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Biomass Evaluation: Including a Case Study on Woodchip Utilisation at Ardverikie Estate, Kinlochlaggan

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Declaration of Author's Right

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  'Remember the banana, when it left the bunch it got skinned'!

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Abstract:

The study looks at the applications, implications and current state of affairs of biomass in general, with particular focus on forestry biomass. The forestry derived biomass concept is explained and the applications are explored. The study has a particular relevance to the problems of climate change and Man's degradation of the environment. It looks at the issues involved, taking into account the 'three pillars of sustainability', namely Economics, Environment and Engineering.

The thesis presents a case study on the Ardverikie Estate at Kinlochlaggan, Scotland. This case study assesses the feasibility of heating the many Estate buildings with woodchip fuel, harvested in a sustainable fashion from the considerable woodlands on the Estate. The study has at its foundation the 'three pillar' model as described above. It also assesses the future trends of such a biomass approach, taking into account the likely future demands in the surrounding areas together with future business opportunities. It also emphasises the desirable displacements of traditional fossil derived fuels such as oil and gas.

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1. Introduction

'Human beings and the natural world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and on critical resources. If not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms. They may so alter the living world that it will be unable to sustain life in the manner that we know. Fundamental changes are urgent if we are to avoid the collision our present course will bring about.'

- *World Scientists' Warning to Humanity, 1992*

1.1 Mankind and the Demand for Energy

It is prudent perhaps to begin with an overview of the driving forces that have brought mankind to a crossroads in time. This crossroads presents itself as a series of stark choices which will have to be made if mankind's survival and indeed the survival of many species of flora and fauna are to be assured. We in the West live in an industrialised society, a consumer society, where the supply of energy is the keystone element. It has been taken for granted that energy is freely available to power our economic system. At the core of consumerism is unsustainable energy demand. This is causing untold environmental damage through rapid exploitation of finite resources and resultant pollution of our biosphere, mainly through the accelerating use of fossil fuels and other less acceptable energy sources such as nuclear.

Our increasing use of fossil fuels cannot continue unchecked. Western society, with its inherent economic beliefs and driving forces, has largely driven the demand for energy. This energy demand is rising at an almost exponential rate. Population growth is a major factor but the western nations with their shrinking populations demand ever increasing amounts of energy, far in excess of their 'Third World' neighbours. Another factor is the drive of these latter nations to industrialise and follow the 'example' of the West. Who can blame them?

The pursuit of profit appears to be the driving force. Large multi-national corporations are becoming ever more powerful, often with more influence than governments. Countries round the globe are being drawn into this system, one of 'globalisation'.

1.2 Energy & Entropy

Entropy: *'Measure of the amount of energy which is no longer capable of being turned into work'*

It is useful to have a fundamental understanding of the reasons for the existence of our industrialised society and its associated demands for energy. This enables an informed and reasoned debate to be undertaken when considering the whole sustainability question. The human race has undergone major changes throughout its (brief) history on the planet. These changes happen at specific times and they happen for good reason. The simplest analogy for change is that of the 'entropy watershed'.

■ The First Law of Thermodynamics can be stated thus:

> **'The total Energy content of the Universe is a constant'**
> i.e. energy cannot be created or destroyed, merely transformed
> from one kind to another.

■ The Second Law of Thermodynamics can be stated thus:

> **'The total Entropy is continuously increasing'**

The entropy law entails that the Universe at large is moving from a state of order to a state of disorder. This is true for any isolated system like the planet Earth, with the exception of the incoming solar flux. The human technological and consumer society transforms raw materials into valuable goods at the price of increasing global entropy. At large, it creates disorder.

If we look at a typical energy conversion process, this demonstrates the concept of increasing entropy: see Fig. 1

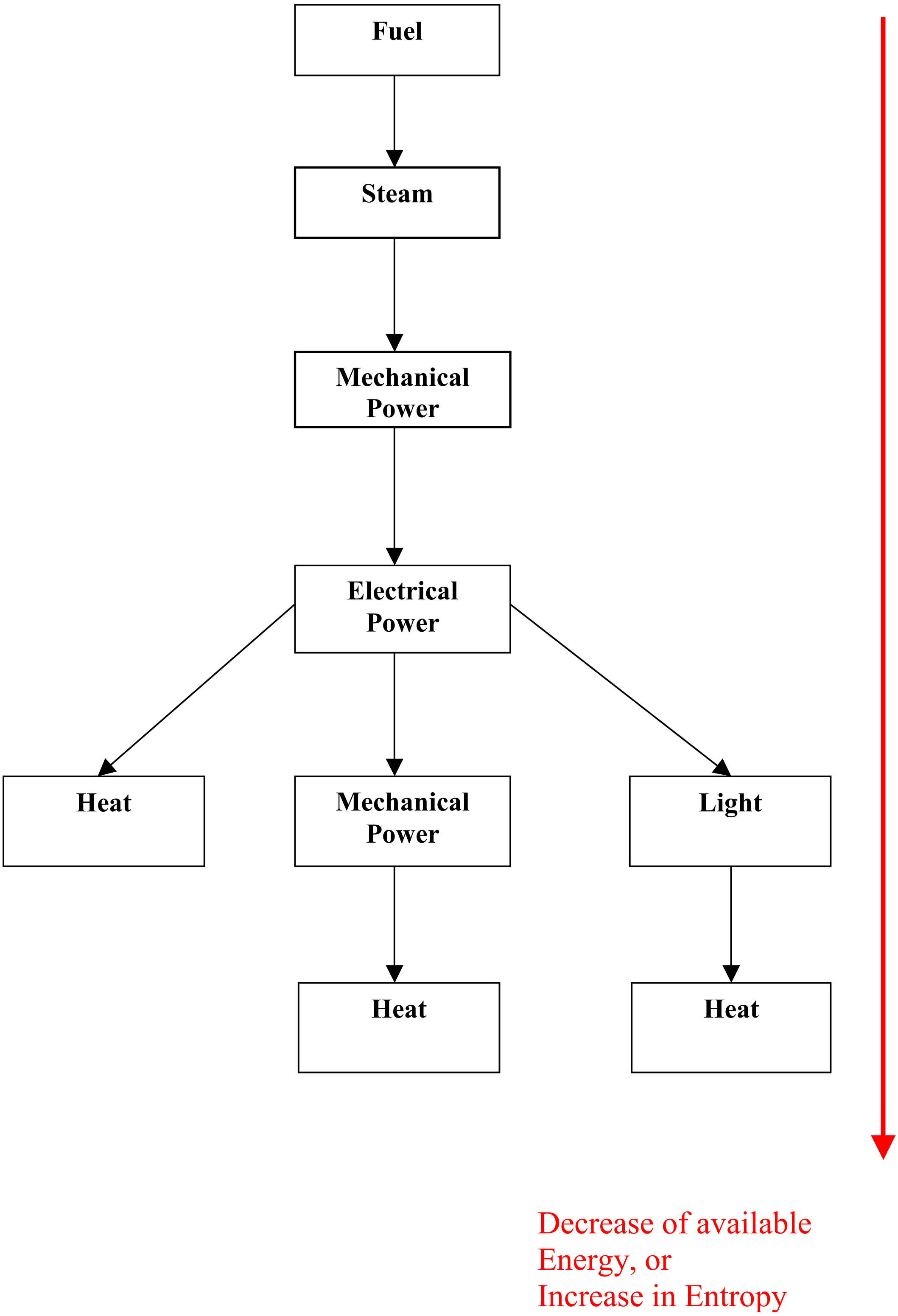


Fig. 1: Entropy [1]

1.3 The Watersheds

■ <u>*Watershed*</u>: *'Turning point in affairs'*

It is useful to understand the core reasons for energy demand, the historical perspectives, how it came to be and, above all, how we can rise to the challenges of sustainability as a means of powering our system thus ensuring the survival of our planet and our race.

The scenario of watersheds is a useful means of charting the development of humankind's energy demands. The maxim, 'nothing happens without a reason' can be applied here. Fig. 2 illustrates the watersheds from an energy basis:

Watershed	Time	Energy Source	Reason
Neolithic System	-8000 years	Wood, watermill, windmill	Hunter-gatherer to farmer
Medieval Technical System (Advanced Neolithic)	1000 AD	"	Continuation, access to new resources, creation of increasingly affluent society
First Industrial System (Industrial Revolution)	1750 – 1850	Coal	Coal mining, Metallurgy, Machine tools, Steam engine, Textiles
Second Industrial System	1850 – 1940	Oil	Automobiles, Chemical industry, etc
Third Industrial System	1940 -	Nuclear Fission	The technology of warfare. Peacetime use of vast energy resource
Fourth System of Sustainable Development?	21st Century	Sustainable Technologies? / Nuclear Fusion?	Nature's intolerance to the current system. Extinction / Salvation?

Fig. 2: The watersheds [1]

The pattern can be summarised thus:

- Technical evolution is the discontinuous change between discrete technical systems occurring when an entropy watershed is crossed.
- People living in a given technical system always eliminate people living in the previous technical systems. Technical evolution is irresistible and irreversible.
- Technical evolution is ambiguous and ambivalent depending on what side of the entropy watershed one sits.
- Technical evolution is a fast and accelerating process of entropy increase, which anticipates the natural extinction of humankind by depleting our capital of resources. (A future watershed, perhaps resulting in colonisation of other planets?)

The Vicious Circle, Fig. 3: for each successive revolution, more energy is required, speed increases and efficiency decreases.

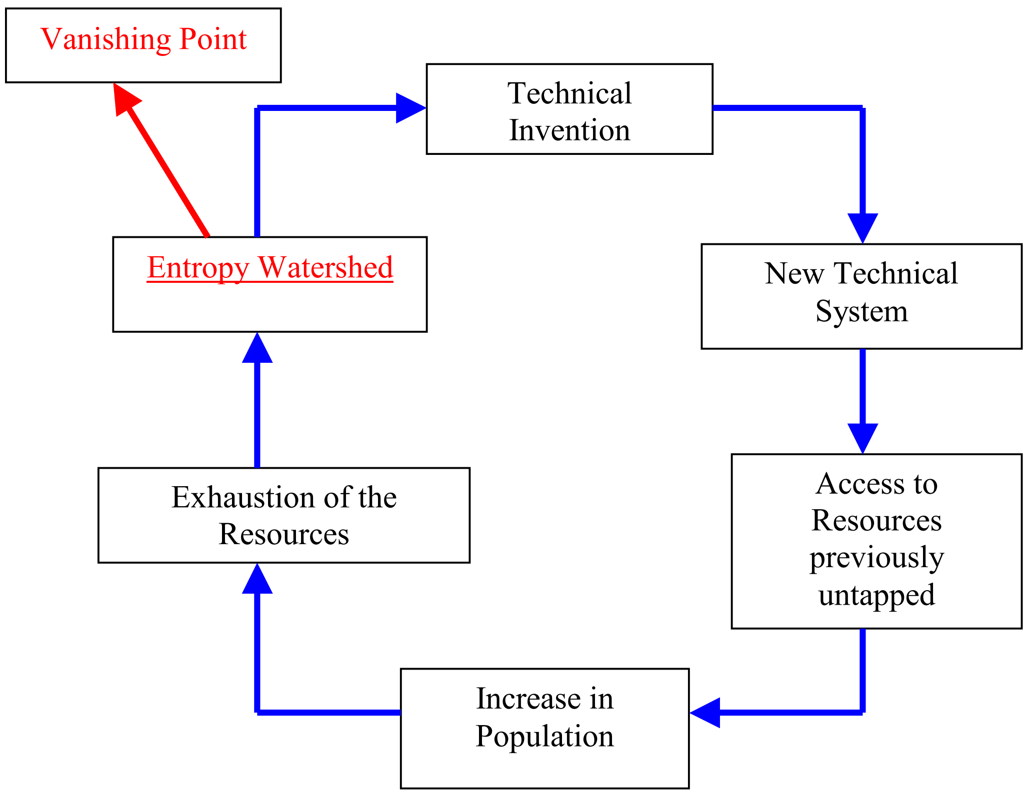


Fig. 3: The vicious circle [1]

2. Sustainability

'The level of consumption that we identify with success is utterly unsustainable. We're gobbling up the world'

- *John Robbins*

2.1 Sustainability Defined

The definition of sustainability can be described thus:

- *'Able to continue indefinitely; the capacity to continue indefinitely'* [2]

- *'Sustainability requires devising ways of life which are dependent upon the mutual interaction of humanity with the current account renewable resources of the ecosystems of the biosphere ... We need to design suitable life structures which function as self-sustaining systems, so that human activity contributes to the dynamic balance of the whole'* [2]

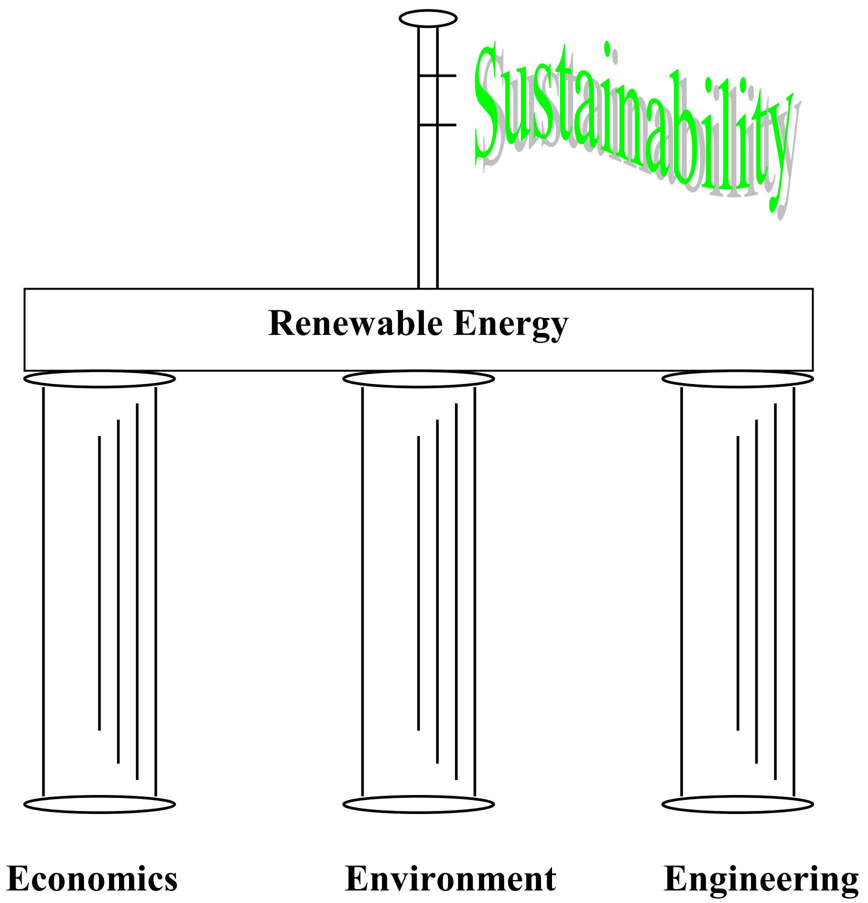


Fig. 4: The Three Pillars of Sustainability [3]

2.2 World Fossil Fuel Reserves

It is worth looking at the estimated world reserves of fossil fuels and to realise that the next watershed is looming fast. Fig. 5 gives an estimate of the global energy reserves. Fig. 6 shows the total fossil fuel energy reserves by nation. These estimates were made in 1996. Fig. 7 illustrates the world annual fossil fuel energy production over the period 1970 to 1996. The total fossil fuel energy production is shown with a linear fit using the *y=mx+c* straight-line formula (regression and correlation: r^2 is the coefficient of determination).

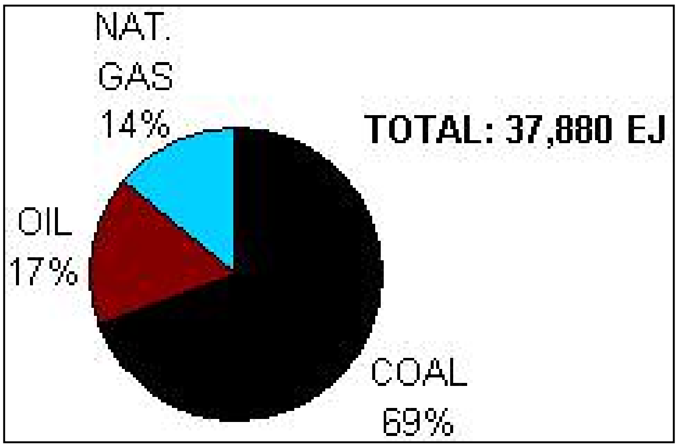


Fig. 5 Estimated global energy reserves (1996) [4]

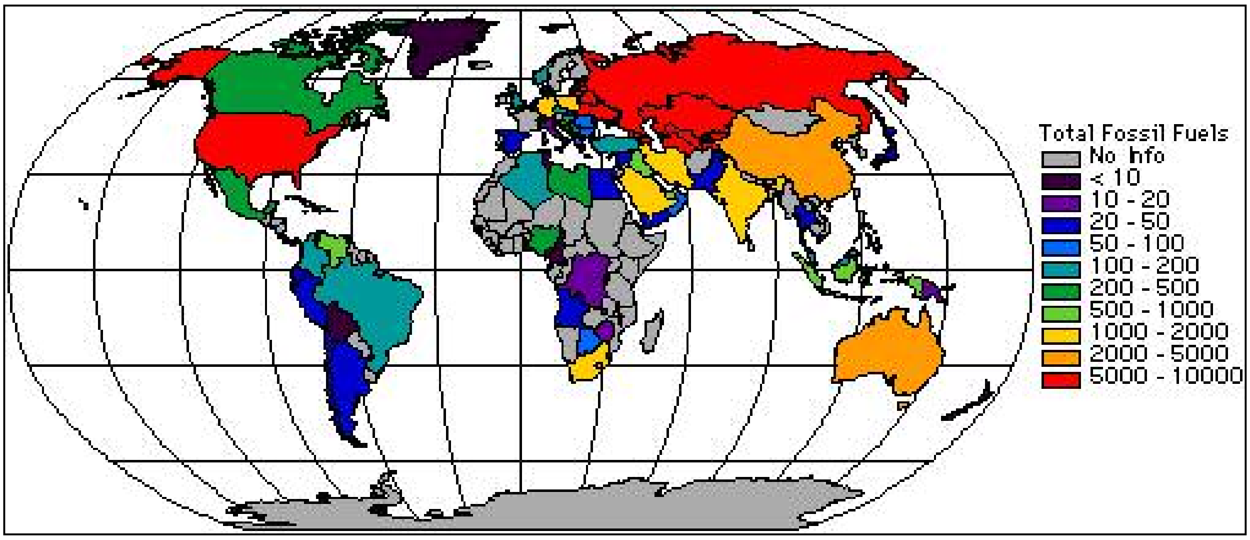


Fig. 6: Total fossil fuel energy reserves (EJ) by nation (1996) [4]

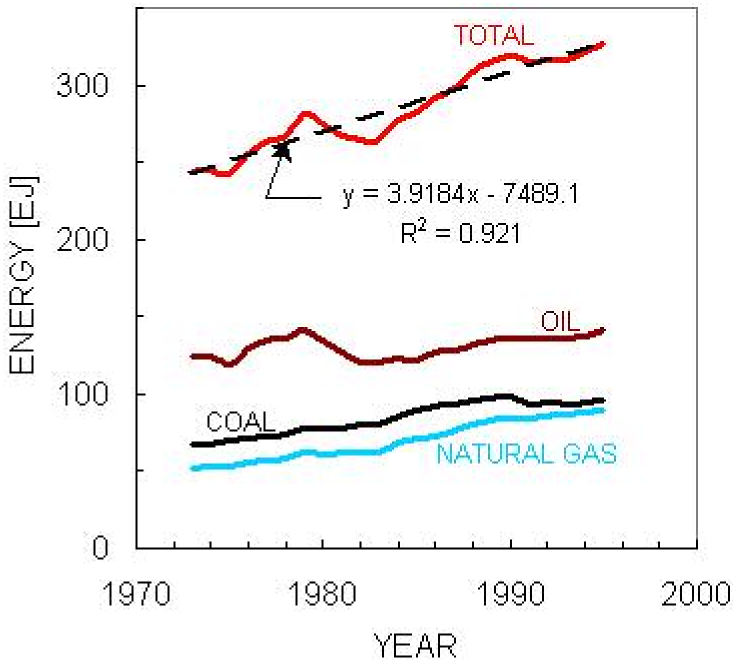


Fig. 7: World annual fossil fuel production (1996) [4]

From Fig. 7, two estimates can be made on the time duration before fossil fuels run out on planet earth:

Estimate #1: If the rate of fossils fuel energy use is taken to remain the same as in year 1995 (estimated at 327.3 EJ/year) for each year thereafter, then the fossil fuel energy resources will be exhausted in the year 2111. [4]

Estimate #2: If an assumption is made that the rate of fossil fuel energy consumption continues to increase in a linear fashion for every year after 1995, then the reserves will be gone by the year 2074. [4]

Of course, these estimates are no more than crude indicators. The fossil fuel use in the future years may be affected by many factors, namely political, economic, environmental, etc. What is beyond reproach is that the fossil fuel reserves on earth are finite and they will definitely run out within a short time if they continue to be used at increasing rates. There is a major need to consider NOW what our alternatives will be. Another entropy watershed surely looms. Perhaps in a perverted sort of way Nature will ensure re-alignment of the balance.

2.3 Renewable Energy

A paradigm shift must be made in our traditional energy policies, towards a sustainable energy system. The world population demand for energy is causing irrevocable damage to the environment through the huge releases of 'greenhouse gases' into the atmosphere. Fig. 8 illustrates the 'Greenhouse Effect'.

