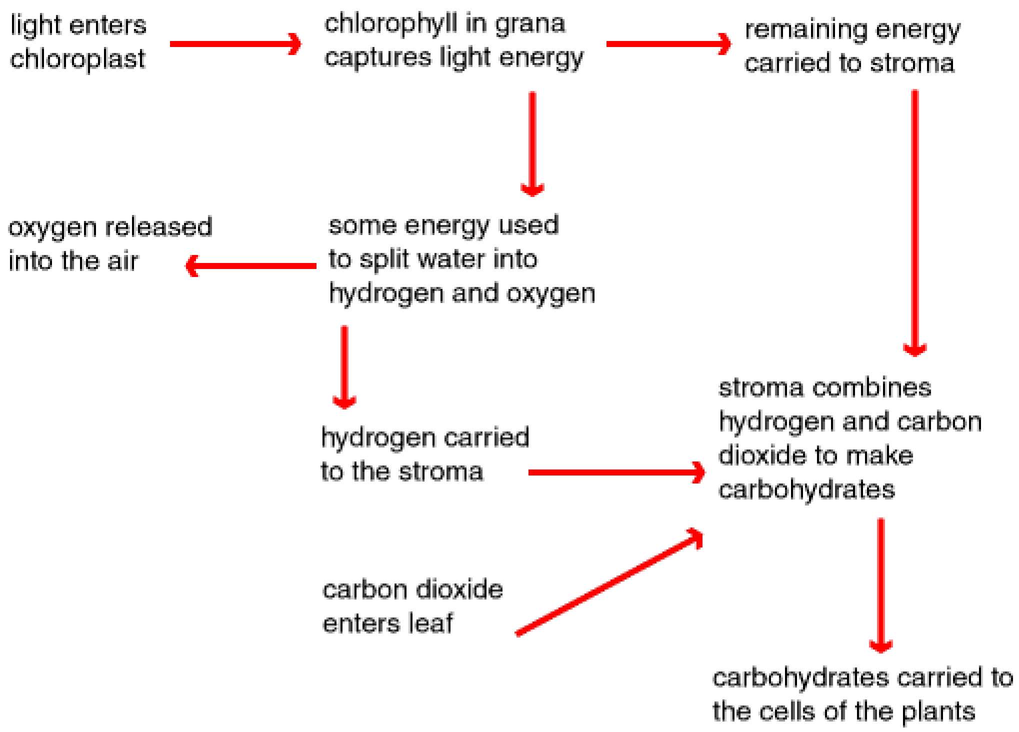



**Figure 16: The photosynthetic process**[49]

[49] http://www.alienexplorer.com/ecology/e62.html

# Appendix II: Cost calculations

| Item | Type | | | Price £/tonne | Price £/tonne | Price £/tonne |
|---|---|---|---|---|---|---|
| Acquisition: | Standing | | | | 2 | |
| | Harvesting | | | | 14 | |
| | transport: | 0.2 | miles | 10 | 2 | |
| | | | | | | |
| | road side | | | | | 18 |
| | transport | 0.2 | miles | 10 | | 2 |
| | | | | | | |
| Chipping | | | | | 5 | 5 |
| Drying | roadside | | | 0 | | |
| | open air | | | 0 | | |
| | air blast | | | 6 | | |
| | hot air blast cheap | | | 7 | | |
| | hot air blast expensive | | | 23 | | |
| | kiln | | | 25 | | |
| Transport | Weight | 0.2 | 0.87 | 40 | | |
| | | | factor | | | |
| | initial MC | 30 | 0.884615 | | | |
| | | 35 | 0.851852 | | | |
| | | 40 | 0.821429 | | | |
| | | 45 | 0.793103 | | | |
| | | 50 | 0.766667 | | | |
| | | 55 | 0.741935 | | | |
| | | 60 | 0.71875 | | | |
| | | 65 | 0.69697 | | | |
| | | 70 | 0.676471 | | | |
| | | 75 | 0.657143 | | | |
| | | 80 | 0.638889 | | | |
| | | 85 | 0.621622 | | | |
| Handling | | | | | 5 | 5 |
| Packaging | | 15 | 0.63 | | 23 | 23 |
| Delivery | | 1 | | | 1 | 1 |
| | | | | | 52 | 54 |

**Table 6: List of values used to produce costs**

| moisture content | roadside | open air | air blast | hot air blast at min cost | hot air blast at max cost | kiln |
|---|---|---|---|---|---|---|
| 30% | 59 | 59 | 65 | 66 | 82 | 84 |
| 35% | 59 | 59 | 65 | 66 | 82 | 84 |
| 40% | 59 | 59 | 65 | 66 | 82 | 84 |
| 45% | 58 | 58 | 64 | 65 | 81 | 83 |
| 50% | 58 | 58 | 64 | 65 | 81 | 83 |
| 55% | 58 | 58 | 64 | 65 | 81 | 83 |
| 60% | 58 | 58 | 64 | 65 | 81 | 83 |
| 65% | 58 | 58 | 64 | 65 | 81 | 83 |
| 70% | 57 | 57 | 63 | 64 | 80 | 82 |
| 75% | 57 | 57 | 63 | 64 | 80 | 82 |
| 80% | 57 | 57 | 63 | 64 | 80 | 82 |
| 85% | 57 | 57 | 63 | 64 | 80 | 82 |

