Wood as a Renewable Source of Energy

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Introduction

Wood has been the most important fuel used by humans for thousands of years. With the harnessing of fossil and nuclear fuels the use of wood declined. However, wood is still a major source of energy worldwide, both in developed and developing countries. Technological advancements over the last five decades in the conversion of wood into both electrical and heat energy have removed many of the barriers to the greater use of wood as a fuel source. The renewed interest in wood fuel is being driven largely by economic and environmental concerns – wood fuel is increasingly price competitive with fossil fuel alternatives and the environmental benefits of wood fuel are now being recognised and valued. The production and use of wood fuel provides social benefits too, including the creation of additional employment, especially in rural areas.

Policy Drivers for the Use of Wood as Fuel

The Republic of Ireland imports 86% of its total energy requirement. With over €5 billion spent on energy every year our import dependence means a large outflow of money from the economy. The EU Green Paper "Towards a European Strategy for the Security of Energy Supply" states that *"If no measures are taken, in the next 20 to 30 years 70% of the Union's energy requirements, as opposed to the current 50%, will be covered by imported products"* (European Commission, 2000). Wood, as an indigenous energy source, can contribute significantly to reducing our import dependence and to improving our trade balance.

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Wood fuel also has a key environmental benefit over fossil fuels in that wood is 'carbon neutral'. Wood is, in effect, stored solar energy – a renewable resource. Using wood as a fuel does release some carbon dioxide but this is merely the carbon that was absorbed from the atmosphere by the growing tree. In this manner the short cycle is complete, with no additional carbon released. The combustion of fossil fuels, in contrast, releases carbon that has been locked away for millennia.

Under the Kyoto Protocol the EU has an overall target to reduce greenhouse gas emissions by 8% below 1990 levels by the period 2008 to 2012. Ireland is permitted to increase greenhouse gas emissions by 13% over 1990 levels to allow for economic growth. The Irish Government launched the National Climate Change Strategy in December 2000, setting out actions to reduce greenhouse gas emissions. It is projected that without the measures in the National Climate Change Strategy greenhouse gas emissions would be at least 34% above 1990 levels by 2010. Energy use (including electricity, heat and transport) makes up over 50% of Ireland's total greenhouse gas emissions. A key strand of the National Climate Change Strategy is to move from fossil fuels to renewable sources of energy.

The use of wood is promoted in EU policy. In November 1997, the European Commission published a White Paper entitled "Energy for the Future: Renewable Sources of Energy". The paper sets an ambitious goal of doubling the contribution of renewable energy to total energy supply in the EU from 6% average in 1995 to 12% by the year 2010. It is planned that biomass (including wood) will provide more than 80% of the total additional contribution from renewable energy sources. At present, renewable energy sources supply only 2% of the energy demand of the Republic of Ireland, with wood the most important due to its use in homes across the country, in sawmills, and in the four panel board production plants.

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In September 2001, the EU Parliament and Council adopted a Directive on the promotion of electricity from renewable energy sources. The Directive sets an indicative target of 13.2% for the contribution of electricity from renewable energy sources to gross electricity consumption in Ireland by 2010. At present, renewables supply 5% of the nation's electricity. The Green Paper on Sustainable Energy (Department of Public Enterprise, 1999) is the most recent statement of Government policy on energy. The Green Paper sets a working target of 500 MW of additional electricity generating capacity from renewable sources for the period 2000-2005, stating that the bulk of this target will come from wind energy. The paper does not address the potential for wood to contribute to renewable energy supply in Ireland, in both the electricity and heat sectors, but does state that targets for other renewables will be set in due course.

The production and use of wood fuel has the potential to create a significant number of new jobs in Ireland, many of them in rural areas where few other employment opportunities may exist. A report by EUFORES (2000) estimates that the development of renewable energy sources could result in the creation of over 900,000 new jobs in the EU15 by 2020. 385,000 jobs could be created from the provision of renewable energy, and a further 515,000 from biomass fuel production (including wood). The figures take account of jobs displaced in conventional energy technologies.