Rachel Carson published her book, 'Silent Spring' in 1962. Her book helped to instigate the contemporary environmental movement.[5] The United Nations Environment Programme was first set up after the United Nations Conference on the Human Environment, held in Stockholm in 1972. In the late 70's, UNEP compiled three comprehensive reports on the impacts of the production and use of fossil fuels, nuclear energy and renewable energy sources. [6]

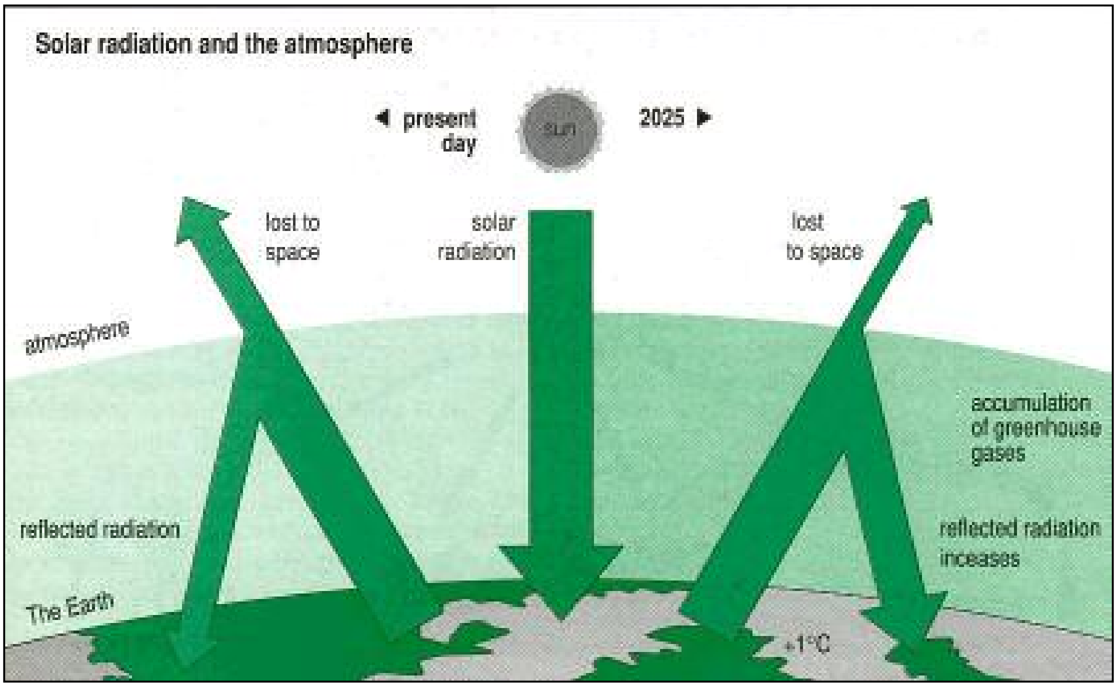


Fig. 8: The Greenhouse Effect [7]

In 1987, The World Commission on Environment and Development (The Bruntdland Commission) placed the concept of sustainability centre-stage. [7] This concept was the result of work carried out by Gro Brundtland, the Prime Minister of Norway. From 1983 to 1987, public hearings were conducted throughout the world, to review the concept of sustainability. The Commissioners' conclusion was that our common future depends on *sustainable development*. There has been considerable on-going concern over the Environment and many nations have at last woken up to the fact that the Planet is in for a rough time if nothing is done. The Kyoto summit, held in Japan in 1997, formally listed the following greenhouse gases:

- Carbon Dioxide (CO_2)
- Nitrous Oxide
- Hydrofluorocarbons
- Methane
- Perfluorocarbons
- Sulphur Hexafluoride

The Kyoto summit brought the majority of the nations of the world to the negotiating table and the result was a commitment to reducing the greenhouse gas emissions to agreed targets as follows:

► Reductions Agreed:

EU countries	8%
USA	7%
Canada, Hungary, Japan, Poland	6%
Croatia	5%
Russia, Ukraine, New Zealand	0%

► Exceptions Permitted:

Norway	Increase of 1%
Australia	Increase of 8%
Iceland	Increase of 10%

Fig. 9 gives an indication of the rising global carbon dioxide levels. The seasonal cycles are apparent but as can be seen, the trend is upwards. Fig. 10 shows the effect on global temperature from 1860 to the present day, the trend also being upwards. Fig. 11 models the projections for global temperature rise to the year 2100.

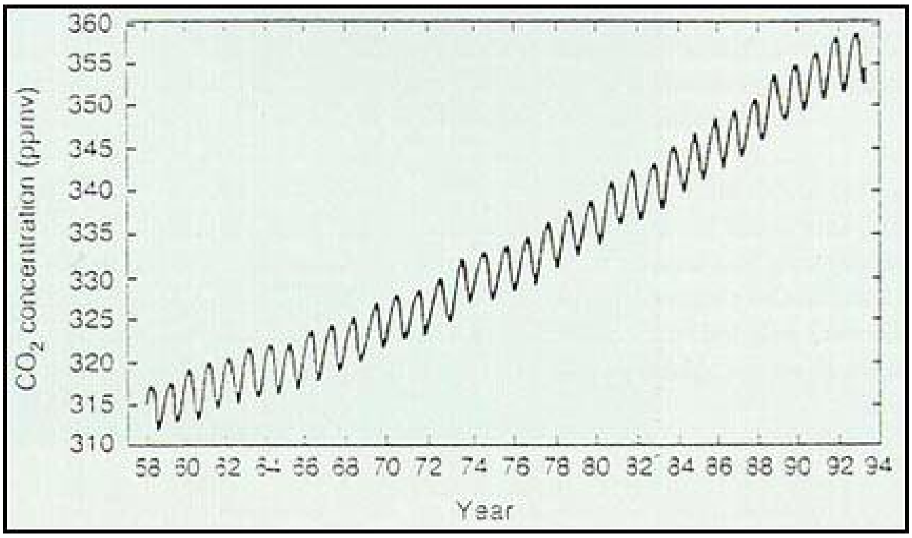


Fig.9: The rising global carbon dioxide levels [8]

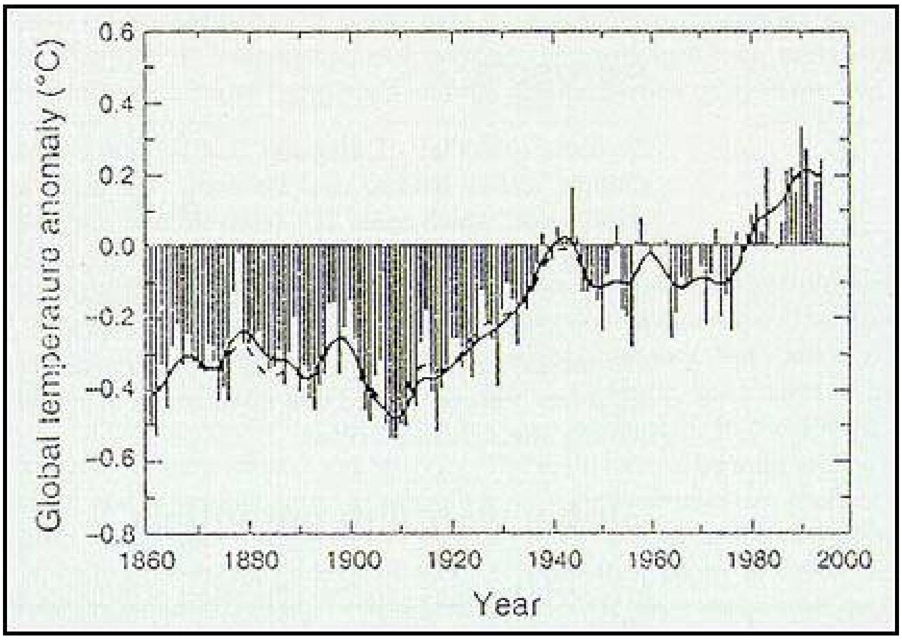


Fig.10: Combined land surface, air and sea surface temperatures since 1860 [8]

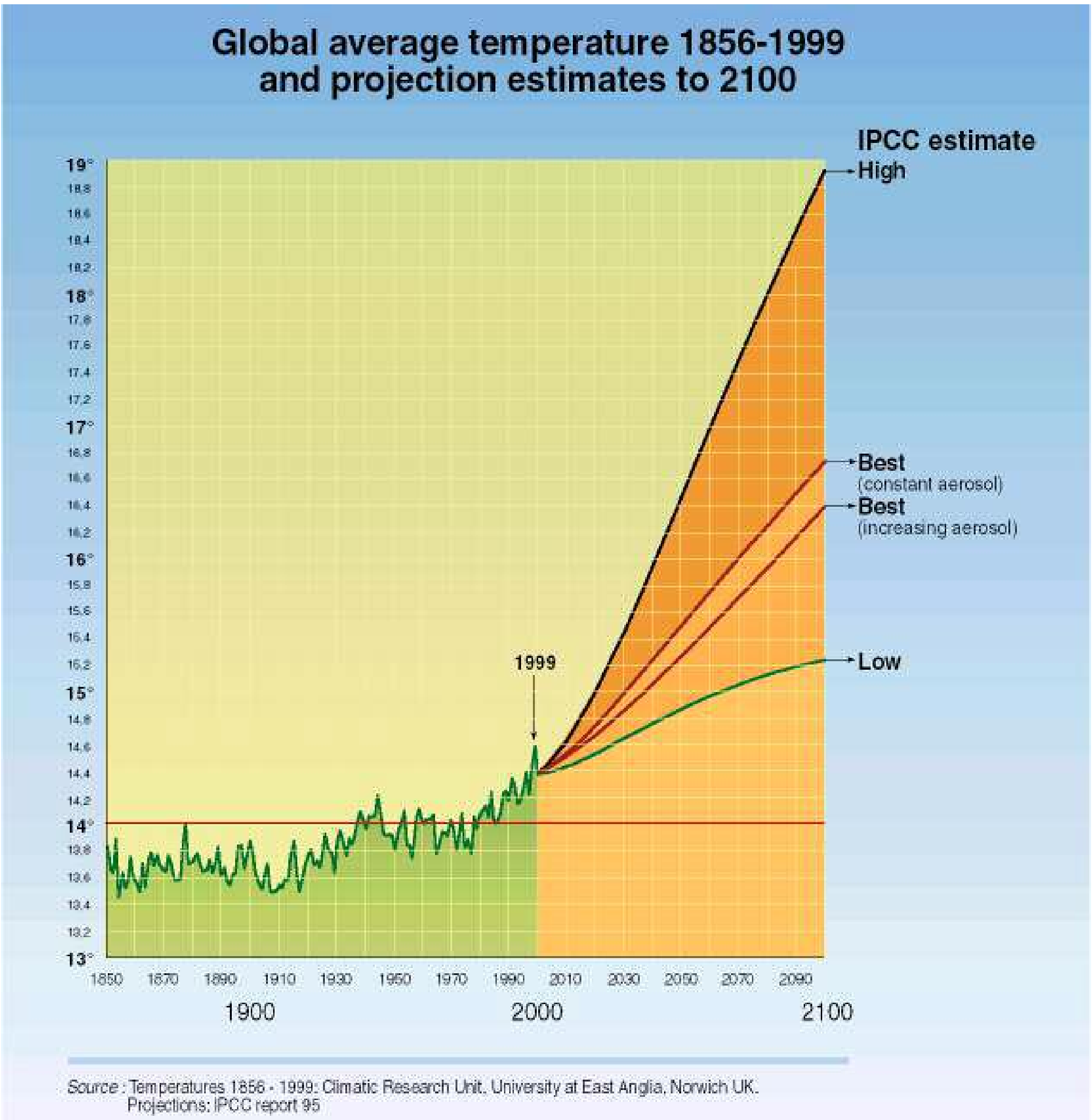


Fig.11: Average global temperature rise projection [9]

Today's societies, with their predominantly fossil fuel based energy dependencies, are facing two major issues with respect to their future fuel supplies. Firstly, the fossil fuel reserves are finite and these fuels are becoming scarce. The second issue is that the environmental degradation associated with their accelerating use is becoming ever more apparent. Sustainability has opened up many new areas of research in pursuit of new and renewable energy sources, which are continuously and sustainably available in the environment. It should be emphasised that these sources release significantly lower levels of environmental pollutants than conventional sources of energy. Ideally they emit no greenhouse gases or are 'neutral' over their life cycle (i.e. carbon balanced). New and renewable energies present new challenges for humankind. There are many avenues open to the development and exploitation of these energy sources.

New and renewable energy sources can be highlighted as follows:

- Wind Power
- Solar Energy (Passive, Active, Photovoltaics)
- Water Power (Hydro, Wave, Tidal)
- Biomass (The theme of this thesis)
- Fuel Cells

Renewable energy sources typically have lower energy concentrations when compared to fossil fuels. There is a dependence on natural processes involving for example, the weather, geographical location, etc. Depending on the renewable source, security of energy supply can be inferior to that of typical fossil fuels.

There are many technologies involved in renewable energies. Depending on investment and political-will to grasp the challenges, the levels of maturity vary from technology to technology and indeed from nation to nation. Most renewable technologies are small-scale and are usually of a modular concept, utilised close to the resource. These small-scale technologies can often be located many miles from large load centres. The implications could be multiple devolved energy sources rather than the centralised, limited number of energy sources current in use, e.g. power stations.

Renewable energy resources are estimated to meet between 15 and 20% of the current global energy consumption. This figure drops to around 6% in the European Union. Medium term, the picture is one of increasing contribution and long-term, the picture is more optimistic, with a very substantial role being played.

The pressure is on for most countries to institute policies and programmes to assist the renewables to become established and also to become competitive in the global market place. Indeed, the World Bank, the International Finance Corporation and the Global Environmental Facility have all initiated aid schemes. The aim is to promote the use of renewable energy in developing countries as a means of limiting greenhouse gas emissions while at the same time assisting their economic development.

The World Energy Council has made projections for renewable energy use globally and estimates on investment in these renewable energies range from £150 billion to £400 billion, between the years 2000 to 2010. Shell, the global oil giant, is making investments in renewable energy. It has estimated that renewables will meet around 40% of the world energy demand by the middle of this century. The EC (European Commission) has estimated the world market for renewables at around €37 billion in 2010, with a further €17 billion from exports into expanding markets. The European Commission has proposed a doubling of the renewable contribution to 12% by 2010. [10]

The United Kingdom government has a central energy policy, to ensure diverse and sustainable supplies of energy at competitive prices. Energy policy reasons can be listed thus: [11]

- Potential contribution to diversity and security in energy supply.
- Environmental benefits of renewables and their contribution to reductions in greenhouse gas emissions with associated climatic benefits.
- Long-term economic viability. Financial support in the early stages can help the technology to compete successfully at a later stage.

Renewable energy sources will be utilised in a portfolio of measures. They would be used in such schemes as fuel switching in power generation, between different types of fossil fuels and Combined Heat and Power schemes. One major area to be addressed is that of energy efficiency. Users of energy must take measures to improve efficiency of use. Measures such as climate change levies are useful tools to drive efficiency measures. These tie consumption of fossil fuels to increasing levels of taxation as a disincentive. This tax can be re-distributed to renewable energy research and development.

3. Biomass: What is it?

'Education for Sustainability is a lifelong learning process that leads to an informed and involved citizenry having the creative problem-solving skills, scientific and social literacy, and commitment to engage in responsible individual and co-operative actions. These actions will help ensure an environmentally sound and economically prosperous future'.

\- *The Vision of Second Nature*

3.1 Biomass: The Definition

The totality of the earth's living matter that is derived from the process of *'photosynthesis'* either directly or indirectly is termed the BIOMASS. Biomass exists on the planet in a thin surface layer called the *'biosphere'*. The biosphere accounts for a fraction of the mass of planet earth but holds an enormous storehouse of energy. [12] This store of energy has at its heart, the Sun. The source is being continually replenished.

Energy radiates from the sun at the rate of some 10^{26} watts. [12] Roughly 98% of the energy emitted into space is conveyed by radiation of wavelengths between 250 and 3000 nm. About 50% of this energy is between 350 nm and 750 nm – the region of photosynthetic activity. Only a small fraction of the Sun's emitted radiation reaches the Earth. At a specific location on the surface of the planet, the insolation is dependent on such factors as the latitude, season, time of day, cloud cover and atmospheric pollution. This all has a marked influence on earth's climate and hence the biological primary production.

The atmosphere modifies the solar spectrum: 20% of the original solar radiation is absorbed, 5% is lost by scattering and 25% is reflected back into space by clouds. The Earth's surface also reflects somewhere in the order of 5%. Around 43% of the solar energy spectrum is potentially photosynthetically active. However, only about 60% of this radiation which eventually reaches the surface of the earth is available for photosynthesis as the remainder falls on oceans, deserts and ice covered areas. The eventual biomass energy use accounts for an overall efficiency of about 0.33%. [12]

The solar energy is utilised by the multitudinous plant species. This organic matter 'fixes' the solar energy. However, it is true to say that only a fraction of this energy is actually fixed. The stored energy is recycled in a series of natural processes, involving chemical and physical mechanisms within the plant itself and the soil. The surrounding atmosphere and other living matter also play an integral role. The energy is eventually radiated away from the planet as low-grade heat. The exception is the formation of fossil fuels, such as peat and coal, which store this energy.

The cyclic process, which is at the heart of the biomass scenario, is the keystone of sustainability when we intervene to utilise the energy resources available. The biomass acts as a store of chemical energy. This chemical energy is effectively a fuel. A major fact of environmental significance should be emphasised:

- **Provided the levels of consumption do not exceed the natural level of recycling when burning biofuels, no more heat and no more carbon dioxide is released than would have been produced in any case by natural processes. This is known as the 'carbon balance'.** [12]

In essence there exists an energy source whose use does not have adverse effects on the environment. Biomass energy conversion does present its own challenges. It is perhaps the most economically, technically and socially complex renewable energy option. Biomass as a resource base is extremely diverse in its composition and its availability for use. It can often be bulky with an added expense in transport. In effect this can limit the area of use in relation to its source. To fully utilise its potential requires judicious application of a multitude of skills and expertise such as resource management, technology development and transfer as well as environmental management and management of social policies.

3.2 Photosynthesis: The Core of Energy Storage

Photosynthesis is Nature's unique mechanism of converting solar energy into stored chemical energy. Most photosynthesis reactions take place in the chloroplasts of green plant cells. The overall process can be converted into two distinct sets of reactions: the first requiring light and the second not requiring light. They are known as the *light* and *dark reactions* respectively. It should be noted that the dark reaction can operate in the presence or absence of light.

Photosynthesis can be simplified into the following equation: [13]

$$CO_2 + 2H_2O + \text{Light} \rightarrow \underbrace{(CH_2O)}_{\textit{Carbohydrate}} + H_2O + O_2$$

A major factor which limits the solar energy conversion by plant matter is what is termed the *'photosynthetic efficiency'*. Referring to the above equation:

- (CH_2O) represents one sixth of a glucose molecule
- The Gibbs free energy (ΔG) stored per mole of CO_2 reduced to glucose is 477 kJ.
- At least 8 quanta of light are required for this reaction, with the usable energy input equivalent to that of monochromatic light of wavelength of about 575 nm. 8 quanta of 575 nm light have an energy content of 1665 kJ.
- This gives a maximum photosynthetic efficiency of $477 \div 1665 = 0.286$

However, since only light of wavelengths 400–700 nm can be used in plant photosynthesis, and this photosynthetically active radiation (PAR) accounts for only about 43% of the total incident solar radiation, the photosynthetic efficiency falls to 0.826 x 0.43 x 0.123.

Land plants can at most absorb 80% of PAR. Respiration can account for about one third of the energy stored by photosynthesis. This leaves 66.7%. Combining the photosynthetic efficiency with the absorption and respiration factors gives an overall efficiency for the conversion of solar energy into stored chemical energy of 0.123 x 0.8 x 0.667 = 6.6%. Typical annual conversion efficiencies are 0.5 – 1.3% for temperate crops and 0.5 – 2.3% for sub-tropical and tropical plants. [12]

3.3 Biomass as a Fuel Source

3.3.1 Biofuels

'Biofuels' is a term which decribes a very wide range of energy sources. This can range from a simple wood fire to industrial sized waste incineration plants. A definition of *'biofuels'* can be given as follows:

'Biofuels are alcohols, ethers, esters and other chemicals made from cellulose-based biomass. This includes herbaceous and woody plant matter, agricultural and forestry residues and a large portion of municipal and industrial waste materials'. [13]

Fig. 12 illustrates the world energy consumption from biomass fuel sources for 1993.

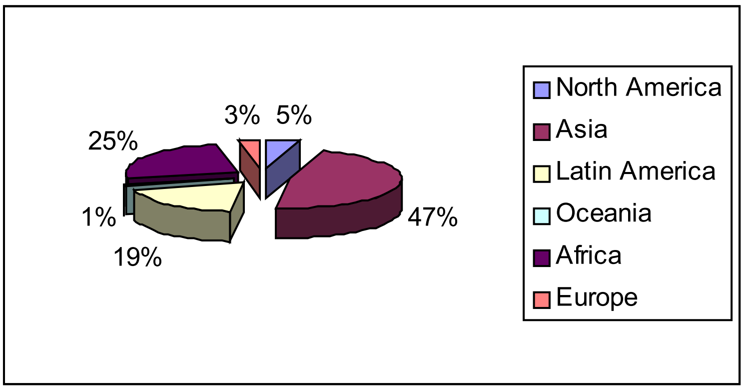


Fig. 12: Global biomass energy consumption for 1993 [14]

3.3.2 Types of Biomass

Biomass, by its definition, comprises three main categories of resource: *forestry and wood processing residues, crop residues and animal wastes*. [15]. Agricultural and forest residues are the main sources of biomass available for conversion to energy. It should be emphasised that animal dung is derived from plants. The following details plant biomass categories:

► **Woody Biomass**

Woody biomass is primarily present in natural forests and woodlands and includes the following:

(a) Trees
(b) Shrubs and scrub
(c) Forest floor litter
(d) Palms
(e) Bamboo

► **Non-woody Biomass**

Non-woody biomass can be grown specifically as a primary source of fuel for conversion to, for example, motor alcohol (ethanol). This primary source of fuel is known as an 'energy crop'.

