# Unit 11
Biomass Resources and Technology

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1. Introduction to Biofuels

1.1 What is biomass?

All the plant and animal life on earth is able to fix and store solar energy, as part of its own growth and procreation. Plants do this through photosynthesis and animals by eating plants, or eating other animals that have eaten plants (see Figure 1). Moreover, as new plants grow, and animals are born, this energy store is being constantly renewed. We can call these materials biomass. Hence, biomass is simply the material of plants and animals.

![Diagram of energy transformation](https://via.placeholder.com/150)

**Figure 1** Some routes for the transformation of energy absorbed by a plant.
(Source: Adapted from Boyle)

From the first law of Thermodynamics, energy doesn't just appear from nowhere and disappear into nothing. The energy that makes things grow comes ultimately from the sun. So where does this energy go to when organic matter "dies", when it is left to rot down or biodegrade? Most of the energy stored in biomass will eventually be radiated away as low temperature heat - the sort of process which no-one notices and which has little effect on anything. But if we can intervene in this process and capture some of that stored energy before it is dissipated, then potentially we have a fuel.

So a biofuel is basically any biomass resource that is capable of being used as, or converted into, a fuel. The U.K. based Energy Technology Support Unit defines biofuels as: "any solid, liquid or gaseous fuels produced from organic materials, either directly from plants, or indirectly from industrial, commercial, domestic or agricultural wastes."

Until a few hundred years ago, all fuels were biofuels. People produced heat for cooking mainly by burning wood, and this is still the case in many parts of the world today. Hundreds of years ago, with the mass production of charcoal as a fuel, came the high temperatures necessary to smelt iron ores. Thus, it was an early biofuel
technology (the burning of wood without oxygen, to produce charcoal) which made possible the production of iron and steel which started the Industrial Revolution.

1.2 Biofuels and the carbon cycle

Biofuels are useful for the management of the enhanced greenhouse effect as they have zero net carbon emissions. Plant matter absorbs carbon in the process of photosynthesis; this organic matter is processed into biofuels; when the biofuels are used, they emit the carbon back into the atmosphere; this carbon is then absorbed by plants. Figure 2 shows the carbon cycle for an energy crop such as corn. Biofuels have zero net carbon emissions because all the carbon that is released by burning ethanol is absorbed later in the cycle. This CO₂ would be normally be released anyway when the plants decay. However, when fossil fuels are burnt they produce carbon dioxide (as well as other gases) that are ‘extra’ to the capacity for absorption in the natural plant life cycle and isn’t reabsorbed within its own useful cycle—there is a large ‘net’ carbon emission.

THE CARBON CYCLE

Crops like corn are finely ground and separated into their component sugars. which releases carbon dioxide which can be used as an alternative fuel.

The sugars are distilled to make ethanol.

Figure 2 The Carbon Cycle (Source – Need, 2002)

2. Types of biofuel

Biofuels can be derived from two sources: products that have previously been considered as ‘waste’ or from specially grown crops.

Many biofuels are derived from the waste or by-products of a process completely unconnected with energy production. These by-products can be agricultural or forestry residues, domestic or commercial wastes. In general, these raw materials for biofuels will be of low value and relatively low energy content. But they are usually in
plentiful supply, and if processed locally, can provide an economical solution to waste disposal problems, as well as producing energy at low cost and with no (or lower) greenhouse gas emissions.

An alternative approach to sourcing the feedstock for biofuels is to grow them deliberately as Energy Crops. This involves selecting high-yield species and intensive growing methods, and includes oil, sugar and starch crops as well as timber. They will be more expensive to produce, but will generally have a higher energy content, than waste-derived fuel.

2.1 Energy from 'waste'

2.1.1 Wood waste

Wood is the oldest fuel of all and the natural wastage that forms as the tree grows - dead or broken branches from the forest floor - has been collected and used as a fuel since people first discovered how to make fire. In this context, wood waste refers to the by-products of road clearing, commercial forestry and timber processing (which can be as much as 50% of the tree, including tops, leaves, smaller branches, bark and the outer layer of the trunk), the building industry and furniture manufacturing.