**Table 7 : Costs of timber bought standing (£/tonne)**

| moisture content | roadside | open air | air blast | hot air blast at min cost | hot air blast at max cost | kiln |
|---|---|---|---|---|---|---|
| 30% | 113 | 113 | 119 | 120 | 136 | 138 |
| 35% | 113 | 113 | 119 | 120 | 136 | 138 |
| 40% | 113 | 113 | 119 | 120 | 136 | 138 |
| 45% | 112 | 112 | 118 | 119 | 135 | 137 |
| 50% | 112 | 112 | 118 | 119 | 135 | 137 |
| 55% | 112 | 112 | 118 | 119 | 135 | 137 |
| 60% | 112 | 112 | 118 | 119 | 135 | 137 |
| 65% | 112 | 112 | 118 | 119 | 135 | 137 |
| 70% | 111 | 111 | 117 | 118 | 134 | 136 |
| 75% | 111 | 111 | 117 | 118 | 134 | 136 |
| 80% | 111 | 111 | 117 | 118 | 134 | 136 |
| 85% | 111 | 111 | 117 | 118 | 134 | 136 |

**Table 8: Costs of timber bought at roadside (£/tonne)**

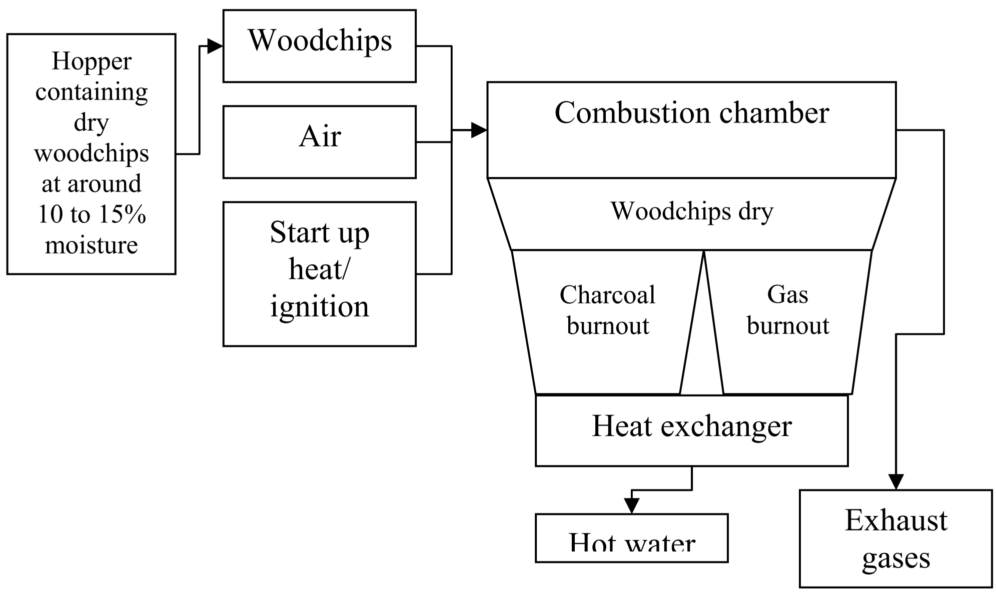
## Appendix III: The Operation of Woodchip boilers

The type of fuel must match the requirements of the system for both handling and burning; this has to do mainly with moisture content and chip size specifications. If the chips are too moist they might not ignite or go out in the process, if they are too small they might be blown away by the air circulation fan.

After ignition gases are produced that burn as flames, the solid particles that remain glow and slowly urn to charcoal that must burnout for complete combustion. The woodchips themselves pass through three stages:

- Drying
- Gasification and combustion
- Charcoal burnout

This leads to the production of ash that is deposited in a chamber below the combustion bed and should be removed at regular intervals. This ash can also be used as a nutrient supplement for trees. A hopper is used as fuel storage, it is directly connected to the fuel feed system of the boiler and woodchips are fed into the combustion chamber as and when needed.




**Flowchart 10: Woodchip boiler operation**

## Appendix IV: List of Interviews and Meetings

| | |
|---|---|
| Wednesday the 15th of May: | Meeting with Mr Jon Priddy, Chairman of the North Highland Forest Trust |
| Friday 24th and Saturday 25th of May: | Attended the Heating up on Wood 2 - developing small woodfuel heating systems, Conference. |
| Sunday the 7th of August: | Meeting with Mr. Sandy Murray, Chairman of the North Sutherland Community Trust |
| Monday the 8th of August: | Meeting with Mr. Tim Cockerill, Forestry Commission |
| | Meeting with Mr. Donald McLean, Forestry Contracting Association. |
| Tuesday the 9th of August: | Meeting with Mr. Jim Johnston, Secretary of Tongue and Farr Sports Association. |
| Wednesday the 10th of August: | Meeting with Mr. Roddy Laing, Manager of the Dunrobin Sawmill |
| | Meeting with Mr Jon Priddy, Chairman of the North Highland Forest Trust |
| Monday the 25th of August: | Meeting with Mr David Palmer, Director of the Campbell Palmer Partnership LTD. |

## Appendix V: Mind-map of thesis considerations