(a) 'Energy Crops' include sugar cane and cassava
(b) Grass
(c) Cereal straw
(d) Soft stems such as pulses, potatoes, etc
(e) Cotton, cassava, tobacco stems and roots
(f) Banana, plantain, etc
(g) Swamp and water plants

► Processed Waste

These wastes are processed on an industrial scale for use in other energy intensive processes such as brick or pottery manufacturing. They include:

(a) Nut shells, flesh, etc
(b) Cereal husks and cobs
(c) Bagasse
(d) Cotton, sisal waste
(e) Sawmill waste
(f) Municipal waste
(g) Plant oil cake
(h) Fruit waste
(i) Husks and parchment

► Processed Fuels from Plant Biomass

(a) Charcoal (wood and residues)
(b) Briquettes / densified biomass
(c) Wood alcohol in form of ethanol or methanol
(d) Plant oils
(e) Bio-diesel / petrol
(f) Producer gas
(g) Biogas

Biomass fuels can provide heat, electricity and mechanical power. Fig. 13 illustrates the general Biomass options. There are five basic categories of conversion process for converting biomass to heat or fuels and these are listed below: [15]

- Direct combustion
- Pyrolysis
- Liquefaction

- Gasification
- Biochemical conversion (anaerobic digestion and fermentation)

Biomass fuels are of significant importance to the world energy supply. Granted, they rank second in importance to fossil fuels in terms of quantities used. It should be emphasised that they are the least studied and the least understood of all the fuels currently used on the planet. Traditionally it has been the norm to measure a limited set of parameters when assessing biomass reserves, particularly those present in forests. It is often the case that 'measured' standing stock is only a fraction of the actual biomass present on the site. Inventories can often fail to account for certain species and sizes of timber, e.g. stems and twigs and general forest floor litter. This is a situation, which is thankfully changing.

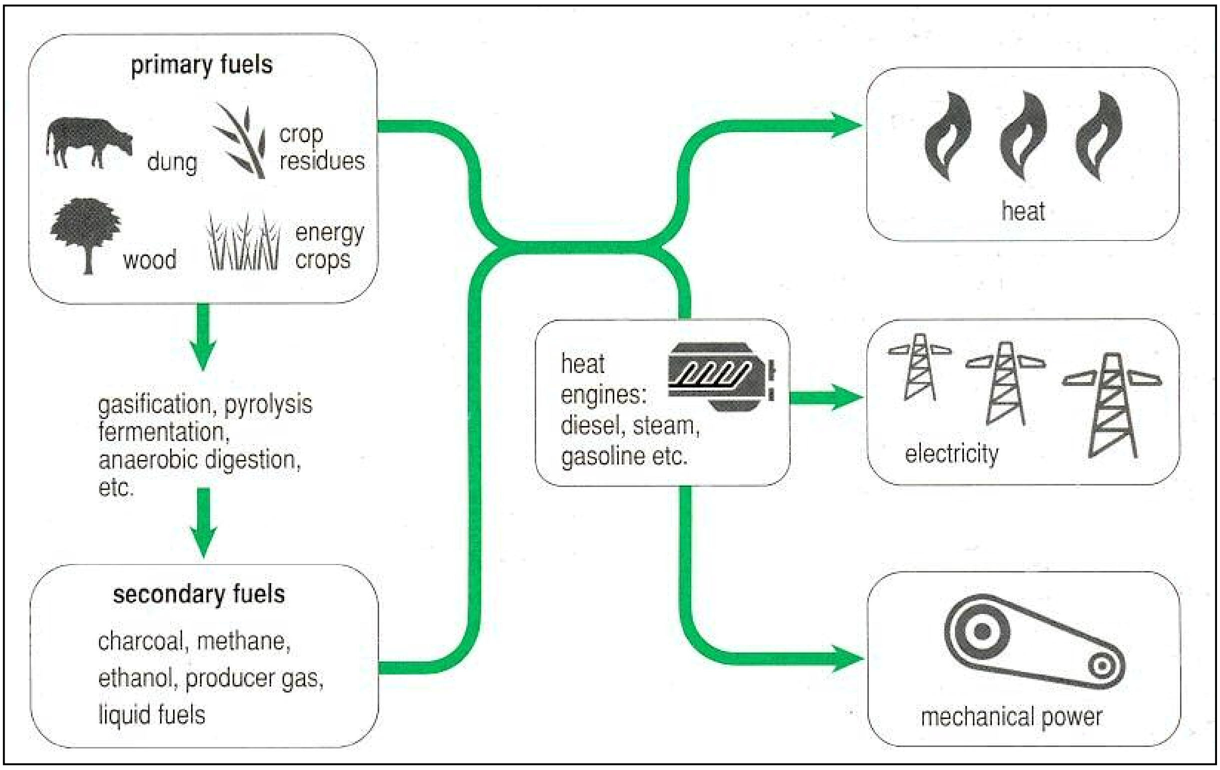


Fig. 13: Biomass Options [7]

3.4 Biomass: The Potential Hazards

It is justified to mention the potential darker side of biomass which can occur where bad planning and insufficient understanding of the processes involved are concerned. Biomass utilisation demands judicious application of land and resource management. There can be some major environmental hazards associated with incorrect use of biomass fuels. The forest resource with its genetic diversity must be protected. This includes care of the soil and food and fodder crops. It is prudent to include this section to emphasise the measures needed to ensure sustainability and care of the environment when utilising biomass. Fig. 14 illustrates some of the adverse effects.

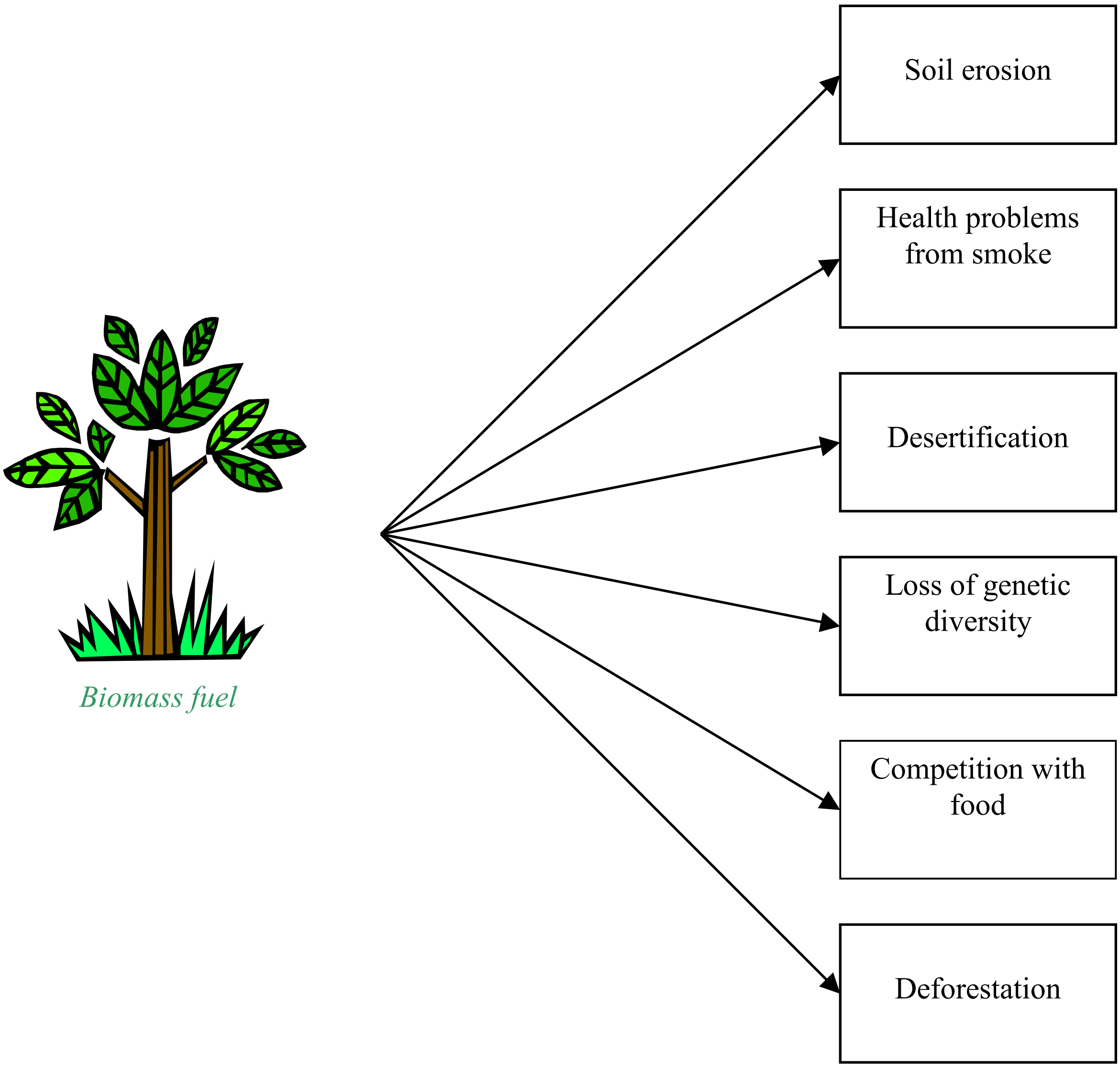


Fig. 14: The darker side of biomass [7]

In detail, the effects can be described thus: [7]

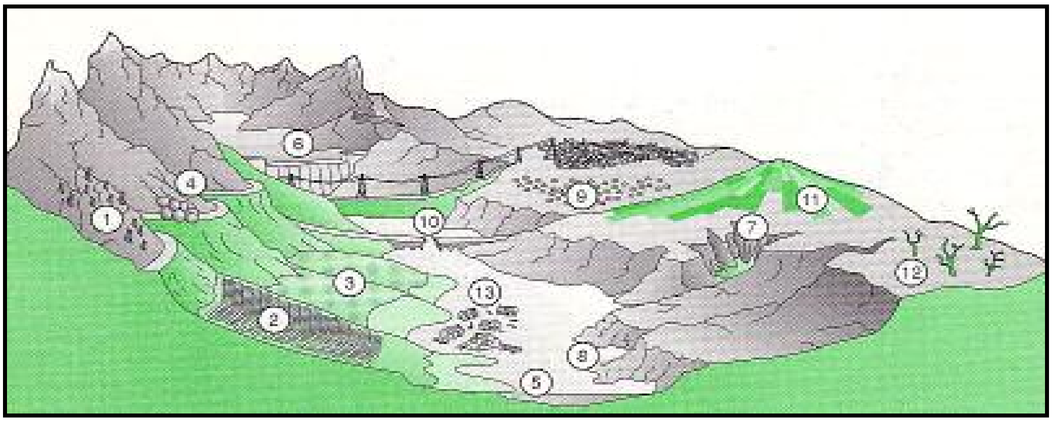
- **Deforestation:** Where trees are felled for fuel, in numbers exceeding those planted then deforestation results. It should be emphasised that deforestation usually is attributable to forest clearing for agricultural purposes and not for fuel needs. Erosion occurs as a result of deforestation, with the resulting silting up of river estuaries. Another direct effect is desertification. Fig. 15 (a) illustrates the effects of erosion and Fig 15 (b) shows the prevention measures that can be applied.

- **Loss of Genetic Diversity:** Biomass used indiscriminately e.g. the uncontrolled felling and clearing of forests, can result in the loss of indigenous species. A side effect can (particularly in rain-forest regions) be the loss of potentially valuable symbiotic plant species, many of which have been found to contain natural agents useful in the fight against disease and by implication can be useful in new drug formulations. Some of the problems with forestry mismanagement in the UK have been the removal of large swathes of indigenous tree species, to be replaced by, e.g. Sitka spruce, which is not a natural to the UK.

- **Competition for food:** Biomass used for fuel can impact on supplies available for fodder for grazing animals. This can be a problem within developing countries.

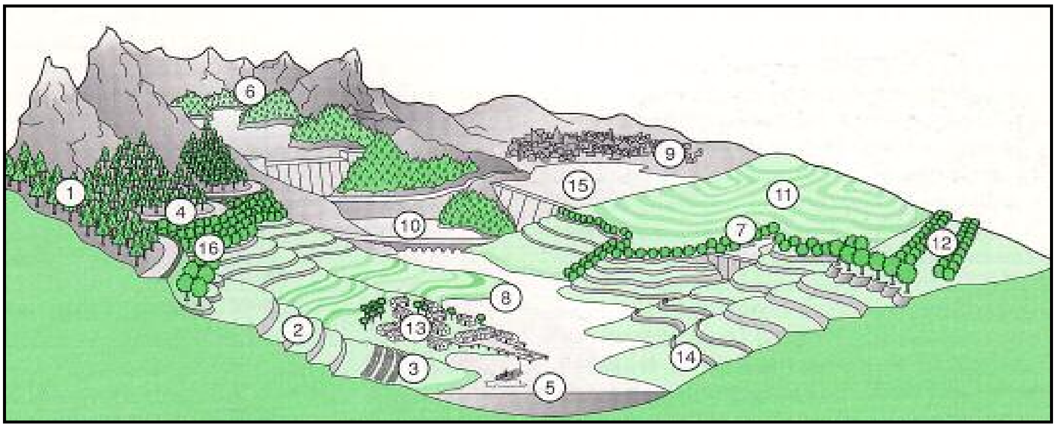
- **Health problems from smoke:** Pollutants can sometimes be released in less than ideal combustion conditions. This can be deleterious to health and would only be a problem in third world countries where biomass is burned in closed unventilated homes.

Careful management of the biomass resource can mitigate against potential adverse effects.



1- Deforested land
2- Cultivating on slope
3- Monocrops over large area
4- Landslide blocks road
5- Fish catch reduced in shallow waters
6- Silt increase, reducing hydroelectric plant life
7- Gully erosion eating into cropland
8- Mud bank: reduces river navigability
9- Urban dwellings increase
10- bridge damaged by floods
11- Crops grown on unprotected fields
12- pasture subject to wind erosion
13- Village flooded

Fig. 15(a): The effects of erosion through unsustainable deforestation [7]



1- Reforested land
2- Steep land bench-terraced
3- Contour cultivation, lower land
4- Absence of landslides
5- River navigation improves
6- Forest prevents silting of reservoirs
7- Gully erosion halted by dams/trees
8- Erosion stopped, flooding reduces
9- Population migration stops
10- Absence of flooding
11- Crop rotation on contour strips
12- Shelter belts reduce wind erosion
13- Rural services improve as village expands
14- bunds to control surface run-off
15- New reservoir for hydro-power
16- Tree crops grown on terraces on steep land

Fig. 15(b): Mitigation measures to aid sustainability [7]

3.5 Wood as a Biofuel

Wood is a key biomass resource and is the basis of this report. Wood can be burned directly as a fuel or it can be put through a conversion process to produce a secondary fuel. There is no one uniform type of wood fuel. The reality is that there are many types of wood fuels, depending on their species and the wood material (e.g. heartwood, bark, sapwood, needles and/or leaves). Fig. 16 shows a cross section of a tree, identifying the different types of materials present. There are different qualities of wood fuels, some listed below in descending order of calorific values: [16]

- Charcoal
- Dry softwood material (pellets, woodchip, shavings, etc)
- Air-dried hardwood
- Logs as direct fuel
- Spent liquor (by product of sawmill, where energy rich lignin is to be found)
- Bark

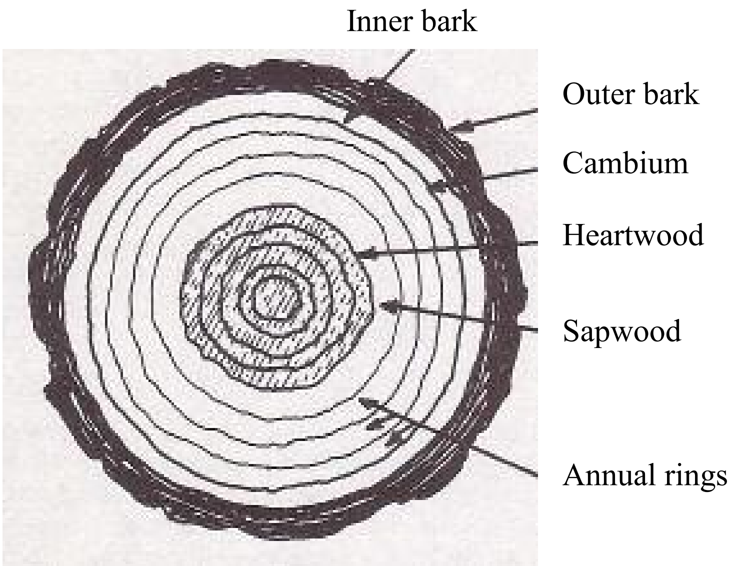


Fig. 16: Cross-section of a mature stem, showing major components [17]

3.5.1 Wood Composition

Wood is composed of a variety of chemical substances. A tree comprises a great number of minute cells which vary in size and type. Some cells are alive whilst others are dead. A tree consists of a crown, stem (or trunk) and root system. The stem is the major raw material for the primary forest products industry. Its main functions are to support the crown, transfer water and mineral nutrients throughout the extremities and to store food. There are three basic polymers present in wood, which are as follows: [16]

- **Cellulose ($C_6H_{10}O_5$)** Cellulose is the major constituent, comprising roughly 50% of weight. Cellulose is a high molecular weight polymer. During the normal growth cycle of a tree, the cellulose molecular chains become oriented to highly structured strands called fibrils. These fibrils are in turn, organised into larger structural elements that make up the cell walls of the wood fibres. Cellulose is insoluble in water and in neutral organic solvents such as alcohol, petrol, benzene, ether, etc. It will however dissolve in sulphuric and hydrochloric acids.

- **Lignin ($C_9H_{10}O_3(OCH_3)_{0.9\text{-}1.7}$)** Lignin is the next largest component by weight. The lignin content can vary from species to species. Softwoods contain around 23-33% lignin whereas hardwood species can have from 16-25% content. Lignin exists largely as an intercellular material. It has a three dimensional structure. Lignin has a high-energy content. It can be used as a fuel in the paper industry and also as a component part in drilling muds.

- **Hemicelluloses ($C_5H_8O_4$)** Hemicelluloses are polymeric units that are comprised of simple sugar molecules. They differ from celluloses in that they yield several types of sugar when reacted with acids. Hardwood species have typically 20-30% of hemicelluloses present. Xylose is the principal sugar. Softwood species have around 15-20% hemicellulose present. The main sugar component is mannose.

Other constituents include tannins, polyphenolics, colouring agents, waxes, gums, resins and starches. These constituents can comprise 5-30% of the weight among tree species and are often known as *volatiles*. There are some minor constituents such as ash-forming minerals: silica, phosphate, potassium and calcium. These can comprise around 0.1-3% of wood.

3.5.2 Wood Composition and Heating Value

As a general guide, hardwood species contain the following proportions of materials: [16]

- Cellulose 43%
- Lignin 22%
- Hemicelluloses 35%

Softwoods contain the following proportions of materials:

- Cellulose 43%
- Lignin 29%
- Hemicelluloses 28%

The different chemical compositions present in wood mean that the heat contents of wood fuels can vary. Cellulose and hemicellulose can be grouped together in a term known as 'holocellulose'. When a comparison of calorific values is made between holocellulose and lignin, it is evident that lignin has a higher energy storage. Taking douglas fir as an example, the holocellulose value is 7527 Btu/lb (4.853 kW/kg) compared to 11479 Btu/lb (7.402 kW/kg) for lignin. In addition, the volatiles can contain high-energy contents, up to 15000 Btu/lb (9.672 kW/kg). Fig. 17 emphasises the fact that there is an association between the lignin and volatile content of wood and the energy value. In other words, as the lignin and volatile content of wood species rise, so does the heating value of the fuel.

Tree species	Cellulose %	Lignin %	Hemicelluloses	Btu/lb
Beech	45.2	22.1	32.7	8455
White birch	44.5	18.9	36.6	8334
Red maple	44.8	24.0	31.2	8400
Eastern white cedar	48.9	30.7	20.4	8400
Hemlock	45.2	32.5	22.3	8885
Pine	45.0	28.6	26.4	8930
White spruce	48.5	27.1	21.4	8890

Increasing energy value

Fig. 17: Chemical composition of some tree species [16]

3.6 Sources of Woodfuel

Woodfuel can be harvested sustainably from several woodland types. The main types can be classified thus: [18]

- Plantations
- Semi-natural woodland
- Natural woodland
- Urban forestry

3.6.1 Plantations

These are planned forest areas planted specifically for producing sawmill products and raw material for the paper industry.

3.6.2 Semi-natural and Natural Woodland

Semi-natural woodland consists of a mix of natural forest base with additional planting of specific species of tree. Natural woodland, as the name suggests, is naturally occurring forest, with a range of species native to the particular area. Woodfuel can be obtained from these forests through thinning and clearing operations. Sometimes a coppicing system can be operated. This involves a rotational cutting back of trees to encourage re-growth with the cuttings being used as fuel. Woodland thinning operations require careful management. Ecological concerns must be addressed. Where high 'windthrow' risk is evident then the stability of trees must be maintained and thinning is not an option.

3.6.3 Urban Forestry

Trees in urban areas need to be managed due to their proximity to roads etc. Arboriculture operations can allow use of thinnings and cuttings as woodfuel and can often present an ideal way of disposing of this waste wood

4. Fuels & Combustion

'Tug on anything in Nature and you will
find it connected to everything else'

- John Muir, Scottish-born
19^{th} century environmentalist

4.1 What is a Fuel?

From experience it is known that some materials will burn very easily. Materials such as natural gas, paper, wood, straw, etc easily combust. Other materials such as sand, water, rock, etc, do not combust. A fuel is a store of chemical energy. Under optimum conditions, the fuel interacts with oxygen and in so doing, releases energy whilst undergoing a chemical transformation in itself. This release of stored energy is a direct consequence of the original fuel and the oxygen supply together having a greater energy potential than the products formed in combustion.