At present, most of this waste is left to rot at the site of the felling, is burnt unproductively or is sent to landfills, without any energy recovery. Potentially, these wastes can be burnt economically in local homes and light industry, although transportation costs of such a bulky material could be prohibitive. Chipping the wood waste allows quicker drying and makes for a more homogeneous fuel, giving controlled combustion in specially designed boilers. The type of chippers used are similar to those used for tree prunings etc. to make chips for garden mulching.

2.1.2 Other plant wastes

In temperate climates, the generation of large quantities of waste straw, as a by-product of cereal production, has led to innovative local heating systems on farms and estates producing the straw. Until recently, straw was often disposed of by being burnt off in the fields; this practice has now been banned in many places because of atmospheric pollution. Much of the straw now is utilised on the land to retain soil fertility, but there may still be an excess that needs 'disposing of'. If this excess can be processed on site or locally to generate cheap heat, it is well worth while.

1 New saw-milling and timber processing techniques such as radial sawing and laminating beams are assisting in maximising the usable timber and reducing the amount of waste per tree milled.

2 Straw, rice husks and stalks are a vital part of maintaining a balanced eco-system. By placing (not ploughing) this waste back onto the soils it not only enables nutrients to be naturally reabsorbed back into the soil, hence no need for artificial chemicals, but helps to maintain a balanced eco-system, with minimum of pests, reduced moisture evaporation and also protects young plants.
Tropical climates generate different kinds of agricultural waste, but the problems - and the solutions - remain basically the same. Rice is the most widely grown cereal crop in the world and rice husks account for about one fifth of the whole rice grain by weight. Although the husks have a high ash content which tends to clog incinerators, they have been found to be particularly suitable for use in simple, open-top gasifiers. (see Section 4.2, page 16).

Bagasse or sugar cane fibres are a by-product of sugar production and are often burned in the factory to produce steam for process heat and/or electricity for the production process. In the past they tended to be burnt deliberately inefficiently, in order to get rid of the bulky waste product. This however is changing, and many sugar mills are effectively burning the bulk of their bagasse for electricity generation for their own use as well as for export to the main grid. In fact, bagasse is currently (2002) Australia's largest source of renewable energy after hydro-electricity. It is estimated that there is potential for up to 50 GW of electricity generation worldwide, from this single feedstock. Indeed, if all the sugar mills in the world burnt their bagasse residue in advanced gas turbines, they would produce an amount of electricity equivalent to one third of the electrical output of all developing countries.

The potential for use of agricultural residues for energy production must always be weighed against their value in maintaining soil health and fertility in sustainable agricultural systems through its use as mulch.

In Australia, it has been conservatively estimated that about 2600 MW of electrical power could be generated with currently available biomass 'waste' resources including bagasse, wood waste and crop-based wastes (GreenECO company estimates, IEA seminar, Brisbane, April, 1998). The real figure is likely to be much higher than this.

2.1.3 Animal wastes

Wherever a large amount of animal manure is generated in a confined area (eg pig farms, dairy sheds and cattle feed lots), the potential exists for effective and efficient biofuel use. These manures can be used as a slurry, with a high liquid content (up to 95%), in a process of anaerobic digestion (see section 4.3, page 17) to produce methane, which in turn can be used to generate heat and/or electricity. The sludge left at the end of the digestion process can be used as a fertiliser. Digesters are particularly useful in disposing of a waste product that is too wet to burn. Benefits to farmers installing methane digesters include:

- Using the methane directly for farm equipment and machinery, or for electricity generation for farm use and export to the grid;
- Reducing odour by processing the manure into an odourless, easily applied fertilizer;
- Reducing physical labour usually spent in moving manure;
- Incorporating human wastes into the process as well.