Wood as a Fuel in Europe

Figure 1 shows the contribution of wood to total energy demand in the Member States of the European Union. Wood supplies about 3% of the EU's energy requirement. France, Sweden and Finland are the three biggest users in absolute terms.

Energy from Wood as a Percentage of Gross Energy Consumption in the European Union 1999/2000

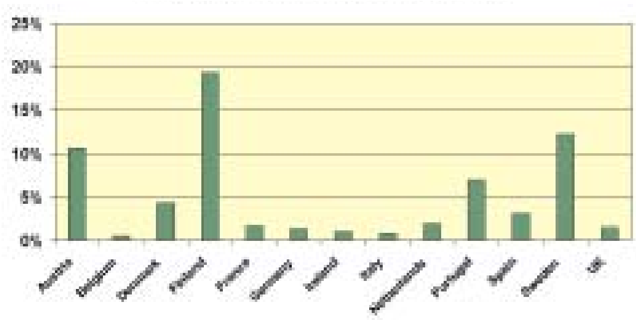

Figure 1: Energy from Wood in the EU as a percentage of Gross Energy Consumption.
Sources: Data on energy from wood from Vesterinen and Alakangas (2001). No data for Greece. Data on energy consumption from Eurostat (2002).

Wood Fuel – Key Concepts

When dealing with the topic of wood fuel, it is essential to understand a number of key concepts including moisture content, wet weight, oven dry weight, density and energy content. There are differences in the terminology used by the forestry sector and the energy sector, and it is important for accurate terminology to be used in order to avoid confusion.

Moisture Content of Wood

The moisture content of freshly felled wood varies considerably according to species, region and time of year. Typical moisture contents are listed in Table 1 below.

Table 1: Typical Moisture Contents of Fresh Wood

Species	MC_{wb}[2]	MC_{db}[3]
Spruce	62%	164%
Poplar	60%	150%
Lodgepole Pine	59%	145%
Willow	50%	100%
Ash	32%	47%

Sources: Poplar and ash from British BioGen (1998); Spruce and pine from Hamilton (1975); Willow from Ledin and Willebrand (1996).

Measuring the Mass ("Weight") of Wood

In the energy sector quantities of wood are often expressed in oven dry tonnes. For example, the wood fuel requirement of a small Combined Heat and Power (CHP) plant might be stated as "750 oven dry tonnes per year". The term "oven dry tonne" derives from the laboratory method used to measure the moisture content of a sample of wood. The method requires that the sample be dried to zero moisture content in an oven. The weight loss (i.e. the water evaporated) is measured and used to calculate the moisture content of the wood sample. The moisture content can be expressed on a dry weight basis or a wet weight basis.

It is important to remember that wood does not exist in an oven dry state outside of the laboratory. To return to the example of the CHP plant requiring "750 oven dry tonnes per year". In reality, the fuel delivered to the plant will not be oven dry. The fuel delivered will have a certain moisture content, determined by a number of factors including the species of wood (see Table 1) and whether drying of the wood fuel has taken place. Thus the plant will receive fuel by the "wet tonne" or "green tonne" (measurable using a weigh-bridge). If the delivered fuel has an average moisture content of 25% on a wet weight basis, 1,000 green tonnes of wood will need to be delivered to the plant per year to meet the requirement for 750 oven dry tonnes.

[2] *Moisture content on a wet weight basis, calculated by expressing the weight of water as a percentage of the total weight of the wood. MC_{wb} is the most common basis used in the energy sector.*
[3] *Moisture content on a dry weight basis, calculated by expressing the weight of water as a percentage of the weight of dry wood. MC_{db} is often used as a basis in the wood processing industry.*

Volume and Density

The weight (mass) of dry wood contained in a unit volume of solid wood is defined as the density of the wood. Table 2 gives the typical density of a number of tree species:

Table 2: Typical Wood Density of Tree Species

Species	Density (Tonnes of dry wood per m^3)
Ash	0.570
Pine	0.480
Spruce	0.390
Poplar	0.380

Source: Centre for Biomass Technology, 1999.