4.2 Combustion

Combustion can be defined as *'a unit operation that employs thermal decomposition via oxidation to reduce carbonaceous matter'*. [19] The basic level of combustion involves the 'fire triangle' of Heat, Air and Fuel as shown in Fig. 18.

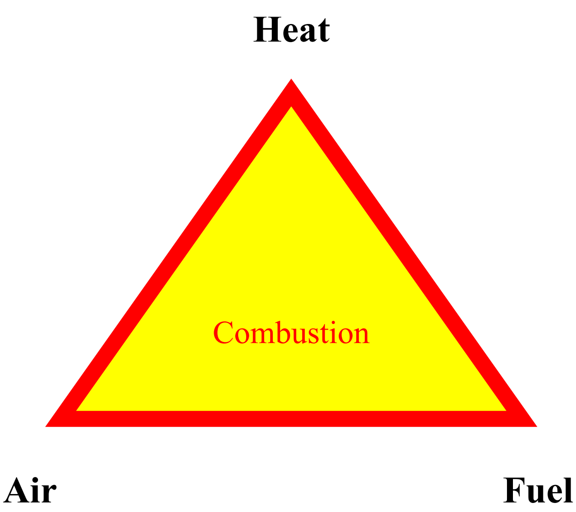


Fig. 18: The Fire Triangle [19]

In more detail, the process of combustion is designed around three important and interlinked variables. These variables can be called the 'three 'T's of combustion as shown in Fig. 19:

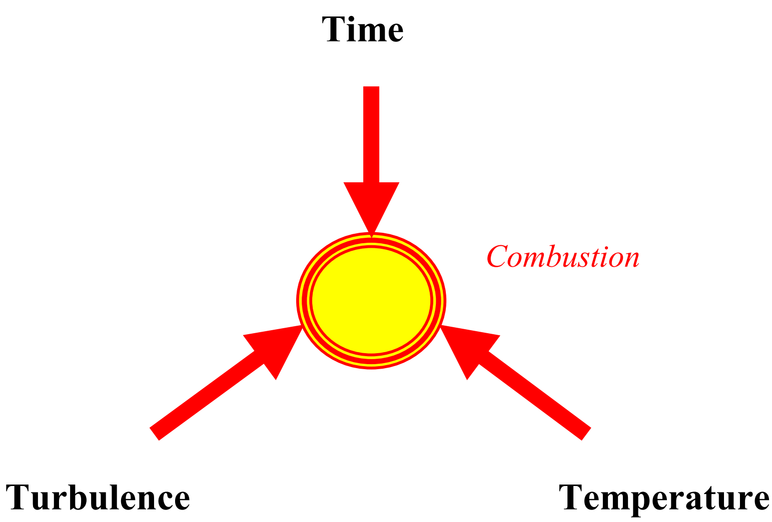


Fig. 19: The Three 'T's' of Combustion [19]

- ► **Time:** The time variable has to be taken into account from the point of view of providing adequate combustion conditions. There should be adequate volume within the combustion chamber and also sufficient flow rates of fuel and air.

- ► **Temperature:** This parameter is another fundamental requirement. Adequate temperature aids combustion efficiency. If the combustion temperature is too low, then the process becomes very inefficient with a resulting wastage of fuel. If the temperature is too high, then the heat exchanger design limits may be breached with the resulting breakdown of the system. It should be emphasised that temperature is probably the most important parameter after air mass flow rate and the fuel:air ratio levels. Moisture present in wood can significantly affect the combustion temperature.

► **Turbulence:** This is in effect a 'mixing' action where the air and fuel are combined in an ideally homogenous mass for efficient combustion.

A supply of oxygen is vital to sustain the combustion process. The rate of combustion is determined by the following parameters:

- The surface area and volume of the fuel
- The moisture content
- The combustion air pressure
- The rate of air flow
- The rate of the fuel feed to the system

The simplest way of utilising the stored energy in biomass is to burn it. The basic chemistry of the complete oxidation of materials containing mainly carbon, oxygen and hydrogen (present in wood) is: [20]

$$C_xH_yO_z \text{ (biomass)} + [x + y/4 - z/2]\, O_2 \quad \rightarrow \quad x\, CO_2 + y/2\, H_2O$$

The terms x, y and z represent the mean elemental composition of the biomass. The heat of the reaction varies somewhere between 16 and 24 GJ/tonne of oven-dried biomass (depending on its type and eventual water content). If there is an insufficient supply of oxygen to the combustion process to ensure complete oxidation of the combustible material then carbon, carbon monoxide, hydrocarbons and other gases are formed. The result is that the heat of reaction is reduced. Nitrogen and other elements present in the biomass are converted to gaseous products and ash.

Knowing that the composition of wood determines its heat content, it is worth looking at how wood offers up its stored energy. The first part of the process is known as *pyrolysis*. [16] During pyrolysis, holocellulose (both cellulose and hemicelluloses) promotes the release of volatile gases. Lignin also releases volatiles but in addition promotes char formation. The volatiles are burned directly in the form of *flaming combustion*, or they can provide wood gas, depending on the process applied. The char oxidises in the presence of air, known *as glowing combustion*. This char can be used as charcoal depending on the process in which it is combusted.

4.3 Wood: Elemental Analysis

Figs. 20(a), (b) and (c) list an analysis of certain wood fuels on a dry weight basis. Wood can be seen to be a highly oxygenated fuel, with about two-thirds the energy content of coal. Softwoods generally contain more energy than hardwoods when compared on a dry weight basis. This is due in the main to a higher lignin content in addition to having more resinous material present.

Elemental Analysis	**Sawdust & Pine bark pyrolized at 400 ^{0}C (%)**	**Sawdust & Pine bark pyrolized at 500 ^{0}C (%)**
Carbon	75.3	80.3
Hydrogen	3.8	3.1
Oxygen	15.2	11.3
Nitrogen	0.8	0.2
Sulphur	0.0	0.0
Ash	3.4	3.4
kW/kg	7.798	8.621

Fig. 20(a): Charcoal [16]

Elemental Analysis	Douglas fir	Douglas fir (bark)	Western hemlock	Red wood
Carbon	52.3	56.2	50.4	53.5
Hydrogen	6.3	5.9	5.8	5.9
Oxygen	40.5	36.7	41.4	40.3
Nitrogen	0.1	0.0	0.1	0.1
Sulphur	0.0	Trace	0.1	0.0
Ash	0.8	1.2	2.2	0.2
kW/kg	5.835	6.125	5.558	5.829

Fig. 20(b): Softwoods [16]

Elemental Analysis	Beech	Hickory	Maple	Poplar
Carbon	51.64	49.67	50.64	51.64
Hydrogen	6.26	6.49	6.02	6.26
Oxygen	41.45	43.11	41.74	41.45
Nitrogen	0.0	0.0	0.25	0.0
Sulphur	0.0	0.0	0.0	0.0
Ash	0.65	0.73	1.35	0.65
kW/kg	5.648	5.59	5.532	5.75

Fig. 20(c): Hardwoods [16]

4.4 The Influence of Moisture

Wood by its very nature has considerable amounts of moisture present. Freshly cut wood may contain between 22 to 67% moisture [16]. The moisture content significantly influences the net heating value of wood, as well as the ignition properties and efficiency of the combustion process.

The influence of moisture on heating value can be calculated by the following formula: [16]

$$NHV = HHV - [0.0114\ (HHV) \times M]$$

where NHV = the net heating value (see below *)
HHV is the higher heating value (see below **)
M is the moisture content, expressed as % of total as-received fuel material

$$(*)\ NHV = HHV - [0.0114\ (HHV) \times M]$$
$$(**)\ HHV \cong C \times 7527 + (1-C) \times 11479$$

Where HHV is the higher heating value in Btu/lb and C is the fraction of wood consisting of holocellulose. (3412 Btu = 1kW).

Fig. 21 shows the influence of moisture on the heating value of wood. It can be seen from the graph that as the water content increases, the net heating value decreases. This trend continues until a point is reached where combustion cannot be sustained. This is known as the '*black out zone*' and occurs at approximately 67% water, 33% wood. Another serious influence of increasing water content is its effect on ignition. In situations of increasing water content, an increase in energy expenditure is required in order to evaporate the inherent moisture and to begin the process of combustion. This results in energy inefficiencies with the resultant economic value of the wood fuel being impaired.

For dry cellulose material, the energy required to obtain ignition at 575 ^{0}F is around 0.145kW/kg and the net heat release is around 3.269kW/kg. For 50% moisture content in cellulose, the energy required to obtain ignition in this instance at 600 ^{0}F is around 0.425kW and the net heat release is around 1.084kW. [17]

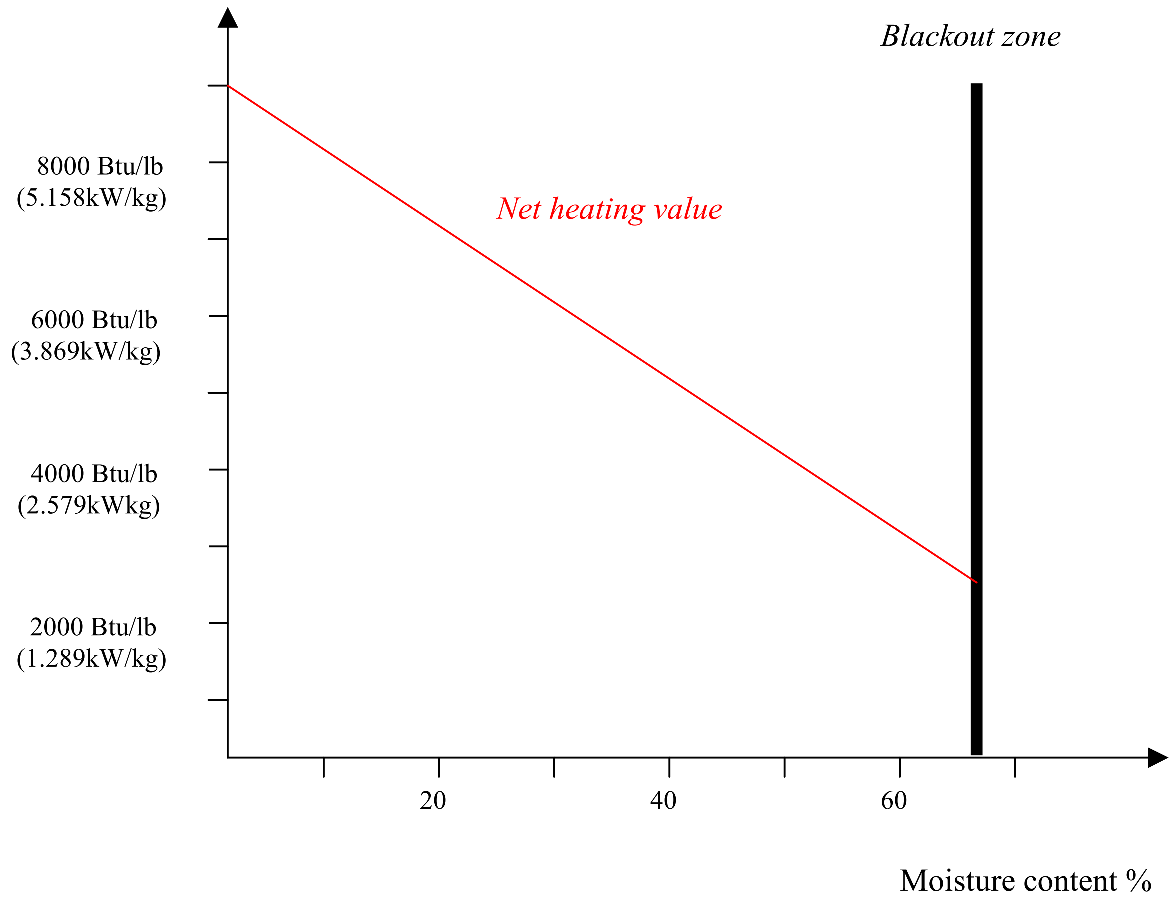


Fig. 21: The Effect of moisture on the heating value of wood [16]

The average moisture content for wood is around 37.2%. This figure will vary from species to species and will also depend on material type as well as the age of the wood. Hardwoods contain, on average, 30.2% moisture while softwoods contain, on average, 46.1% water. [17] Note that this percentage is based on a weight proportion. Young trees contain more moisture than older ones. The foliage of a tree contains more moisture than the bole (stem). Inside the bole, the sapwood contains more moisture than the heartwood. It is necessary to take into account these variables when assessing energy content and moisture. Fig. 22 gives a simplified model of combustion balance.

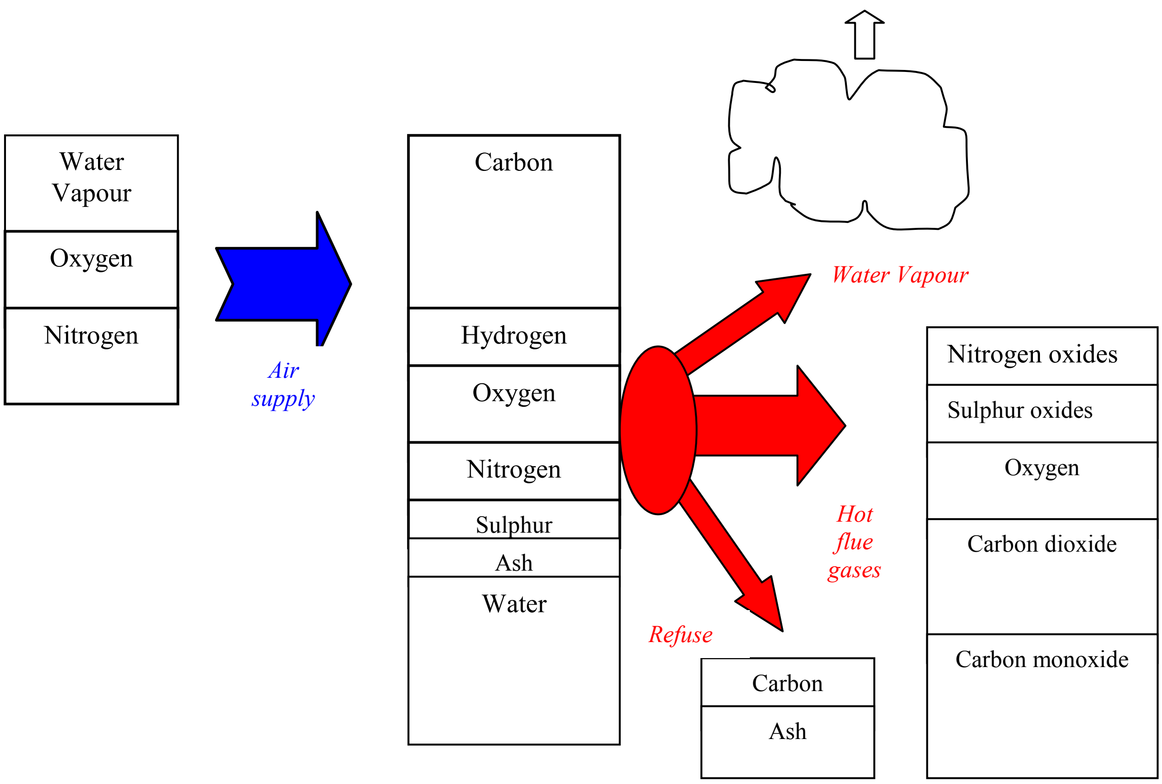


Fig.22: Simplified model of combustion balance [21]

5. Biomass Process & Conversion Technologies

'Engineering problems are under-defined, there are many solutions: good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice'

\- *Ove Arup*

5.1 Processed Wood Fuel Types

There are several different types of processed wood fuel that can be utilised. The choice of fuel 'package' is dependent on a number of variables such as, material available, whether space heating is required or secondary processing (e.g. steam production to generate electricity), the system heat capacity, etc. It is important to match up the correct fuel type with the correct boiler capacity and indeed, design.

Wood fuels can be divided into <u>four</u> main types as follows: [18]

- **Logwood**
- **Woodchips**
- **Pellets**
- **Specialist wood-fuels: faggots, bavins, kindling, charcoal**

Critical to the quality of these fuels is the moisture content (covered in section 4.4), the size or 'quality' and finally the wood density. These parameters determine the bagged weight of the fuel.

Logwood: Logwood is specified by its maximum length. Logs used as fuel have to be *seasoned*. This is a process of drying the wood in a sunny, airy place. Logs with a diameter over 15 cm should be split before they are seasoned, to ensure proper drying. In general, logwood can be described as '*green*', '*seasoned*' or '*two-year seasoned*'.

Woodchips: Woodchips are the result of processing forest timber through a chipping machine. The wood chips can vary in size from 1 to 100 mm. There are various grades of woodchips available. The 'fine' grades (smaller than 30 mm) and the medium grades (smaller than 50 mm) are suitable for small-scale combustion systems. Wood chip burning plant will operate best on material between 2 and 25 mm dimensions. Very fine, almost dust-like material will upset the combustion balance in a boiler. Large chunks and long fibrous material can interfere with auger feed systems. Retail woodchip material is classified by three grades in the UK, as in Fig. 23.

Size	< 2mm	2–25 mm	2 –50 mm	50–100 mm	100–200 mm
Description	*Dust*	*Small*	*Medium*	*Oversize*	*Slivers*
Super	< 15%	Any	0%	0%	0%
Fine	< 15%	Any	10%	2%	0%
Coarse	< 15%	Any	Any	< 30%	< 2%

Note: *A maximum of 5% of ' tramp' material permitted.*
No stones > 25 mm allowed

Fig. 23: UK Woodchip material classification [18]

Pellets: These originate from wood wastes, mainly from the woodworking industries. The raw material consists of wood shavings, sawdust, etc. The raw material is extruded under extremely high pressure into a cylindrical shape. Typical dimensions of pellets can be around 6 – 8 mm in diameter and between 5 and 30 mm long. The maximum water content is 8%. [22] Fig. 24 shows the physical appearance of pellets.

Fig. 24: Biomass wood fuel in the form of pellets [22]

The advantage of wood in pellet form is that it behaves as a liquid. A tanker can supply the pellets and they can, in effect, be pumped into a storage vessel. Another advantage is that they have a very high energy content due to the compression process. Often, figures of 4.3 to 5.0 kWh/kg at a density of 1.2 t/m^3 are quoted. [22] The energy content of pellets is somewhere in the order of 3 times that of woodchips. It is likely that pellet-type fuel will prove to be a major force in the biomass market in the UK in coming years.

Traditional woodfuels: These include the following:

- *Faggots*: Bundles of small diameter (< 50 mm) sticks, 120 cm long, < 200 cm across; tightly tied together with two combustible ties.
- *Bavins*: These are similar to faggots but only 60 cm long.
- *Kindling*: The maximum length is 30 cm; the maximum width 5 cm and moisture content 20%.
- *Charcoal*: This can vary in grade depending on use.

5.2 Woodfuel Harvesting & Preparation

Wood fuel can be bought in, in its many forms, or it can be harvested on-site. This report covers the harvesting of wood biofuel on-site. Harvesting the wood material depends on the specific site. There are many issues to consider, among them the forest or estate layout, the scale of the operation, access to roads for transporting the raw fuel, whether to contract out the operations or keep them in-house, etc. The choice of harvesting and processing equipment is vast, with many companies involved in their manufacture and supply.

5.2.1 Harvesting Methods

Whole tree harvesting:

This involves the actual felling of the tree and transporting it to the side of the forest road. It is important to have a network of these forest roads to ensure easy access by heavy equipment. Equipment types used for this operation are typically *skidders* or *cable cranes.* Figs 25 and 26 show a 'skidder' and 'cable crane' respectively. This operation would be used where the timber had to be transferred to a remote saw-mill for further processing.

Fig. 25: A 'skidder' [18]

Fig. 26: 'Cable cranes' [18]

Whole-tree chipping:

The complete tree, (which would be limited to a particular size) is felled and then chipped in-situ. Larger trees would require to be split, probably at a remote sawmill before further processing. It is also possible carry out a complete chipping operation for all trees at a local site-based sawmill, if required. There are three general types of chipping equipment available:

- *Mobile chippers:* These machines have sharp blades, which cleave the wood against a stationary anvil. They are used primarily for green wood as dried wood increases the wear rate. Mobile chippers are useful for smaller scale operations from a cost point of view. They can be moved to any particular site, offering flexibility. The major disadvantage is the limited throughput and the limit on wood size input. Fig. 27 shows a typical portable chipping machine [18].
- *Tub grinders:* These comprise a large diameter rotating hub, which feeds a hammer mill. They are semi-portable and can handle large timber sizes. [18]
- *Stationary hammer mills:* They differ from tub grinders in that they are fed by a conveyor system. Both the tub grinder and the hammer mill can process large volumes of material. They can include screening equipment to grade various sizes of final product. The main disadvantages are their capital costs and increased maintenance requirements for the hammers. [18]

Fig. 27: A typical portable chipping machine [18]

5.2.2 Drying & Storage Methods

Drying timber increases the calorific value and also makes storage easier. In addition, dry wood resists fungal decay. In the UK, timber can be air-dried to around 20% moisture content. Often further drying is required particularly in the case of woodchips. Storing the woodchips in a covered but well ventilated hangar can be sufficient. Forced air provided by a fan can be considered and this would dry the chips in a faster time. Heated air can be used, however this obviously has implications for energy conservation and would only be considered where waste heat, e.g. from an exhaust, was available.

Once the woodchips are of the required moisture content, they must be transported to the place of use and stored. It is necessary to have a storage facility that is dry. Water penetration degrades the calorific value of the woodchip fuel. The actual size of the storage vessel depends on several factors. The boiler may have a hopper attached to it, which is filled as required. For smaller boilers running on dry woodchip, a $1m^3$ hopper will provide up to 24 hours of continuous running, based on availability of fairly dry chips (moisture content 25%) and density of 220 kg/m^3. [18]

It may be that daily filling is not feasible and in this case, a larger hopper may be required. A hopper of $4m^3$ would give approximately 4 days of operation on a continuous basis or 1 week on intermittent use. Larger boiler installations require more fuel storage capacity and this can take the form of external storage silos. For a boiler rated at 100kW, operating for one week on a continuous basis would require a silo with a storage capacity of $6m^3$ [18]. Fig. 28 illustrates the likely storage capacities required for various boiler sizes.