Alternatively, relatively dry animal waste such as chicken litter - a mixture of manure and straw - can be burnt. There is a small power station in Suffolk, U.K. running on chicken litter as a fuel. The plant burns 130,000 tonnes of fuel each year and as well as providing its own power, exports about 13 MW to the local electricity grid.
Human sewage too is largely treated by anaerobic digestion. The methane produced used to be flared off into the atmosphere, but more recently its potential for heat and/or power production on site has been utilised. At the Werribee Sewage Treatment Plant near Melbourne, the initial treatment lagoon is covered with a sheet of High Density Polyethylene (HDPE), 3.3 hectares in area, to capture the methane. This cover also intensifies the warm, dark conditions needed for anaerobic digestion and so makes the whole process more efficient. The gas from this one lagoon can produce enough electricity to power 450 average Victorian households, although at the moment the electricity is used on site and saves the Treatment Plant $270,000 a year.

The Brisbane City Council's Luggage Point Sewage Treatment Plant has been producing its own power for many years. It has a peak capacity of 3.2 MW and exports about 50 MWh per month (the demand of about 90 average homes in Queensland). This could be increased substantially if the plant were operated at peak capacity continuously. The excess electrical energy could then supply about 900 homes. If used directly for heating purposes, it would provide about twice as much energy since the losses in conversion to electricity would be avoided.

2.1.4 Domestic and commercial waste

Many countries are now utilising domestic and commercial waste materials as an energy source. This helps to reduce a waste disposal problem as well.

The U.K. produces 25 million tons of Municipal Solid Waste (MSW) each year. Over 90% of this goes to landfill sites. Britain is a small island and is rapidly running out of space to dump its rubbish. Also there is concern over the long-term polluting effects of non-biodegradable waste. So, alternatives such as incineration and recycling are being explored, to cut down the volume of waste to be disposed of. Also, better design of products can reduce packaging waste and improve recyclability.

Figure 3 and Figure 4 show the amount and proportions of Municipal Solid Waste and its treatment in the USA in 1998.
There are 350 MSW incinerators (often referred to as Waste-to-Energy (WTE) facilities) worldwide. Switzerland and Japan treat 80% of their waste in this way. (See Figure 5) The large amount of recoverable heat can be used in district heating systems or to generate electricity. The ash or clinker residue can be used as hard-core in construction and road building.

The main problem with this is the pollution caused by burning unsorted waste, particularly from plastics. But recent controls on this kind of incineration, such as the 1990 European Community Directive, should minimise this risk. Of course, with a little time and effort, domestic waste can be sorted, at least separating out the non-combustibles such as plastics and metals, and fuel pellets created with the remainder. These are known as Refuse Derived Fuel or RDF.

Domestic waste can also be used to produce landfill gas. When left to rot in the ground, organic matter will eventually form a dense compost, such as you might put round your garden. The density is due to the lack of air, and if decomposition...
continues in the absence of air or oxygen, you have a process called anaerobic digestion. This process produces a gas which typically comprises 50-65% methane, a highly flammable gas similar to that used for domestic heating and cooking. Mostly it is left to escape to the atmosphere, where it acts as a very potent greenhouse gas, (about 20 times more potent than carbon dioxide). Capturing and combusting the methane (either through flaring or for electricity generation) has a number of benefits:

- Reduction in greenhouse gas emissions (When flared, the methane is converted to CO₂, a less potent greenhouse gas.)
- Inhibits the spread of odours (the landfill has to be ‘capped’ to capture the methane)
- Decreases the risk of explosions from gas buildup at the landfill site
- Destroys contaminants such as Volatile Organic Compounds (VOCs)
- Conserves non-renewable energy sources (when methane is used for electricity generation)

Commercial wastes too can be incinerated (e.g. tyres), gasified (e.g. black liquor, the waste from the paper industry) or digested (e.g. food processing wastes). They are subject to more stringent environmental controls than domestic wastes as they are likely to contain more potentially toxic materials.