For example, a one cubic metre log of solid pine contains 0.480 tonnes of dry wood. Because wood in its natural state always has water contained within its structure the actual weight of the log is greater than 0.480 tonnes - at 50% MCwb it would weigh 0.960 tonnes. A one cubic metre log of solid pine when chipped produces about three loose cubic metres of wood chips (Centre for Biomass Technology, 1999). Therefore the form of the wood fuel is an important factor to consider in estimating transport and storage requirements.

Energy Content of Wood

The number of units of energy produced by the combustion of a unit mass of a fuel is termed its calorific value (Centre for Biomass Technology, 1999). The calorific value of wood can be expressed as:

- Gross Calorific Value of dry wood
- Net Calorific Value of dry wood
- Net Calorific Value of wet wood

The Gross Calorific Value is defined as the amount of energy produced by the complete combustion of a unit amount of wood at constant pressure, with condensation of the water vapour that is formed during combustion. Condensing the water vapour increases the amount of energy recovered from the wood (this is why a condensing boiler is more efficient than a normal boiler). The water vapour can arise from two sources: the moisture content of the wood, and the formation of water from the hydrogen contained in the wood (about 0.5 tonnes of water are formed from the hydrogen content of one tonne of oven dry wood). The Gross Calorific Value is also termed the Higher Heating Value (HHV). The Gross Calorific Value of oven dry wood is about 20 GigaJoules (GJ) per tonne (Centre for Biomass Technology, 1999). One GigaJoule is one billion (10^9) Joules. There is little difference in the Gross Calorific Values of oven dry wood from different tree species, but bark does have a lower energy content than pure wood.

The Net Calorific Value is defined as the amount of energy produced by the complete combustion of a unit amount of wood at constant pressure, with the water vapour that is formed during combustion remaining in a gaseous state. The Net Calorific Value is also termed the Lower Heating Value (LHV). The Net Calorific Value of oven dry wood is about 19.5 GigaJoules (GJ) per tonne – some energy is lost in the uncondensed water vapour arising from the hydrogen content of the wood.

The Net Calorific Value of wet wood is perhaps the most practical measure of energy content. The moisture content of wood fuel is evaporated as it burns - that process requires energy. The higher the moisture content of the wood, the more energy is required for evaporation. If the wood is burned in a non-condensing boiler, the energy required for evaporation is lost to the user. The amount of useful energy released is shown in Figure 2.

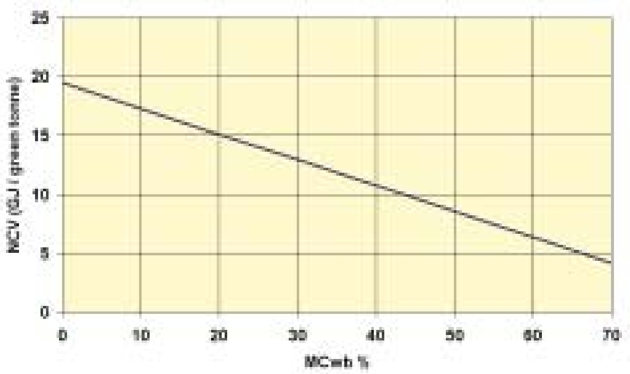

Figure 2: Net Calorific Value of Wet Wood (Based on equation in Centre for Biomass Technology, 1999.).

When stating the net calorific value of wet wood the moisture content should be specified. For example, $NCV_{50\%MCwb}$ = 9 GJ per green tonne. Small-scale wood boilers, including domestic systems, are normally of the non-condensing type. Therefore it is very important to use wood of low moisture content to maximise the amount of useful energy produced. Hence, domestic firewood should be seasoned for at least one year, and preferably two, before being used. Since 1980, payment for fuel wood chips in Denmark has been based on their energy content, determined on the basis of the net calorific value of wet wood. Prices are quoted on a "per GJ" basis, rather than on measures of wood volume or weight (Centre for Biomass Technology, 1999).

Converting Wood to Energy

The energy content of wood can be released in two principal ways:

1. Direct combustion. Combustion is a thermochemical

process in which the wood is combined with oxygen and converted to carbon dioxide and water (and other minor constituents), releasing energy.