Boiler Output	18kW	80kW	350kW
Fuel Input	**6.25kg/hr (25kW)**	**25kg/hr (100kW)**	**200kg/hr (400kW)**
1m^3 Storage	24 hours	6 hours	Too small
4m^3 Storage	4 days	24 hours	6 hours
16m^3 Storage	Too big	4 days	24 hours
48m^3 Storage	Too big	Too big	3 days

Fig. 28: Storage capacities v. boiler sizes [18]

It should be emphasised that transfer of woodchips from the carrier vehicle to the repository be considered. The design of the storage container should be such that this is carried out at minimum costs as far as transfer equipment is concerned.

5.3 Converting the Woodchip Energy

The woodchip fuel is now ready to be utilised. The stored energy must be released by the process of combustion (already covered in section 4). Wood requires relatively little *primary air* (air that is supplied at the point of solids combustion, usually under the grate) compared to, for example, coal. This is the main reason why logs burn well on a bed of ash and coal requires an open grating. Wood does however require a good supply of *secondary* (over-grate) *air* to ensure that the volatiles released by the wood burn efficiently.

Wood burning systems should be designed such that provision is made for separate control of the primary and secondary air supply. This ensures that combustion is correctly balanced. Balanced combustion ensures the absence of smoke. Smoke is a sign of unburnt volatiles passing up the flue. This is a pollution concern and indicates an inefficiency of the combustion process [18].

5.3.1 Modelling the boiler

It is perhaps prudent at this juncture, before assessing the different types of boiler and gratings, to look briefly at a typical boiler model, in order to appreciate the basics.

Output = Input – Losses
Efficiency η = Output / Input
= Qb / HHV

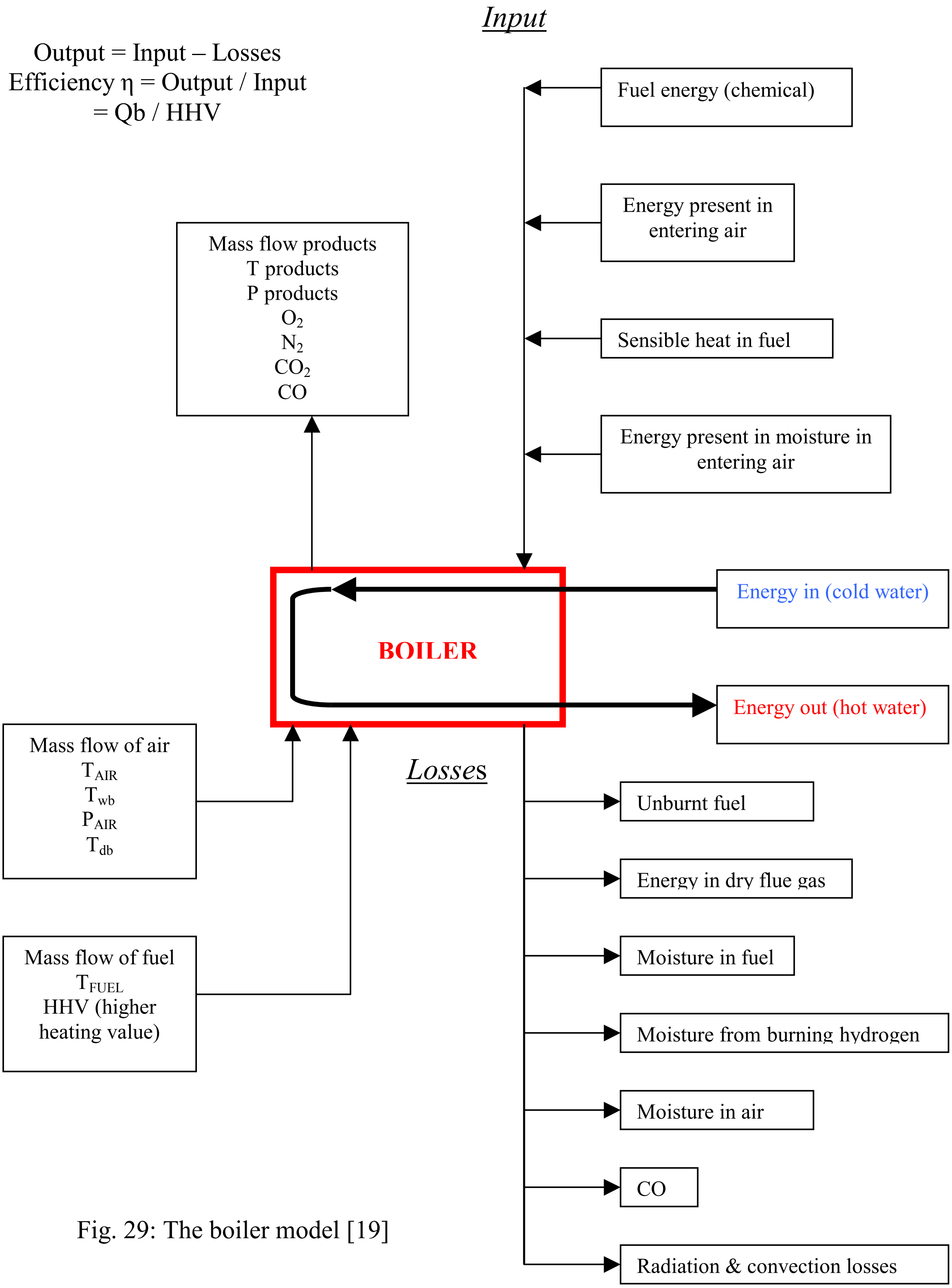


Fig. 29: The boiler model [19]

The following, Fig. 30, shows a model for the actual woodchip burning system. The different types of boilers, gratings and systems are discussed in a later section in this report.

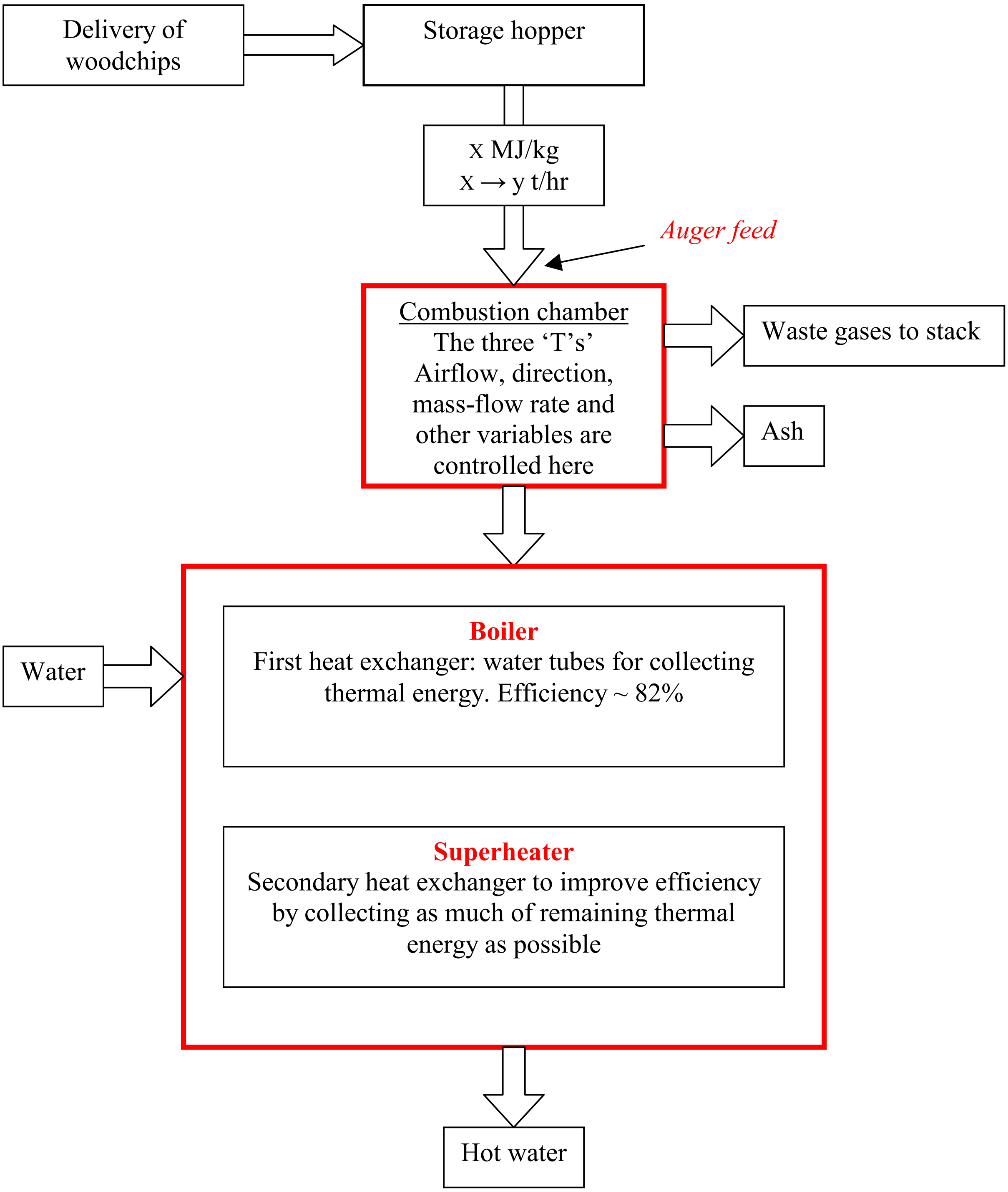


Fig. 30: Model for wood burning boiler [19]

5.4 Combustion Devices

There are many devices and systems that have existed over the years for burning wood. Many are being re-designed and improved upon. This section of the report focuses mainly on *woodchip boilers* but the other main types are briefly described:

- ► **The traditional fireplace:** Often seen as low-tech, this has been a standard method of heating rooms.

- ► **Wood burning stove**: This is the simplest and often the cheapest way of utilising wood energy. They come in a variety of types such as ceramic, cast iron and steel. Well-designed stoves can operate at quite high efficiencies in the range up to around 15kW. These stoves are used to provide background heating.

- ► **Logwood boilers:** These designs are larger scale and can be used to meet heating demands of whole buildings. Typically they have high efficiency levels. Modern logwood boilers operate on typically, a two-stage process; gasification in the first stage and high-temperature combustion in a specially designed chamber in the second stage. Fig. 31 shows the appearance of a typical logwood boiler.

Fig. 31: A typical logwood boiler [22]

- **Pellet Boilers & Stoves:** These utilise the high energy density pellets described in section 5.1. Due to the high-energy content of the fuel, the boilers are often cheaper and simpler in design. [22]

- **Woodchip boilers:** This design will be looked at in more detail in the coming pages. The advantage of wood chip boilers is their automatic feeding system for fuel delivery. This permits full automatic operation. In addition, they are more user-friendly. State of the art woodchip boilers have continuous power control and do not need a heat storage accumulator. The feeding and control mechanisms require more sophisticate electronics to deal with the possibly varying humidity present in the woodchip fuel. They are good solution for larger heat loads where the handling of heavy logs becomes unfeasible. Figs. 32(a) – (c) illustrate the key components of a woodchip boiler system. [23]

Fig. 32(a): A woodchip boiler system (pre-combustor design: see also 5.4.1.4) [23]

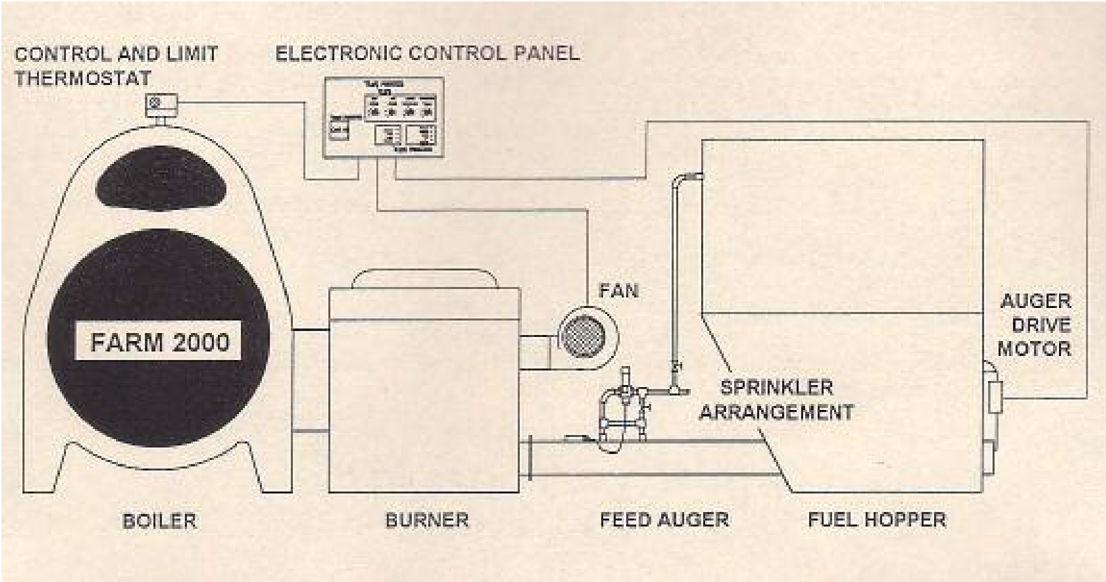


Fig.32 (b): The above woodchip system in schematic form, showing key components [23]

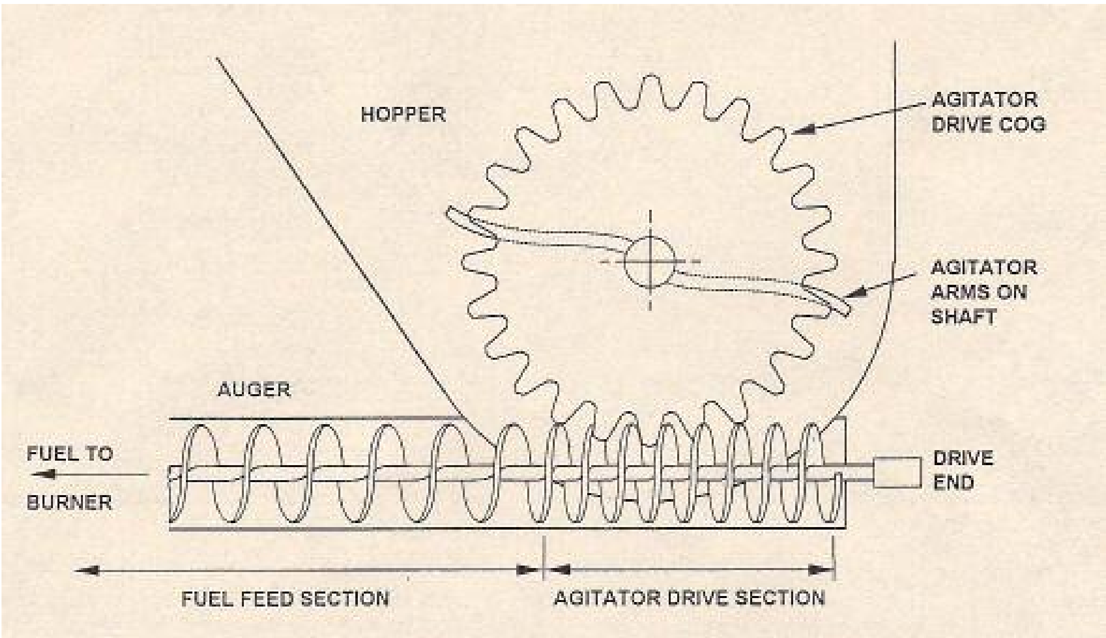


Fig. 32(c): The fuel feed system [23]

5.4.1 Woodchip Combustion Designs

The heart of a woodchip boiler system is the combustion arrangement. There are several different system designs.

5.4.1.1 The Underfeed Stoker

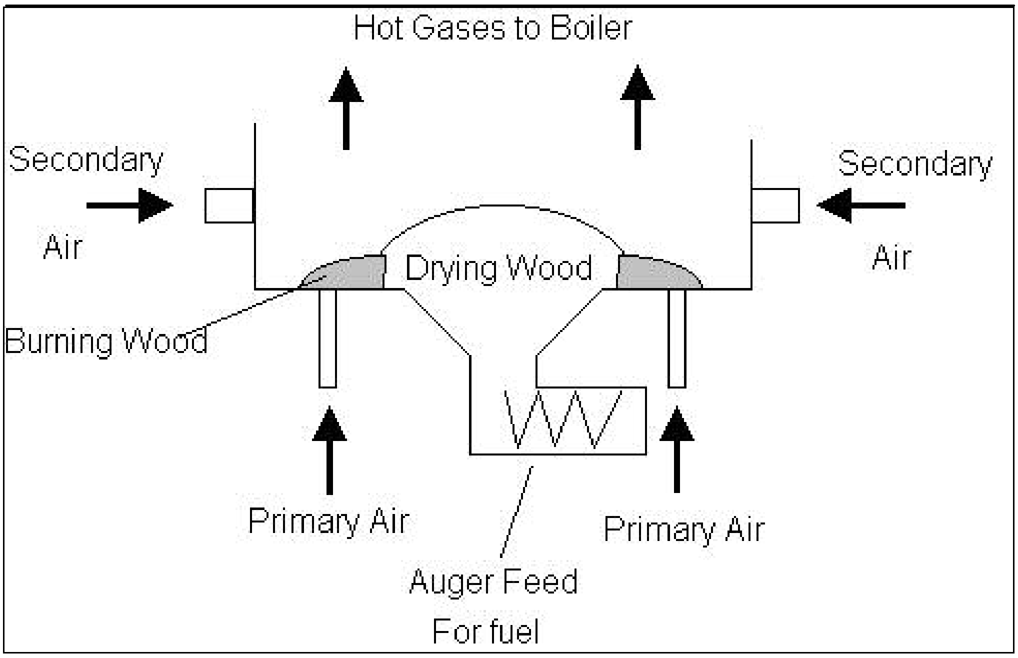


Fig. 33: The Underfeed Stoker arrangement [18]

This design (Fig. 33) is a relative of the designs used for burning coal. It is a commonly used system for combusting dry wood. For woodfuel above 30% moisture content, it is less suitable. The main reason is that the 'wet' woodfuel is not exposed to radiant heat in order to dry out, prior to it entering the combustion zone. The woodfuel is fed by an auger feed (so-called 'Archimedes spiral') from below. The fuel passes into an inverted pyramid from where it wells up into the combustion area, falling to the sides. Primary air is supplied below the fuel and secondary air is fed in from above.

Underfeed stoker designs are usually part of the complete boiler package. They can also be built as an individual unit, apart from the boiler. For this design, the boiler has an open-bottom construction that fits on top of the stoker unit. Larger units may comprise a stoker unit within the combustion chamber of a shell and tube boiler. Fig. 34 illustrates this design.

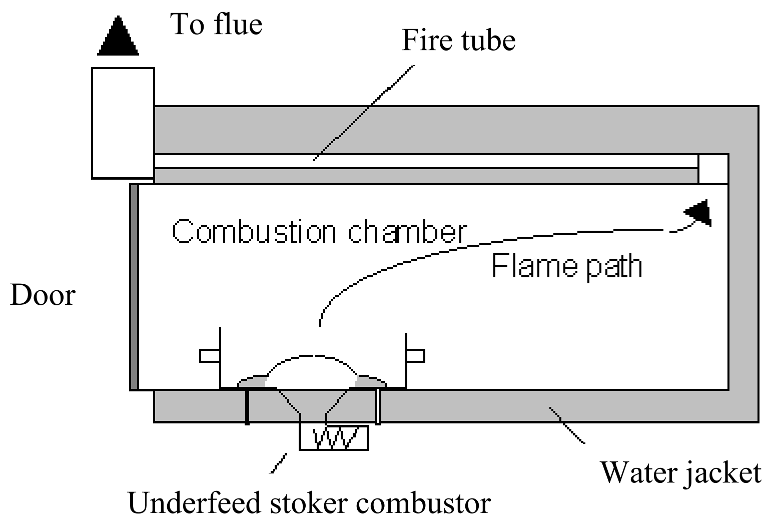


Fig. 34: Underfeed Stoker, shell and tube boiler [18]

With all combustion processes there is a build-up of ash which has to be removed. Often this has to be done manually and is not a particularly pleasant job. The ash build-up appears in a circular formation in this design. The problem is to design a simple clearing system, ideally an automatic type.

5.4.1.2 The Stoker-Burner

The analogy of this design is that of a pressure-jet oil burner. The woodchip fuel is transferred via an auger feed into a burner head. The burner head has a lining of cast-iron to transfer heat back onto the fuel. The cast-iron acts as a very good thermal reservoir. Combustion air is blown into the system by a small fan, passing around the outside of the cast-iron liner. The air becomes warmed and then enters the fuel space through small perforations, some below the fuel level and some above. This provides primary and secondary air respectively. Fig. 35 shows this layout.