2.1.5 Liquid biofuels

Several different types of liquid biofuels can be made from both energy crops (see section 2.2, page 9) and municipal and industrial solid and liquid waste. The two main ones (in Australia) are listed below.

Ethanol is really an alcohol that is formed during the fermentation of organic materials that contain sugars, starches or cellulose. It can be blended with petrol or diesel up to a rate of about 15% for unmodified engines. With some engine modifications, higher percentages (even up to 100%) can be used.

Biodiesel is a fuel produced by adding methanol or ethanol to most vegetable or animal fats and oils (either waste oils from commercial use or oils compressed from oily energy crops). The first diesel engine, by the way, was designed by Rudolph Diesel initially to run on peanut oil, and biodiesel can be used safely and effectively in unmodified diesel engines in any proportionate mix with petroleum based diesel. It is superior to petroleum diesel in several aspects:

- Lower greenhouse gas emissions (about 78% reduction)
- Dramatically reduced odour
- Lower tailpipe emissions (about 50%; including very little sulphur)
- Reduction in carcinogenic toxins (70 – 90%)

Australia has a small but growing biodiesel industry (e.g. there are plants in NSW and new plants planned for Picton in Western Australia and Dalby in Queensland.) The Australian Government has an aim to increase production of biofuels (predominantly ethanol and biodiesel) to 350 million litres/year by 2010. See section 4.4, page 21 for more information.
2.2 Energy crops

This refers to crops that are grown specifically as a fuel. Wood is still the major fuel in many countries and is an obvious candidate as an energy crop. A major problem with this, however, is the length of time it usually takes for timber to grow to a useful size, particularly in temperate climates. To overcome this, a technique called Short Rotation Coppice has been developed in Northern Europe and North America. This entails planting crops of fast growing trees such as willow. Every three years or so, the trees are harvested mechanically by cutting them back to above the roots and wood-chipping this timber for fuel. A similar method, developed in Sweden, involves planting conifers at high density, followed several years later by vigorous thinning, which is then chipped. This is called Modified Conventional Forestry and is another way of providing fuel from timber in the short term.

Crops rich in sugar or starch can be grown specially for fermentation to produce ethanol, a form of alcohol. Sugar cane is particularly appropriate for this use if it is available locally, but maize or sweet sorghum can also be used in temperate zones. (See Table 1).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Average Yield (odt/ha.y)</th>
<th>Best Yield (odt/ha.y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td>Maize (corn)</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Wheat</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Rice</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Cassava</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>Wood (temperate region)</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Wood (tropics)</td>
<td>20</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 1 Annual yields of various crops.

Many plants, such as coconut, palm, sunflower, rape and maize, yield vegetable oils with high energy contents, comparable to that of diesel. These oils are extracted by a simple pressing process. After a further chemical process involving distillation and mixing with ethanol or methanol, these oils provide a very effective diesel substitute, and are known collectively as "bio-diesel". Where rape seed oil is used, the product is known as Rape Methyl Ester or RME. At present, these oils attract better prices as food or cosmetics than as fuel so their use as a biofuel has often been limited to those countries where diesel is expensive or in limited supply.

It is worth remembering that most biofuels such as bagasse are not suitable for long-distance transportation, because they are bulky and they will start to decompose after a short time. Therefore any system designed to extract the energy from biomass, if it is to be economically viable, needs to be located close to a generous and freshly available source of supply (or processed on site into energy intensive briquettes or pellets: - see section 4.5, page 23).

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3. Energy Content of Biofuels

3.1 Useful energy

Like any other fuel, biofuels can be burnt in the presence of oxygen to produce heat energy. This heat energy can then be converted further into mechanical energy and electricity.