2. Gasification or pyrolysis. These are also thermochemical processes which convert wood into a gaseous or liquid fuel. The gaseous or liquid fuel is then combusted in a second step to release energy. Development work is also underway on using biochemical processes to convert wood into ethanol, which could then be used in an internal combustion engine for transport applications.

Theory of Combustion

Combustion is the principal method used to release energy from wood, with applications ranging in scale from burning wood in a domestic open fire to the use of wood residues for large-scale CHP production in the forest industry. In all cases it is essential that the wood fuel is combusted efficiently and completely, in order to maximise energy output and minimise environmental emissions. The combustion of a wood particle is illustrated in Figure 3. The combustion occurs in three stages:

1. Drying. The wood particle is heated, water evaporates and the fuel dries.
2. Pyrolysis, gasification and combustion of volatiles. At 100°C to 105°C gasification and pyrolysis processes start. The volatile components of the wood evaporate and the wood surface becomes porous. At 500°C to 600°C the volatile components (now gaseous) start to combust – this process is visible as long flames above the fuel. Most (75 to 80%) of the energy produced from wood results from the combustion of the volatiles.
3. Charcoal burnout. At 800 to 900°C the glowing charcoal burns out leaving ash.

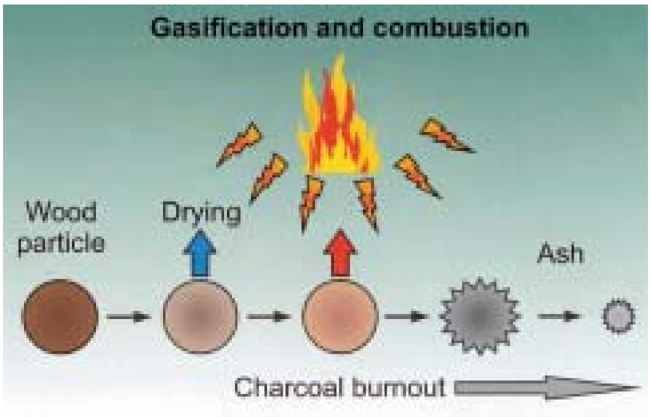

Figure 3: How a Wood Particle Burns
Source: Centre for Biomass Technology (1999). Used with permission.

The objective of a good combustion process is to ensure that the volatile and charcoal contents of the wood are converted completely to ash. Good combustion is that which:

- maximises the energy output from the wood,
- minimises the amount of fuel required,
- minimises emissions of unburnt volatiles and carbon monoxide to the environment,
- minimises unburnt charcoal in the ash,
- minimises tar and soot deposits in the chimney/flue.

The requirements for efficient and complete combustion are time, turbulence (to ensure mixing of air and volatiles), temperature and controlled oxygen (air) to fuel ratio. The combustion equipment must be designed to ensure that these requirements are met.

Sustainable Sources of Wood Fuel

Table 3 describes nine existing or potential sources of wood for fuel in the Republic of Ireland.

It is expected that wood fuel production from the forest will in future become more closely integrated with forest management planning, harvesting logistics, quality management systems and forest certification (Hakkila and Fredriksson, 1996). For example, research is underway in Denmark to examine if afforestation policy could contribute more wood for fuel by increasing the initial planting density and using nurse trees (Centre for Biomass Technology, 1999).

Forms of Wood Fuel

Table 3 lists potential sources of wood for fuel. The wood from some sources can be used as fuel without any further processing. However, in general, wood undergoes further processing before being marketed as fuel. The three most common forms of wood fuel are firewood, wood chips and wood briquettes or pellets (see Figures 4 and 5). Converting wood to these forms makes the fuel