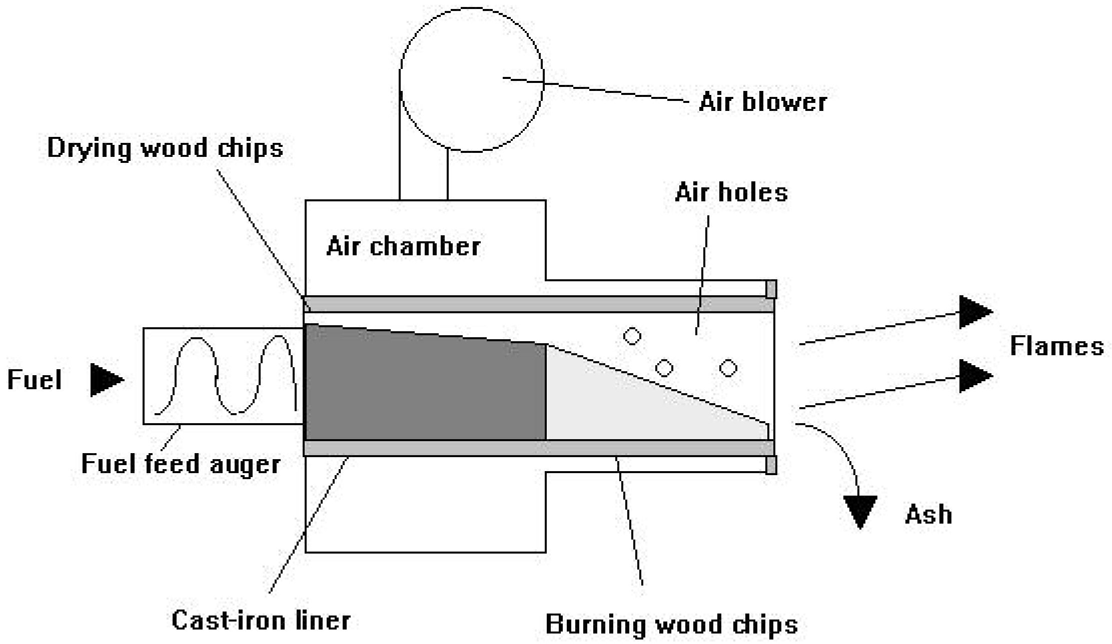


Fig. 35: The Stoker-burner layout [18]

A vigorous flame is produced from the burner head. This passes into the boiler. Fig. 36 shows this design of burner layout attached to a purpose designed steel boiler.

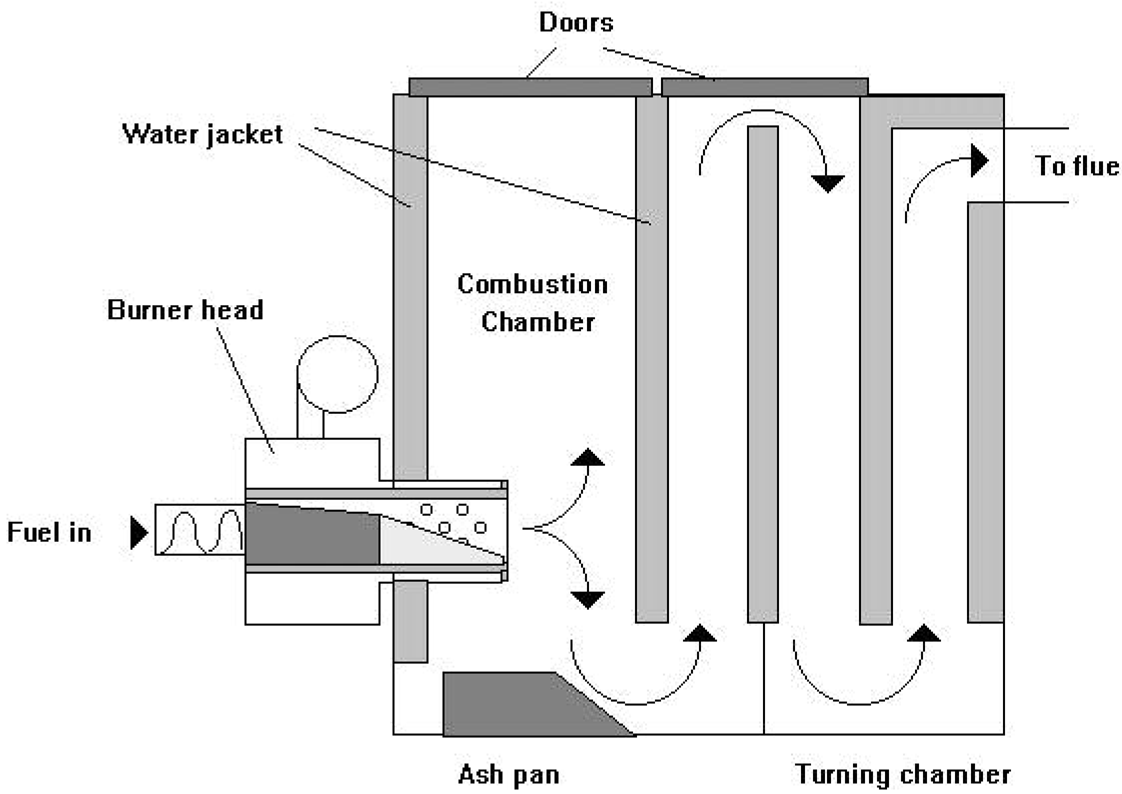


Fig. 36: The Stoker-burner attached to a purpose designed steel boiler [18]

The ash problem is dealt with fairly easily in this design. Ash is pushed off by the incoming woodfuel. The ash is taken up by the ash-pan, situated below. However, the ash-pan does have to be emptied manually. The stoker-burner design is perhaps the cheapest form of woodchip burning. There are some limitations however:

- The moisture content of the woodchips should be ideally less than 25%.
- The woodchip size must be consistent to avoid disrupting the fire.
- There is no separate provision for primary and secondary air, thus limiting any fine-tuning control to take into account varying fuel parameters.

There are some advantages though:

- The heat generated in 'slumber' mode is very low. No 'heat leak' is required. Heat leak is a guaranteed load, which cannot be turned off. It acts as a safety measure to prevent overheating when no other load is present.

5.4.1.3 The Inclined Grate

These designs are the most versatile. At the same time, costs can be higher. Woodchip fuel is delivered by auger to small boiler designs and to larger units by lock-hoppers. In all designs, the fuel arrives at the top of a sloping grate. The grate may comprise several panels of 'fire bars'. These bars are moved in a sequence to facilitate fuel movement down the grate. The bars can be actuated by hydraulic or electrical means.

Primary air is supplied under the grate. The fuel in effect passes through a sequence of *drying, volatile emission* and *char burnout* as it is transferred down the grate. This graded combustion lends itself to efficiency and good design practice. It is possible to burn different types of fuels due to the fact that parameters such as grate speed, fuel speed and air supply can be controlled. Sometimes a ceramic arch is included over the grate. This has the desired effect of reflecting heat back onto the fuel, encouraging drying and combustion. Woodfuels up to 70% moisture content can be considered. Fig. 37 shows this design.

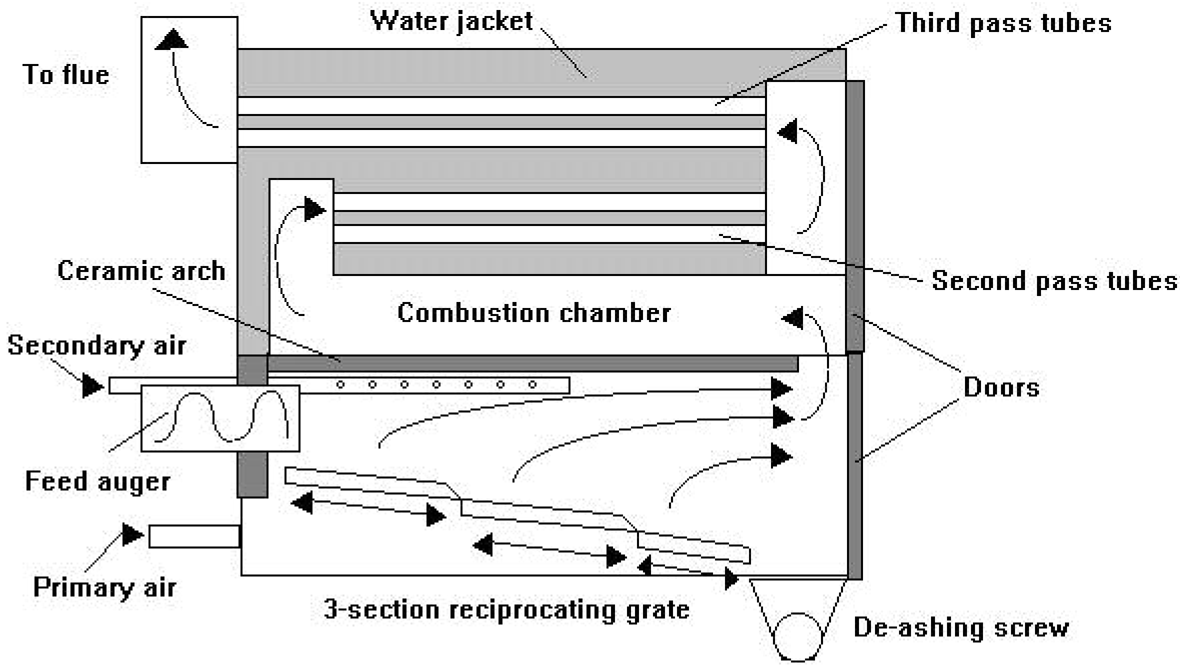


Fig. 37: The Inclined Grate design [18]

5.4.1.4 The Pre-combustor

This design separates the combustion unit from the boiler. Woodchip is partially combusted to provide a hot, combustible gas. In effect, the wood is burned separately from the volatile gases. A two-stage process exists. This can allow for better control of combustion conditions. Indeed, there are designs that incorporate fully modulating (load-following output) by control of the air fan speed and as a result, the air mass flow rate. This degree of control can often demand strict woodchip size and closely monitored moisture content. [18]

5.5 Connecting A Woodchip Boiler into an Installation

The following two Figs. 38 and 39 [23] show the different combinations of connection of a woodchip boiler to a central heating / domestic hot water system.

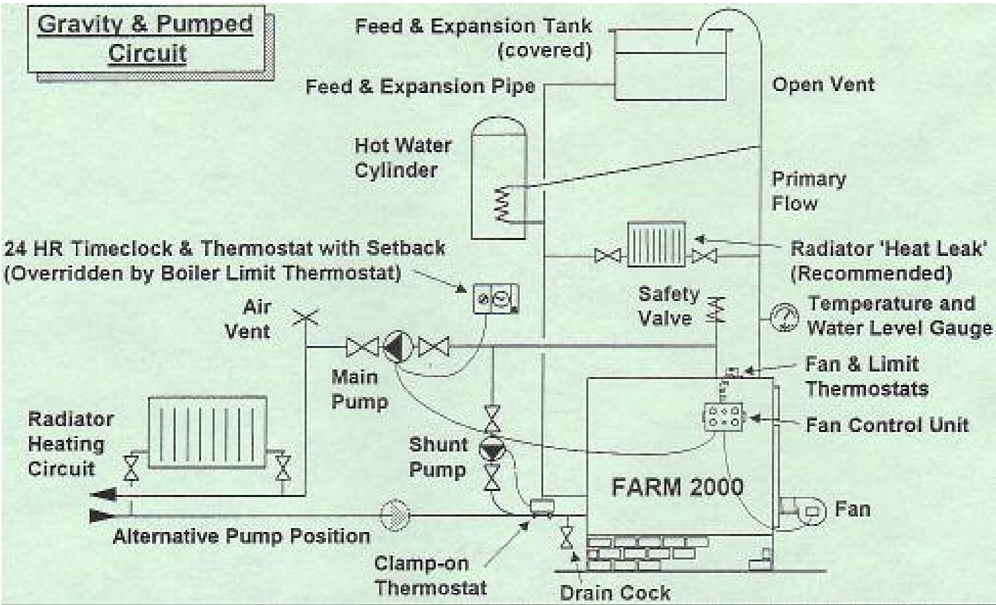


Fig. 38: Woodchip boiler ('Farm 2000' model) connected into a Gravity & Pumped Circuit [23]

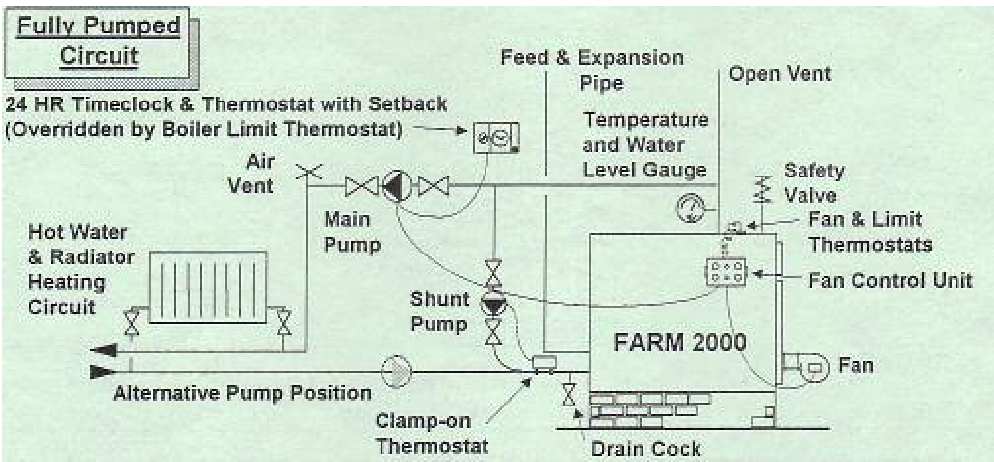


Fig.39: Woodchip boiler ('Farm 2000' model) connected into a Fully Pumped circuit [23]

5.6 Good Practice Guidelines for Woodchip Boiler Installations

CIBSE and BSRIA offer guidelines for good practice. [18] These guidelines ensure efficient and safe operation of installed plant. Some salient points are listed:

A. Where an hybrid installation exists, i.e. an oil and woodchip tandem arrangement, care must be exercised to ensure that heat circulation through off-line boilers be avoided. For example, in the case of a large oil and small woodchip tandem installation, the energy used to keep the oil boiler hot while off-line could account for a fair proportion of the output of the woodchip boiler, resulting in gross inefficiencies.

B. Installations of woodchip boilers in the UK are often done on a 'retro-fit' basis In the case of adding a woodchip boiler to an existing oil boiler system, using a single pipe header with boiler primary pumps may be the best way to achieve reliable hydraulic control.

C. Provision should be made for the disposal of waste heat on slumber mode. The woodchip boiler needs to be kept lit in order to respond to heating demands. Controls need to be adequate to ensure that this heat is utilised, as often the heat produced in 'slumber' mode can be high. Ways of dealing with this include dumping the heat into under floor heating systems, using an accumulator to store this heat, night set-back to allow some base load, heating of DHW (direct hot water tanks).

5.6.1 Boiler controls [18]

The majority of woodchip systems operate on an 'on-off' basis. A water thermostat switches between *high fire* mode and *slumber* mode. The high fire mode comes on with full air and maximum fuel feed when the water temperature is below the set point. On slumber mode, minimum air supply and fuel feed is initiated when the water reaches the desired temperature. An analogy is that of a gas-fired boiler, which switches between' burner on' and 'pilot flame'. Woodchip boilers do not react as quickly as their gas-fired counterparts.

When the boiler senses that the water temperature is high enough and the boiler goes into slumber mode, woodchip fuel remains in the combustion area. This wood continues to produce volatiles. If the air supply is restricted, smoking occurs with the potential for the release of carbon monoxide. For this reason, many woodchip systems incorporate a *lag* period after the fuel feed has been instructed to stop by the controller. The reverse situation exists when going from slumber mode to full on. This time, a *lead* control can be provided for.

The rate of fuel feed and air mass flow are normally pre-set on smaller systems. Simply starting and stopping the auger can control fuel feed rate. Typically, a profile would be set into the system such that the auger would run for a pre-set time, say 5 seconds *on* and 20 seconds *off*. The air mass flow can be controlled by dampers in the forced draft fan inlet or by electronic speed control of the fan motor.

Feedback control exists only with thermostats for the smaller (less than 100kW) systems. For larger systems, flue gas and oxygen (lambda) sensors are often employed. They are used to stop the fuel feed during the 'high fire' part of the cycle when either the flue temperature exceeds a limit or when the oxygen content drops below a certain level. The latter prevents volatile release into the atmosphere and also carbon monoxide release.

Large systems often have a high/low/slumber control facility. This is to provide for proportional control (load following). Water temperature is used to vary the air intake fan speed and the fuel feed is then controlled by sensing the fuel level in the grate.

5.6.2 Woodchip Boilers Operation & Maintenance [18]

Woodchip boiler systems obviously have fuel costs to consider but they also require some electrical power for such things as auger drives, controllers, etc. This however is minimal. Planned maintenance is desirable. It is necessary to clear ash deposits from flue channels, ideally on a quarterly basis. Refractory linings require inspection based on manufacturer's recommendations. Occasionally, blockages need to be cleared in the fuel delivery system. CIBSE estimate a total maintenance figure of 8% of the capital cost for automatically stoked boilers over 150kW. Insurance for the boiler pressure vessel is normally a requirement.

5.6.3 Health & Safety Issues [18]

Combustion chamber flashback can occur when opening combustion chamber doors. This should be borne in mind, particularly when carrying out maintenance or periodic checks.

Dust can be a by-product of storing woodchip, particularly if the woodchip has been subject to some fungal attack. Mould spores and organic dusts can be injurious to health. Appropriate dust masks should be worn when handling such material.

Flue gas leakage can be dangerous, because of the risk of carbon monoxide being present. CO is a silent killer; it has no taste or smell. It occurs when there is insufficient oxygen present for complete combustion. All boiler houses should be fitted with sufficiently large air intake louvres. The installation of CO detectors is a recommended practice.

Fire hazards: It is theoretically possible for fire to travel back from the combustion chamber, along the route of the feed auger and into the fuel storage hopper or silo. Good design practice minimises these risks:

- All installed systems should incorporate a water dousing system. This can take the form of a sensor or fusible link in the fuel feed system. An excessively high temperature will cause the fuel feed system to be doused with water. Alternatively, a mechanical drop could be included to provide a barrier to the fuel feed.

- The fuel feed system should be designed to prevent any backflow of hot gases from the boiler towards the fuel store. This could include sealed fuel hoppers on smaller units or rotary air valves on the larger systems.

6. The Ardverikie Case Study

'He who plants a tree, plants a hope'

- *Lucy Larcom, 'Plant a Tree'*

6.1 Introduction

Ardverikie Estate is set in approximately 40,000 acres of land, easily accessed by the A86 Newtonmore – Spean Bridge road. Fort William and Ben Nevis are located to the west and Strathspey with Aviemore and the Cairngorm mountains to the east. Ardverikie is set amongst striking scenery. Lochs, woods and mountains blend to produce some of the most spectacular landscape in Scotland. The Estate has its fair share of history, being considered by Queen Victoria as a Highland retreat back in the nineteenth century.

The area caters for mountaineering, skiing, fishing, golf, pony trekking and hill walking. The Ardverikie Estate caters specifically for pursuits such as shooting, stalking, fishing and numerous other vacation activities. It also has considerable forestry interests and has its own sawmill on site. The Estate has been used for filming 'Mrs Brown' starring Dame Judy Dench and Billy Connolly. Presently, Ardverikie House is the location shoot for the BBC drama, 'Monarch of the Glen'. Figs. 40 and 41 give an indication of the geographical location of the Estate.

The Estate has many properties dotted over its vast area, ranging from small cottages, hunting lodges, to the impressive Ardverikie House itself. The majority of the buildings are of traditional sandstone construction from the Victorian era. There are some more recent buildings but these are in the minority in the property list. The Estate has its own hydroelectric installation. This comprises two generator sets of 1 MW and 100 kW.