The basic raw material of biofuels, biomass, is composed of organic material and water. The more water content there is in a fuel, the less energy content it will have per tonne. Most plant material has a water content (by mass) of about 50% just after harvesting. Over time, this will dry out naturally, to around 10% - 15% of the mass. Artificial drying in kilns or ovens (which can be solar heated) will hasten this process, but that in itself uses energy and sometimes we just can't afford to wait.

If you have ever tried to burn wet wood, you will know that it is very frustrating and practically impossible. All that you produce is smoke and very little heat. Even if you succeed in getting it to light, the energy required to evaporate the excess water is 2.3 MJ per kg of water. That energy has to come from somewhere and it comes from the energy content of the original biomass. The useful energy produced will therefore be reduced by that amount.

So, for a fuel to burn efficiently, it needs to be reasonably dry. And if we are using figures for energy yield, we need to know the moisture content of the original material - or at least whether it is classified as "wet" or "dry".

The energy content of a fuel is known as its Calorific Value. The Gross Calorific Value (GCV) in MJ/kg or GJ/tonne (also called Heat of Combustion) is the total amount of energy contained in the material that is theoretically available for use. Most plant crops, being basically carbohydrates, will have a similar GCV. If the biomass is completely dried in an oven before use, then more energy is available. The GCV is then measured in gigajoules per oven dried tonne (GJ/odt).

Many biofuels may be dried before use to reduce the moisture content (mc) to 20 percent or less and hence improve energy content. Drying may be by:

- air racks using ambient air conditions (slow rate of drying, but cheap),
- using simple, air heating solar collectors to heat the ambient air before passing it over the biomass (2 to 4 weeks), or
- in gas dryers (a few days).

The Net Calorific Value (NCV) measures the actual amount of energy that can be recovered after evaporation, and depends largely on the moisture content of the feedstock. It could be presented as

\[
NCV = GCV - (\text{energy required to evaporate the moisture content})
\]

It is the more useful figure when calculating energy yields. Table 2 shows the NCV for biofuels in comparison with other fuels.

The following equations may be useful for performing calculations involving the moisture content of a biofuel:
Gross Fuel Mass  =  Mass of Fibre + Mass of Moisture ............................... (Eq 1.2a)

Mass of Moisture  =  Gross Fuel Mass x mc .............................................. (Eq 1.2b)

Mass of Fibre  =  Gross Fuel Mass x (1-mc) ................................................ (Eq 1.2c)

\[
\frac{\text{Mass of Moisture}}{\text{Mass of Fibre}} = \frac{mc}{(1-mc)} .......................................................... (Eq 1.2d)
\]

where mc = moisture content expressed as a fraction

<table>
<thead>
<tr>
<th>Fuel</th>
<th>NCV</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gases:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>10.2</td>
<td>MJ/m³</td>
</tr>
<tr>
<td>Methane</td>
<td>33.9</td>
<td>MJ/m³</td>
</tr>
<tr>
<td>Natural gas</td>
<td>34.8</td>
<td>MJ/m³</td>
</tr>
<tr>
<td>Sewage gas~3</td>
<td>20 to 26</td>
<td>MJ/m³</td>
</tr>
<tr>
<td>Wood gas</td>
<td>4.5 to 7</td>
<td>MJ/m³</td>
</tr>
<tr>
<td><strong>Liquids:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiesel</td>
<td>38.8 (34.7)</td>
<td>MJ/kg (MJ/L)</td>
</tr>
<tr>
<td>Diesel</td>
<td>42.9 (38.4)</td>
<td>MJ/kg (MJ/L)</td>
</tr>
<tr>
<td>Ethanol</td>
<td>27.2</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Methanol</td>
<td>19.9</td>
<td>MJ/kg</td>
</tr>
<tr>
<td><strong>Solids:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>10 to 30</td>
<td>GJ/odt</td>
</tr>
<tr>
<td>Refuse</td>
<td>7 to 10</td>
<td>GJ/odt</td>
</tr>
<tr>
<td>Straw (15% mc)</td>
<td>14.8</td>
<td>GJ/odt</td>
</tr>
<tr>
<td>Wood (20% mc)</td>
<td>13.7</td>
<td>GJ/odt</td>
</tr>
</tbody>
</table>