Figure 4: Cross-cut, split and seasoned firewood

Table 3: Potential Wood Fuel Sources

Fuel Source	Description
Firewood	Generally sourced from hardwood species, either from thinnings or the tops, branches and butt ends resulting from clear-felling.
Sawmill Residues	Bark, off-cuts, brown and white chip, sawdust and wood shavings from the sawmilling sector. Existing markets include panel board production, mulch, animal bedding and fuel.
Wood Industry Residues	Off-cuts, sawdust, shavings, trimmings, sandings and reject product from wood product and panel board manufacture. Uses at present include fuel for plant and process heating.
Arboricultural Residues	Tree surgery residues from the maintenance of parks, gardens and hedgerows. May be used for mulch or fuel, but sometimes disposed of by burning (to waste) or landfilling.
Small Diameter Roundwood	Small diameter roundwood arising from early thinnings or the clearing of pre-mature or damaged stand. New harvesting methods are developing including whole tree chipping.
Forest (Logging) Residues	Often referred to as "brash" or "lop and top" – the tops and branches of the tree left after harvesting of the main stem. Residue bundling and baling systems have been developed.
Unmerchantable Timber	Wood that is not of a high enough quality for sale as roundwood, but that could be used for fuel (e.g. dead or crooked stems).
Short Rotation Forestry	Production of fuel wood from certain tree species (generally willow or poplar) which are harvested in rotations of three years or more. Usually managed as a coppice system.
Waste Wood	Includes broken pallets, crates, and waste timber from building and demolition work. Some clean waste wood is chipped and used as fuel or raw material in panel board manufacture.

Figure 5: Forms of Wood Fuel Forest wood chips, sawdust, bark, wood pellets
Source: Centre for Biomass Technology (1999). Used with permission. Photograph by Flemming Rune, Danish Forest and Landscape Research Institute (FSL).

easier to handle. Some countries have well established quality standards for firewood, wood chips and wood pellets. Other countries do not. There is work progressing at EU level to develop common standards for solid biofuels.

Converting the Wood into Useable Energy

Wood is converted into heat and/or electricity using equipment appropriate to the scale of operation, including:

- Manually-fed fireplaces, ranges and stoves
- Automatically-fed chip and pellet boilers
- Electricity generation plants or combined heat and power plants
- District heating systems
- Co-firing

Depending on the scale, the conversion system may include some or all of the following components: Fuel reception; Fuel storage; Fuel handling equipment; Combustion unit; Boiler; Turbine; Generator; Exhaust gas cleaning; Stack (chimney); Ash removal and processing; Control equipment.

Modern equipment is efficient at converting the energy content of the wood into useful energy for the consumer. The efficiency of the conversion appliance has a huge impact on the amount of fuel required: a system of 90% efficiency will require only half of the wood required by a system of 45% efficiency, in order to provide the same energy output. Efficiencies are generally given on a NCVwb basis – this is why a condensing boiler can be over 100% efficient – it recovers the energy normally lost with the water vapour in the flue gas.

Manually-fed fireplaces, ranges and stoves

The simplest way to use wood as a fuel is in a manually fed fireplace, range or stove. Significant advances have been made over the last 15 years in the design and manufacture of stoves and boilers, to improve the efficiency, reduce emissions and increase convenience. The efficiency of manually fed stoves and boilers is now up to 75%, compared to about 20% for the typical open fire (IrBEA, 2000). Systems are available for air heating, central heating and domestic hot water. About 300,000 wood stoves are in operation in Denmark (Centre for Biomass Technology, 1999).

Automatically-fed chip and pellet boilers

The efficiency of automatically fed boilers is up to 85%. Automatically fed systems offer a greater level of convenience than manually fed systems and may include advanced controls, automatic ash removal, automatic cleaning and auto ignition. Boilers are available in a wide range of sizes, from small domestic to large commercial and industrial systems. Figure 6 shows a typical automatic chip-fired system.