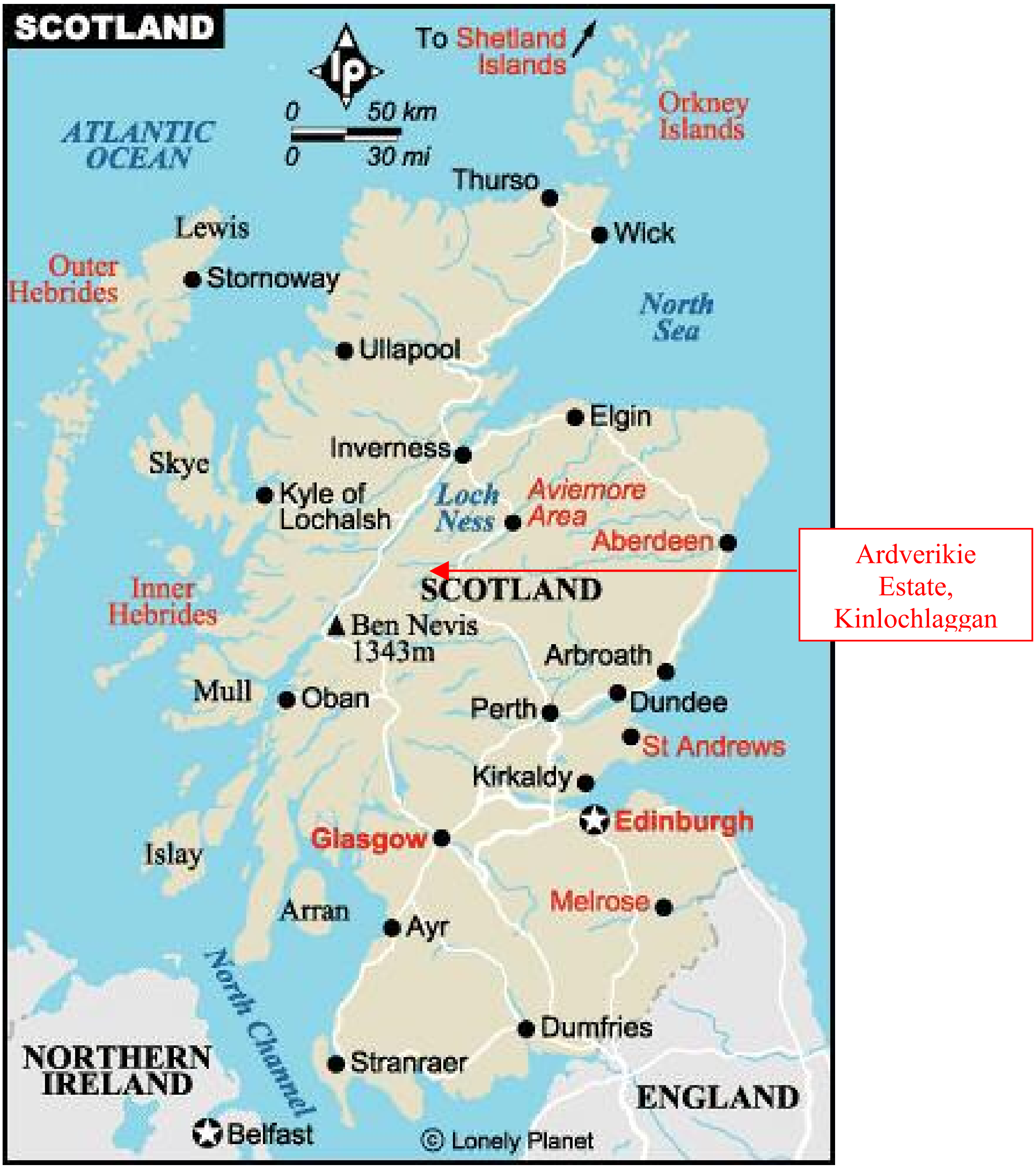


Fig 40: Location of Ardverikie Estate, Scotland

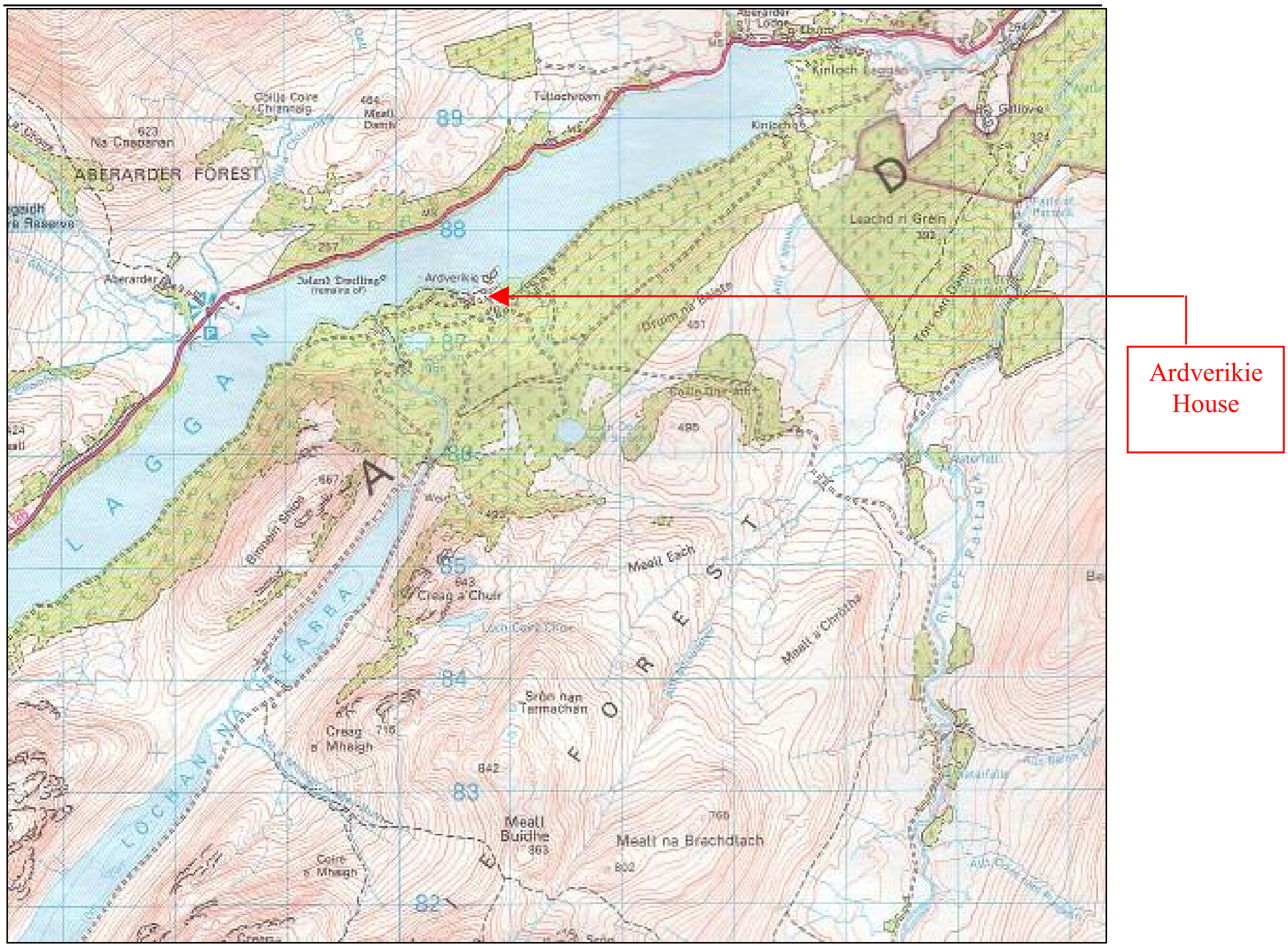


Fig. 41 The approximate area of the Ardverikie Estate

6.1.1 The Case Study Overview

The hub of the case study was an assessment of the significant potential for the development of a sustainable building heating strategy for the whole Estate. In addition, it assessed the potential for a new business activity for the Estate, i.e. the harvesting of local timber and conversion into woodchip fuel for supply not only to the Estate but also possibly to sites in the neighbouring areas. The availability of the Estate's own hydroelectric plant was considered as a source of cheap electrical energy. The heating fuel options considered were gas oil (the main fuel in current use), propane gas and the possibility of displacement by woodchip-fired boilers.

The study included a field trip to the Estate to collect such data as the site layout, infrastructure, the property portfolio, building assessments and floor areas, specific fuel types and usage figures. In addition, the Estate operations were observed and data obtained for the forestry operations from the Estate factors in Inverness.

6.2 The Forestry Operations

The Ardverikie productive forestry inventory comprises the following: (see Fig. 42). The Estate is well served with forestry tracks, capable of handling large and heavy forestry plant.

<table>
<tr><th>Species Breakdown</th><th>Area</th><th>Comments</th><th>Biomass Yield per Annum</th></tr>
<tr><td>Scots Pine
Larch
Lodgepole Pine</td><td>279 hectares</td><td rowspan="2">Presently at thicket stage and at least 10 to 15 years away from commercially viable thinnings. Old growth now beyond any marketing opportunity. Now ‘features’ and ideal for ‘mother’ trees (natural regeneration).</td><td rowspan="3">Assumed yield based on ‘Yield Class 10’ = approx. 9240m^3 per annum.

Approx. 2000m^3 per year currently harvested in general thinnings</td></tr>
<tr><td>Sitka Spruce
Norway spruce
Douglas Fir</td><td>514.4 hectares</td></tr>
<tr><td>Grand Fir
Noble Fir
Western Hemlock</td><td>130.5 hectares</td><td>Not possible to market viably at present</td></tr>
</table>

Fig. 42: Ardverikie productive forestry inventory [24]

It should be emphasised that there are other species of trees on the Estate such as oak, etc. that are not considered as harvestable. The drive is to balance harvesting of wood crop with renewed growth.

6.2.1 Ardverikie Estate Forestry Operations Costing:

The forestry / general estate squad comprises of 3 men trained in the use of a full range of forestry equipment. In addition, contract labour is often employed for larger projects. The working year is generally allocated as follows:

- Forestry 30%
- Firewood supply to the Estate houses 20%
- General Estate (fencing, repairs, etc.) 50%

Based on the information provided by the Estate forestry factors, the following cost chart was compiled (Fig 43):

Description	Cost	Comment
Forestry / Estate Squad = 3 men	£9.10 per hour each =£27.30 per squad hour	Available for woodchip duties for 25% of time
Contract Labour as required	£8 to £10 per hour depending on work	Possible scope for additional local labour & student vacation / work placement experience
Machinery (Tractor / Trailer with grab)	£12 per hour	Excluding operator: operator cost to be added
Timber Harvesting **Thinnings**	£16 per tonne	175 to 225 tonnes per week average
Timber Harvesting **Clearfells**	£11 – 12 per tonne to roadside	300 – 400 tonnes / week average

Fig 43: Forestry Cost Chart [24]

Assumptions:

- ► The calculations following are based on 3 estate workers being available for 25% of the working year = £12,000

The figures are calculated on the basis of providing adequate supplies of woodchip fuel for either use only on the Estate and/or for sale externally. The various options are as follows:

(1) For Thinnings (Fuel use on Estate only)

Equipment cost to harvest 350 tonnes of thinnings to drying shed = 350 x £16 =£5600

Cost of providing timber thinnings to drying shed = Equipment cost (£5,600) + Labour cost of £2,100 (3 men @ hourly rate of £9.10 x 2 weeks)

Total = £7,700. (Processing thereafter may incur extra cost e.g. drying operations).

(2) For Thinnings (For Fuel Use: External Sale Only)

Equipment cost to harvest a tonne of thinnings to the drying shed = £16 per tonne.

Cost of labour = £5 per tonne (calculated for 3 men for 1 week = £1025. Also, mean of 170 to 225 tonnes = 200 tonnes → £5 per tonne

Total = £21 per tonne to the drying shed. (Processing thereafter may incur extra cost e.g. drying operations).

(3) Clearfell (For Fuel Use on Estate Only)

Equipment cost to harvest <u>350 tonnes</u> of clearfell timber to the drying shed = £12 x 350 = £4200.

Labour costs for 1 week = £1050

Total = £5250 to the drying shed. (Processing thereafter may incur extra cost (e.g. drying operations).

(4) Clearfell (For Fuel Use: External Sale Only)

Equipment cost to harvest = £12 per tonne

Labour costs for 1 week @ £1025 and 350 tonnes (assumed mean of 300 and 400 tonnes) = £3 per tonne.

Total = £15 per tonne for clearfell to the drying shed. (Processing thereafter may incur extra cost (e.g. drying operations).

6.3 The Property Survey Results

There are many buildings on the Ardverikie Estate, some occupied permanently, some with partial occupancy and some that are in effect, 'mothballed'. Time and resources limited the study and for these reasons, the properties that have been assessed in detail are: *Ardverikie House, Aberarder Lodge and Cottage*, *The Gate Lodge, Gallovie Farmhouse, Inverpattack Lodge and The Old School House.* The first three properties required heat load assessments, as they are not properly equipped with wet central heating systems (Ardverikie has had a partial system which is now out of commission). A spreadsheet was used to estimate heat loadings. The latter five properties already have functional wet central heating systems fitted and the requirement would be for 'retro-fitting' of woodchip boilers.

6.3.1 Ardverikie House

Ardverikie House has had a partial central heating system in operation until recently. The current installation comprises two separate oil-fired heating and hot-water boilers. The heating boiler has been out of commission for the past two years. The hot water boiler is still in use. Additional heating in the form of 23 electric radiators and around five open fires has been used. The house has proved impossible to heat, even with all these sources in operation. Heating is crucial to maintaining the building fabric. A long-term heating strategy is mandatory.

6.3.2 Ardverikie House Heat Load Calculations

- The U value is defined as the overall heat transfer coefficient in W/m^2K.
- The heat transfer rate is expressed as $Q = UA\Delta T$.

As a guide, older buildings such as Ardverikie (which are typically very draughty with little or no insulation) have poor U values, in the range 160 – 200 W/m^2. This compares to ‘normal’ buildings, which have U values in the region of 80 – 100 W/m^2, and modern insulated buildings of approximately 20 W/m^2. [11]

A summary of the figures is given as follows:

Assumptions:

$U_{Wall} = 2$

$U_{Glazing} = 6.7$

$U_{Roof} = 0.6$

$U_{Floor} = 0.25$

ACH (Air changes per hour) = 1.5

Inside air temperature = 21^{0}C

Outside air temperature = -5^{0}C

Building dimensions:

Length of external walls (2-storey) = 100m

Gross area = 800m^2

Glazing area = 80m^2

Net wall area = 720m^2

Length of external walls (3-storey) = 70m

Area = 840m^2

Glazing area = 84m^2

Net wall area = 756m^2

Floor/roof area = 1200m^2

Building volume = 22880m^3

<u>Fabric Loss</u>	Walls = 77kW	<u>Ventilation loss</u>	= 297kW
	Glazing = 29kW		
	Roof = 18.72kW		
	Floor = 7.8kW		
<u>Total</u>	= 429kW		

Heat-up allowance = 129kW

Heating boiler size = 558kW = 155W/m^2 + Additional allowance of 50kW for hot water supply to 11 bathrooms, kitchens and washbasins = approximately 600kW.

Heating costs 1,280,430 kWh Oil @ 3.2p/kWh = £40,974

This assumes 16-hours/ day; 41 weeks/year; 7 days/week; 50% average heating load.

Whole house heated = approx £40,000 per annum.

6.3.2.1 Electric Heating Option

Ardverikie House has undergone a recent re-wire for electric heating. The Estate has its own hydroelectric scheme and this on the face of it would appear to be a supply option, particularly at night. There are reasons however, why this would not be feasible. There are two generators, of 1 MW and 100 kW capacities. During daytime, the majority of output of the larger generator is fed to the grid (pool price permitting). The sale of hydro electricity is a major income stream for the Estate and it would not make sense to use up to 50% of the generator output to heat the house. At night, the larger generator could be used to supply heating in theory but there are constraints. The larger generator cannot be operated at below 500kW output. This would constrain the maximum output at night available to the House to less than the 100kW of the smaller generator, as other customers are fed directly from the hydro station, including the adjacent Carrour Estate and the BBC location filming portacabin village.

6.3.2.2 Woodchip Heating

The installation of woodchip boilers and a wet heating system would be the option of choice for any proposed heating system. The calculations for a woodchip system, based on locally produced woodchips, are presented later in the study. The proposed heating system for the House would ideally include underfloor heating for the principal rooms on the ground floor, access for installation being gained from the basement area. This would ensure basic fabric protection, providing the majority of the heat input required. The large glazing areas of some rooms would certainly require heating to be provided, in order to offer protection for the building fabric and furnishings. Additionally, it would provide comfort to those living and working within.

6.4 Aberarder Lodge and Aberarder Cottage

Aberarder Lodge is a 15-bedroom solid sandstone construction. The Adjacent Cottage is of similar construction. The Lodge building is undergoing phased refurbishment at present. Remedial work has uncovered evidence of damp ingress through the stonework. Unheated buildings of this type are very susceptible to damp for a number of reasons:

- Wind-driven rain penetration of the stonework
- Osmosis: The rainwater passes from the outside face to the inside.
- Inverse vapour pressure profile across the wall: this occurs when the inside temperature is lower than the outside temperature. It can occur throughout the year in an unheated building with thick sandstone walls and a small glazing area. The net result is moisture passing into the building.

Aberarder Lodge and the Cottage do not have central heating systems installed at present. There are propane fuelled open radiant panels in the Lodge, which release vast amounts of water vapour into the building when in use. This has had a deleterious effect on the inner fabric of the building. There exists an outhouse attached to the Lodge. An old oil-fired ‘Potterton’ boiler and cylinder supplies hot water to the Lodge. Fuel oil is also used to heat an ‘Aga’ in the Lodge and also to heat a cooking range in the Cottage. It would be feasible to provide one woodchip boiler to provide all the heating and domestic hot water needs of the two buildings, as they are located in close proximity to one another.

6.4.1 Aberarder Lodge & Cottage Heat Load Calculations

<u>Aberarder Lodge</u>

Assumptions:

$U_{Wall} = 1.4$

$U_{Glass} = 6.7$

$U_{Roof} = 0.3$

$U_{Floor} = 1$

ACH = 2

IAT = 15^0C

OAT = -5^0C

Building dimensions:

Length = 20m

Width = 15m

Height = 7m

Floor area = 750m^2

Roof plan area = 300m^2

Gross wall area = 490m^2

Glazing area = 73.5m^2

Net wall area = 416.5m^2

Volume = 2520m^3

<u>Fabric loss</u>	Walls = 11.7kW
	Glazing = 9.8kW
	Roof = 1.8 kW
	Floor = 6.0 kW
	Sub-total = 29.3kW
<u>Ventilation loss</u>	= 33.6kW
Total losses	**= 62.9kW**
Heat-up allowance	= 18.9kW

Heating boiler power = 81.7kW = 109W/m^2

<u>Heating costs</u> 187,676kWh Oil @ 2.9p/kWh = £5,433

This assumes 16 hours/day; 41 weeks/year: 7 days/week

Whole house heated = £6,855 per annum.

Note: This figure represents oil heating only. The house is actually heated at present by a mix of oil, propane and electricity. The figure for the latter mix is £5,660. This corresponds well to the oil-only figure. For later woodchip calculation, the figure of £5,660 is considered

Aberarder Cottage

The Cottage is of similar material construction to the Lodge and the assumptions are identical.

Total losses = 16.2kW
Heat-up allowance = 4.9kW

Heating boiler power = 21.1kW = 146W/m² (see also Lodge for hot water)

Heating costs 48,370kWh Oil @ 2.9p/kWh = £1,403
This assumes 16 hours/day; 41 weeks/year; 7 days/week

Whole house heated £1,359 per annum

Grand total = 81.7kW + 21.1kW + Allowance of 25kW for supplying hot water to the Lodge and Cottage = **Approximate total 130kW boiler power for combined properties.**

6.5 Estate Properties Summary Table

The following table (Fig 44) gives a summary of the property portfolio with floor areas, construction, heating and current fuel costs where available:

No	Property	Total Floor Area (m^2)	Construction	Heating	Fuel Costs
1	**Ardverikie House**	3,600	Traditional Sandstone	Partial wet central heating, Oil-fired (defunct) + Oil-fired domestic hot water + 23 Electric radiators + 5 Open fires	**£40,000 p.a.**
2	**Aberarder Lodge**	750	Traditional Sandstone	Propane Open-panel radiants + Oil-fired 'Potterton' boiler for domestic hot water + Oil-fired 'Aga' in kitchen + 'Jotul' wood stove in kitchen	Fuel oil = £3,200 + LPG = £1,200 + Electricity = £1,260 = **£5,660 p.a.**
3	**Aberarder Cottage**	150	Traditional Sandstone	Oil-fired 'Raeburn' cooker + Portable electric heaters + Open fires	(Fuel-oil as part of the above bills for the Lodge) + Electricity @ **£650 p.a.**
4	**Gate Lodge**	250	Traditional Sandstone	Oil-fired wet central heating + Open fires	£588 from October '00 to April '01 + 25% assumed cost for summer period of £150 = **Total £738 p.a.**
					Continued below

Fig. 44: Summary (part)

No	Property	Total Floor Area (m^2)	Construction	Heating	Fuel Costs
5	**Gallovie Farmhouse**	380	Traditional Sandstone & Roughcast	Oil-fired wet central heating system + Oil-fired 'Esse' in kitchen + Open fires	Fuel oil @ 10,050 litres = **£2,249 p.a.** (From 15/06/00 to 03/04/01)
6	**Inverpattack Lodge**	280	Traditional Sandstone	Oil-fired wet central heating system	Fuel oil @ 3,450 litres = £785 from Jun '00 to Dec '00 + Assumed 100% for remainder of year. **Total= £1,570 p.a.**
7	**Old School House (Office)**	346	Traditional Sandstone	Oil-fired wet central heating system	Bills not available therefore estimated on basis of floor area and full occupancy = **£2,000 p.a.**
8	**Aberarder ex-Gardener's Cottage**	150	Brick & Roughcast	Wood-fired 'Aga' & Open fires	Could perhaps be considered as part of a mini-district-heating scheme with Aberarder Lodge and Cottage
					Continued below

Fig. 44: Summary (part)

No	Property	Total Floor Area (m^2)	Construction	Heating	Fuel Costs
9	**Gallovie Cottages**	330	Traditional Sandstone	Wood-fired 'Aga'	Not applicable to this study
10	**Kinloch Cottages**	260	Traditional Sandstone	Wood-fired 'Aga'	Not applicable to this study
11	**Stan's & Sue's Cottage**	135	Timber & Brick	Wood-fired 'Aga'	Not applicable to this study
12	**Pinewood Cottage**	To be demolished for Log Cabin	N/A	Unknown at present	Could be included in a mini district heating system with Kinloch Cottages in future

Fig. 44: Summary (part)

6.6 Woodchip Requirement for Estate

Woodchip quantities required to provide fuel for the Estate buildings are calculated as below. In addition, the results are summarised in the table in Fig. 45. The following assumptions are made:

- Woodchip average energy content = 4kWh/kg
- Boiler efficiencies = 80% but this is applicable to oil or woodchip
- Net calorific value of gas-oil Class ‘D’ = 9.98kWh/l
- Net calorific value of propane = 12.86kWh/kg

6.6.1 Ardverikie

From calculations the boiler size for heating only = 558 kW. Hot water for domestic use has to be included in the overall calculation and this has been assumed to bring the overall boiler size to 600kW. Taking into account the boiler efficiency of about 80%, the woodchip requirements would be:

750kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 187.5kg of woodchip per hour at maximum load.
This equates to 4.5 tonnes of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 2.25 tonnes.

6.6.2 Aberarder Lodge & Cottage

From calculations the boiler size for heating the Lodge and Cottage and providing hot water (from a central woodchip boiler) = 81.7kW (Lodge) + 31.1kW (Cottage) + 25kW (hot water) ~ 130kW. Taking into account the boiler efficiency of about 80%, the woodchip requirements would be:

162.5kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 40.6kg of woodchip per hour at maximum load.
This equates to 975kg of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 487.5kg per day

6.6.3 The Gatelodge

The Gatelodge has an existing wet central heating system. Based on the floor area and the current fuel use and associated cost, an estimated size of woodchip boiler for heating and domestic hot water = 50kW. Taking into account the boiler efficiency of about 80%, the woodchip requirements would be:

62.5kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 15.6kg of woodchip per hour at maximum load.
This equates to 375kg of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 187.5kg per day.