Electricity Generation and Combined Heat and Power Plants

A typical Irish solid fuel electricity generating station burns fuel to convert water into steam at high temperature and pressure. This steam then drives a steam turbine, which in turn drives a generator to produce electricity. The steam is then condensed (in a cooling tower, or using river or sea water) and goes through the cycle again. The average efficiency of electricity generation in Ireland in 1998 was 36%

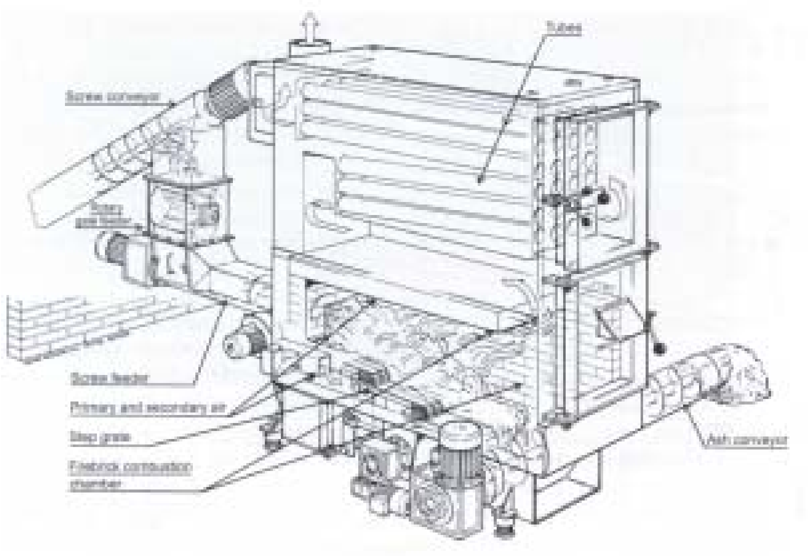

Figure 6: Automatic Wood Chip-fired Heating System
Source: Centre for Biomass Technology (1999). Used with permission.
Drawing by Maskinfabrikken Reka A/S.

(Department of Public Enterprise, 1999). The other 64% of the energy content of the fuels is wasted. In a combined heat and power plant, the heat resulting from power generation is also harnessed. The overall efficiency of a CHP plant can therefore be 85% (though the electrical output is typically less than an electricity-only generating plant with the same fuel input). The size of a CHP plant is generally based on the available heat demand. The plants are now highly advanced and can be designed to use a number of different fuels. CHP based on steam turbines is not generally considered viable at smaller scales (typically under 5 MW_e). Gasification, Stirling engines and steam engines show promise for viable small scale CHP.

District Heating Systems

District heating is the communal production, distribution and supply of heating and hot water services. The concept was first implemented in the USA in 1870. District heating is now used in northern, western and eastern Europe, Russia, North America, China, Korea and Japan. The three main components of a district heating system are: a heat production plant; a heat distribution network (underground pre-insulated pipes); and network/consumer interface equipment. Typically hot water at 70 to 120°C is produced by the plant and pumped into the network. A branch from the network serves each consumer. There is a heat exchanger at the consumer's premises which takes the heat from the district heating network for the consumer's use. The water returning to the district heating plant typically has a temperature of 40 to 65°C. There is a natural gas-fired district heating scheme in Dublin, serving the Dublin Corporation offices and a number of other buildings. Denmark has over 50 wood chip-fired district heating plants, with an average output of 3.5 MW_{th} (MegaWatts thermal) (Centre for Biomass Technology, 1999). Most of these have flue gas condensation units which recover energy by cooling the flue gas below 100°C (the return water from the district heating network is used for cooling).

Co-firing

It is estimated that 150 large energy plants in the EU burn biomass together with other non-biomass fuels (Alakangas and Veijonen, 1998). This technique is referred to as co-firing. For example, the Rauhalahti CHP plant in Finland burns mainly peat and sawmill residues, and has a capacity of 80 MW_e and 210 MW_{th}. There are also several examples of the co-firing of wood with coal across Europe (reducing emissions from the coal plant). Co-firing allows wood fuel to be introduced into the conventional energy system at relatively low cost and risk. The feasibility of co-firing wood with peat in peat-fired power stations in the Republic of Ireland is under investigation.

Conclusion

The key advantage of wood fuel is its potential to provide a combination of environmental, economic and social benefits. Key ingredients for successful wood energy enterprises include good business planning, community consultation, well designed conversion facility, reliable and competitive fuel supply, high quality conversion technology, professional installation, well-planned fuel delivery and storage, and high standards of operation and maintenance. With appropriate care, the development of wood as a fuel in Ireland will provide multiple benefits.

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