6.6.4 Gallovie Farmhouse

Gallovie Farmhouse has an existing wet central heating system. Based on the floor area and the current fuel use with associated cost, an estimated size of woodchip boiler for heating and domestic hot water = 80kW. Taking into account a boiler efficiency of about 80%, the woodchip requirements would be:

100kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 25kg of woodchip per hour at maximum load.

This equates to 600kg of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 300kg per day.

6.6.5 Inverpattack Lodge

Inverpattack Lodge has an existing wet central heating system. Based on the floor area and the current fuel use and associated cost, an estimated size of woodchip boiler for heating and domestic hot water = 65kW. Taking into account the boiler efficiency of about 80%, the woodchip requirements would be:

80kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 20kg of woodchip per hour at maximum load.
This equates to 480kg of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 240kg per day.

6.6.6 The Old School House (Office)

The Old School House has an existing wet central heating system. Based on the floor area and the current fuel use and associated cost, an estimated size of woodchip boiler for heating and domestic hot water = 75kW. Taking into account the boiler efficiency of about 80%, the woodchip requirements would be:

94kW to be met from woodchip:
Woodchip @ 4kWh/kg
= 23.5kg of woodchip per hour at maximum load.
This equates to 564kg of woodchip per day at maximum loading. The system may well be operated at loads lower than this, with corresponding lower woodchip requirements. At 50% loading, the requirement would be 282kg per day.

The total woodchip requirements are summarised in the table in Fig. 45

No	**Property**	**100% Loading**		**50% Loading**	
		Daily	**Weekly**	**Daily**	**Weekly**
1	Ardverikie House	4.5t	31.5t	2.25t	15.75t
2	Aberarder Lodge & Cottage	975kg	6.82t	487.5kg	3.4t
3	Gatelodge	375kg	2.625t	187.5kg	1.3t
4	Gallovie Farmhouse	600kg	4.2t	300kg	2.1t
5	Inverpattack Lodge	480kg	3.36t	240kg	1.68t
6	Old School House (Office)	564kg	4t	282kg	1.97t
Totals		**7.5t**	**52.5t**	**3.747t**	**26.2t**
Cost (Thinnings) @ £16/t		**£120**	**£840**	**£60**	**£419.2**
Cost (Clearfell) @ £12/t		**£90**	**£629**	**£45**	**£314**

Fig.45: The Estate woodchip demand summary

6.7 Cost Analysis of Installing Woodchip Boilers

Ardverikie Estate has a large number of buildings for consideration. It would be perhaps prudent to introduce woodchip systems over a phased basis. That decision would obviously be down to the Estate owners. This analysis assesses the likely costs of supplying and installing new woodchip boilers for the properties listed in the table in Fig.45.

It should be emphasised that in the case of *Ardverikie House, Aberarder Lodge and Aberarder Cottage*, the costs, design and layout involved in the installation of wet central heating systems are not in the remit of this project. There are many reasons why installation of central heating systems in these buildings is desirable and have been highlighted elsewhere in this report. The remainder have central heating already fitted. Retrofit of woodchip boilers is possible in these cases.

6.7.1 Cost Analysis of installing the SWEBO range of woodchip systems

The tables in Fig. 46(a) and (b) list the SWEBO woodchip systems most suitable for the boiler ratings of the buildings, together with cost data. SWEBO systems are manufactured in Sweden to very high standards. Sweden has been in the forefront of biomass application for many years and leads the field in the application of biomass technology. The systems are of the ‘pre-combustor’ design as described in section 5.4.1.4.

Identifier	Property	Required Boiler Rating kW	SWEBO Models
A	Ardverikie House	600	2 x SWEBO 250/40
B	Aberarder Lodge	130	1 x SWEBO 250/40
	Aberarder Cottage		
C	Gate Lodge	50	1 x SWEBO 130/22
D	Gallovie Farmhouse	80	1 x SWEBO 130/40
E	Inverpattack Lodge	65	1 x SWEBO 130/22
F	Old School House (Office)	75	1 x SWEBO 130/40

Fig. 46 (a): The SWEBO woodchip systems [23]

Identifier	Ex-Works cost £	VAT @ 17.5% £	Total £	Insurance, Delivery & Installation @ 4% of ex-Works cost £	Total £
A	2 @18,900 = 37,800	6,615	44,415	1,512	45,927
B	18,900	3,307	22,207	756	22,963
C	12,650	2,214	14,864	506	15,370
D	13,000	2,275	15,275	520	15,795
E	12,650	2,214	14,864	506	15,370
F	13,000	2,275	15,275	520	15,795
Totals	108,000	18,900	126,900	4,320	**131,220**

Fig.46 (b): SWEBO woodchip systems cost summary [23]

6.7.2 Calculating the payback on SWEBO woodchip systems

$$\text{Present Value of Annuity} = C\ (1/r) - [1/r(1+r)^{t}]$$

C = Annuity (annual repayment)

r = Interest rate, assumed to be 9%

t = Repayment time, assumed to be over 15 years

Capital loaned by bank or lending institution = £131,220 (from table, Fig. 46 (b))

131,220 = C (11.1111111 – 3.0504)

C = £16,279.

This would be the annual repayment on the capital borrowed against the purchase of the SWEBO systems as in the table in Fig. XX. The total paid over this period providing the interest rate remained at 9% would be **£244,185**.

6.7.3 Calculating the future fuel costs: a comparison

The table in Fig. 47 summarises the annual fossil fuel costs and the costs of woodchip.

Total Fossil Fuel Costs £ p.a.	Woodchip Fuel Costs £ p.a.			
	100% Load		50% Load	
	Thinnings	Clearfell	Thinnings	Clearfell
51,107	43,680	32,708	21,798	16,328

Fig. 47: Fossil fuel and woodchip costs

The future costs of fuels were calculated to give an indication of the effects, particularly on fossil fuel costs. The assumptions made are listed below.

$$\boxed{F = P\,(1 + i\,)^n}$$

Where:

F = the future value of money

P = the present value of money

i = inflation rate, assumed to be 10% due to normal inflation, instability in world markets and climate change levy.

n = number of years between present and end-of-term, assumed to be 15 years

- ► **Fossil Fuels**

$F = 51{,}107\ (1 + 0.1)^{15}$

$F = 51{,}107 \times 4.1772$

F = £213,486

This is the annual fossil fuel cost in 15 years time, taking into account inflation, etc.

- ► **Woodchip (Thinnings) @ 100% loading**

Rate of inflation applied to the costs of harvesting and processing have been assumed to be less, at 5%

$F = 43680\ (1 + 0.05)^{15}$

$F= 43680 \times 2.0789$

F = £90,808

This is the annual cost of woodchip (thinnings) in 15 years time.

- ► **Woodchip (clearfell @ 100% loading)**

$F = 32{,}708\ (1 + 0.05)^{15}$

F = £67,998

This is the annual cost of woodchip (clearfell) in 15 years time.

Based upon the assumptions made, it can be seen that the costs of fossil fuels are likely to accelerate whilst woodchip fuel would not be subject to the same inflation.

7. Conclusions

'The essence of ecoforestry is to learn to perceive what the forest can supply us without altering its basic ecological functions and intrinsic values'

- Alan Drengson

7.1 Conclusions

Traditional fossil fuels are certain to run out in the future. In addition, they are subject to the vagaries of the world markets and to world politics. The current situation, post-World Trade Centre terrorist attack has made the world a very different place. The political climate and the world markets have become even more exposed and volatile. I emphasised the concept of 'watersheds' in my introduction (1.3) in order to invite the reader's attention as to why change is inevitable. The application of the Climate Change Levy to fossil fuels is likely to raise commercial heating costs by between 20 and 50% and the costs will certainly rise in the future. Rising fossil fuel prices may be the catalyst that causes the pendulum to swing towards renewable energy deployment, including biomass. Biomass can be utilised very efficiently in smaller scale settings such as the Ardverikie Estate.

Biomass energy has an extremely important role to play in a sustainable energy programme. Its use enables fossil fuel displacement, thus benefiting the environment. From the table in Fig. 47, it can be seen that biomass use on Ardverikie Estate, based on the 100% heating load assumption saves £7,427 (thinnings) and £18,399 (clearfell) per annum, over fossil fuel use. Biomass use requires careful management but it can provide for heating energy self-sufficiency, particularly on an Estate such as Ardverikie. Ardverikie Estate has the benefits of vast forestry reserves complete with infrastructure including roads and a sawmill. Arboriculture and energy crop management can ensure sustainability of the resource. The importance of self-sufficiency in heating-energy needs cannot be underestimated. It allows close control of costs and benefits the environment from the 'carbon neutral' standpoint. Money spent on fossil fuel is of little value to local rural economies, with the great majority of revenue going to multinationals and to the government. Woodchip heating uses locally produced fuels with inherent benefits to the rural economy. Additionally, some employment opportunities can be created and existing jobs secured.

Taking cost as a deciding factor, the benefits of heating the large properties are many. Building fabric and contents are maintained in good condition. This ensures longevity of the buildings and contents and mitigates against future repair and maintenance bills. Additionally, comfort levels for those living and working inside are vastly improved.

Communities could become involved in biomass application. It may be possible to supply woodchips externally from the Estate as a business venture, dependent on the scale of production. From my experience moving around the area, there are many hotels for example, that would be interested in converting to woodchip, or at least to a ‘hybrid’ system with fossil fuel backup.

This study, although limited by time and resources, has demonstrated the feasibility of the application of a biomass system. It goes without saying that investments are required to be made in such things as plant and machinery. Taking the long-term view, these investments will reap rewards in terms of quantitative benefits and also qualitative benefits such as fossil fuel displacement.

The Estate would benefit from implementing a long-term energy policy. Although the proposal for utilising biomass application has been shelved at present, reference the communication from the Estate owner (Appendix 3), it would in my opinion be beneficial to set up at least one woodchip system in a property on the Estate as a ‘prototype’. There are interest-free loans available from such organisations as ‘Loan Action Scotland’ for amounts between £5,000 and £25,000. This could be used for purchasing such a system. This could be evaluated and possibly implemented in the other properties, perhaps on a phased basis.

THE FUTURE IS BRIGHT, THE FUTURE IS GREEN, THE FUTURE IS BIOMASS!

8. References & Bibliography

‘We have entered the century of the environment, whether we wanted to or not. In this century, everyone who calls himself a realist will be forced to justify his behaviour in light of the contribution it made towards the preservation of the environment’

- Ernst von Weizsacker

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9. Appendix

'You don't filter smokestacks or water.
Instead you put the filter in your head
and design the problem out of existence'

- William McDonough

Appendix 1

Appendix 1(a): Ardverikie House

Appendix 1(b): Aberarder Lodge (front view)

Appendix 1(c): Aberarder Lodge (rear view)

Appendix 1(d): Aberarder Lodge: Housekeeper's Cottage (adjacent to lodge)

Appendix1(e): The Gatehouse

Appendix 1(f): The Old School House, (now used as Estate Offices), front view

Appendix 1(g): The Old School House, (side view)

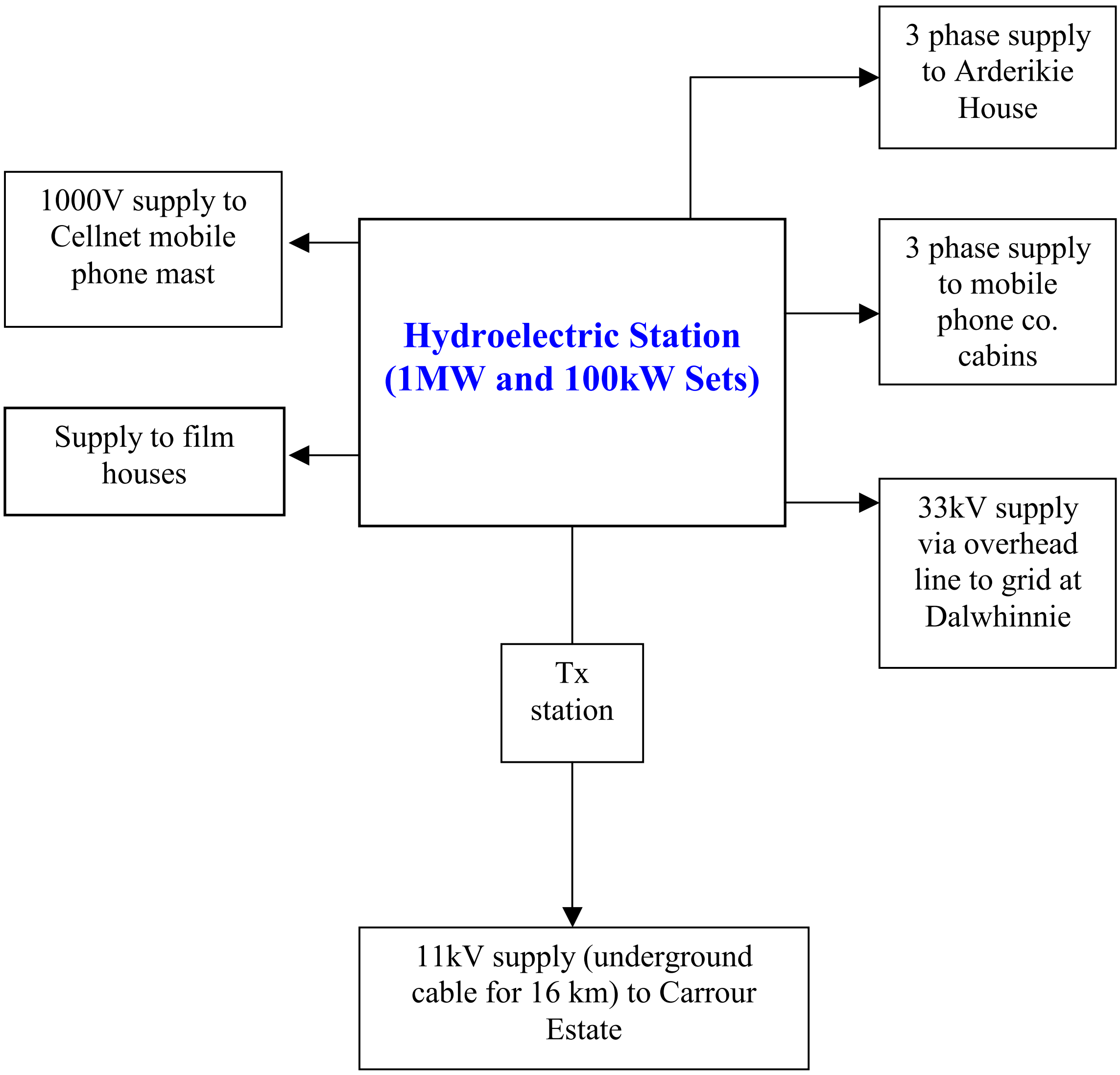
Appendix 1(h): Gallovie Farmhouse

Appendix 1(i): Inverpattack Lodge

Appendix 1(j): Gallovie Cottages

Appendix 1(k): The Hydro Station

Appendix 1(l): Inside the Hydro Station



Appendix 1(m): The Estate Hydro Schematic

Appendix 1(n): The Sawmill

Appendix 1(o): The Sawmill Grid Supply

Appendix 2

SWEBO woodchip systems burner ratings chart

SYSTEM PRICES			
EQUIPMENT DESIGNATION	BURNER SIZE (kW)	HOPPER SIZE (m^3)	PRICE £
SWEBO 65/08	65	0.8	5,138
SWEBO 65/12	65	1.2	5,605
SWEBO 65/22	65	2.2	6,930
SWEBO 65/40	65	4.0	7,292
SWEBO 130/08	130	0.8	6,611
SWEBO 130/12	130	1.2	6,763
SWEBO 130/22	130	2.2	8,291
SWEBO 130/40	130	4.0	8,569
SWEBO 160/08	160	0.8	7,944
SWEBO 160/12	160	1.2	8,166
SWEBO 160/22	160	2.2	9,652
SWEBO 160/40	160	4.0	10,013
SWEBO 250/08	250	0.8	10,777
SWEBO 250/12	250	1.2	11,145
SWEBO 250/22	250	2.2	12,333
SWEBO 250/40	250	4.0	12,708
Delivery within the UK is charged extra.			

Appendix 3

Conversion factors and related information

1kW = 3412 Btu = 3.6 MJ

1Btu = 1,054.8 Joules = 0.2931kWh

1Mbtu = 1.055 GJ

I kilocalorie = 4.1868 KJ = 3.698 Btu

1 kW = 3,413 Btu/hr

1 MW = 3.4 MBtu/hr

Gas-oil = 10.83kWh/kg gross, 9.9kWh net

Propane = 13.89 k/Wh/kg, (0.512kg = 1 litre)

kilo = 10^3

Mega = 10^6

Giga = 10^9

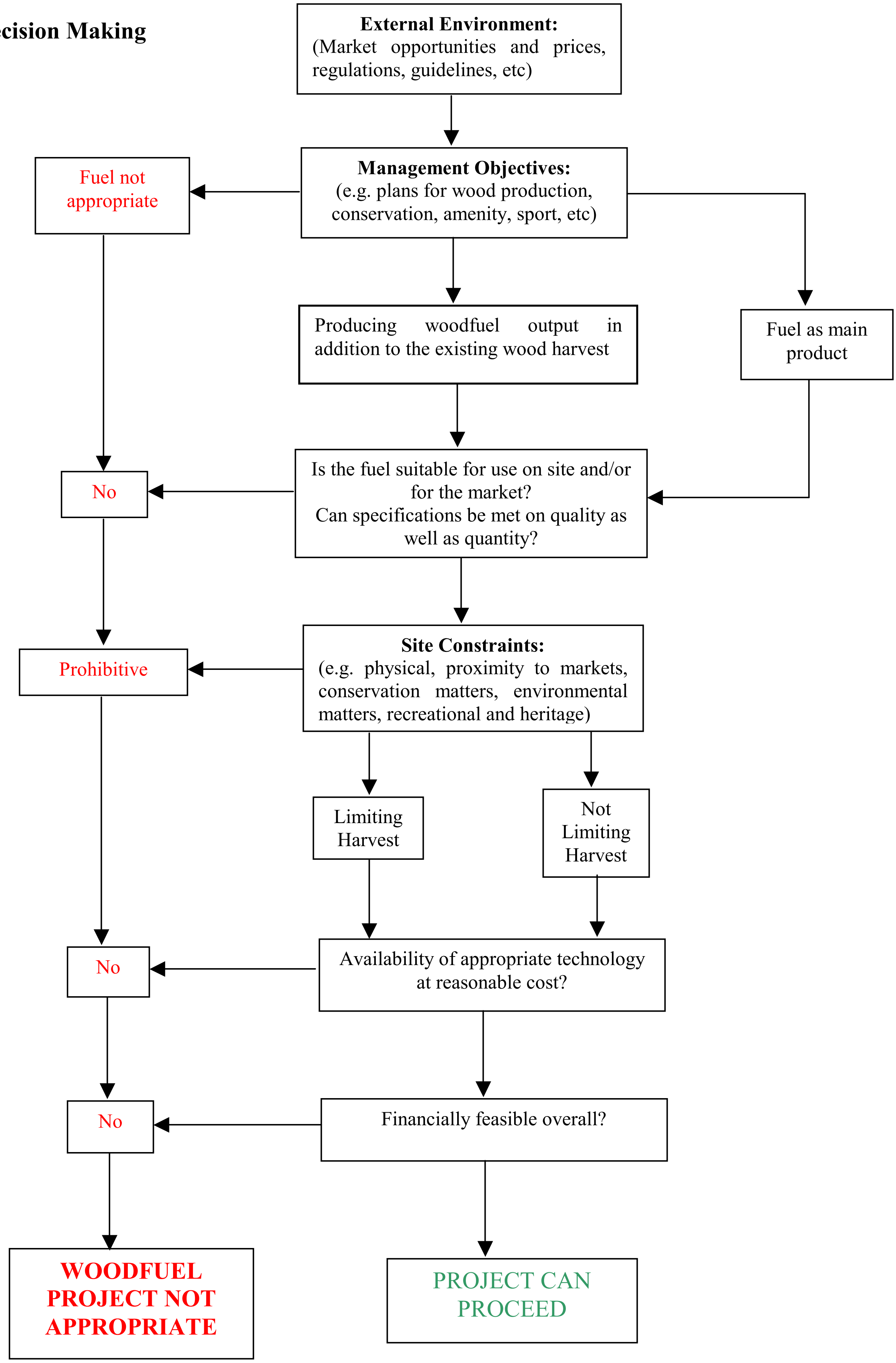
Tera = 10^{12}

Peta = 10^{15}

Exa = 10^{18}

Appendix 4

Decision Making



Appendix 5

Communication from Estate owner (e-mail):

Dear Ian
Thank you very much for the figures and report that you sent us. We had a detailed meeting with XXXXXXXX (name deleted) yesterday to go through all the figures.
Sadly it does not look as if the scheme for the estate to produce chips itself works unless we are continuously producing timber for sale, and the chip is a profitable side product. At Ardverikie we are rather short of mature timber, and will be for another ten/fifteen years, after which things will start up again on a regular basis, and the wood chip may become much more viable. The volumes that Andrew wants could not be produce at a profit as a standalone operation. Thank you very much for your help, and if we can be of further help to you do be in touch with XXXXXXXXXX (name deleted)
XXXXXXXXX (name deleted)

(4) CLEARFELL (For Fuel Use: External Sale)

Costs of machinery to harvest= 12 pounds per tonne

Labour costs for one week @ 1025 pounds and 350 t (mean of 300t and 400 t)
=
3 pounds per tonne.

Total = 15 pounds per tonne for clearfell to the drying shed. (Additional costings for processing thereafter to be provided by XXXXXXXX (name deleted).

I hope these figures let you complete your calculations. The figures are based on estimated heat loads of the buildings. Boiler efficiencies (where boilers are installed) have been taken into account. The calculations are based on the total estimated floor area of the Estate buildings.

May I also re-emphasise the possibility of financial assistance from sources
such as 'Loan Action Scotland".

Best Regards

Ian