Table 2  Energy content of various fuels (NCV)
(Source: Home and others)

The relationship between the energy demand and the mass of fuel required is:

\[
\text{Mass of Fuel (kg)} = \frac{\text{Energy Demand (MJ)}}{\text{NCV of the Fuel (MJ/kg)}} .................................................. (Eq 1.2e)
\]

As energy demand is always quoted for a period of time (e.g. daily), the mass of fuel calculated will be for the same period (i.e. 1 day).

3 Landfill gas and sewage gas varies in composition depending on the feedstock. It typically contains 50 – 65% methane, 35-45% CO₂ and small amounts of nitrogen and oxygen. This accounts for its lower energy content.
3.2 Resource size and potential

How much stored energy is there in the world’s biomass, and can it really make a serious contribution to supplying our demand for energy?

The amount of solar energy converted into biomass energy on an average day accounts for a small fraction of the total amount of solar radiation striking the earth (a little over 0.02%). Refer to Figure 1 in Unit 8. Nevertheless, this rate of production of biomass is enough, in theory at least, to supply all our energy needs. Currently this represents about eight times our total primary energy consumption.

In fact, most of our energy needs nowadays are met by burning fossil fuels (coal, oil and gas). This is the case even in developing countries (58% fossil fuel based as opposed to 75% for the developed world). But biomass still contributes 14% towards the worldwide total. Some countries, such as Nepal and Ethiopia, derive virtually all of their energy from biomass. In Australia, about 5% of primary energy demand is met by biomass. (Note: as mentioned in Unit 1, Section 2.2, many uses of renewable energy are not accounted for so that the actual usage of biomass may be underestimated). However, of the 3000 EJ* supplied each year by the natural renewal of the earth’s biomass, only 2% is used for fuel and 0.5% is used for food. It is obvious that at present, biomass remains a massively under-utilised resource.

Of course, we would not want to convert all biomass into biofuels. We also need biomass for human food, animal fodder and fibres for textiles and construction products. As well, biomass is an essential ecological life support system for all animals including humans, helping to maintain biodiversity, moderate climates and absorb wastes.

It is extremely difficult to make predictions about the possible future potential for biomass on a worldwide basis, given the wide variations that exist in terms of type of fuel, climate, land availability, soil quality, technical advances and government support. However, a comprehensive study carried out for the United Nations Conference on Environment and Development in 1992, estimated that it was technically feasible for biomass to supply half of the world’s annual energy demand by the year 2050. In this scenario, specially planted energy crops could supply over 50% of the energy yield from biomass. (see Table 3)

<table>
<thead>
<tr>
<th>Biomass Resource</th>
<th>Potential annual supply (EJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy crops</td>
<td>128</td>
</tr>
<tr>
<td>Dung</td>
<td>25</td>
</tr>
<tr>
<td>Forestry residues</td>
<td>14</td>
</tr>
<tr>
<td>Cereal residues</td>
<td>13</td>
</tr>
<tr>
<td>Sugar cane residues</td>
<td>12</td>
</tr>
<tr>
<td>Existing forests</td>
<td>10</td>
</tr>
<tr>
<td>Urban refuse</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>205</td>
</tr>
</tbody>
</table>

* EJ = Exajoule = 1 million million million Joules (10^18 Joules)

Table 3  World potential for biomass energy supplies in the year 2050.  
(Source: Boyle)
In the next section you will take a closer look at different types of biofuels, how they are produced, and their relative advantages and disadvantages for energy production.

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4. Conversion and treatment processes

Now that we are familiar with the different types of biofuels and their energy content and potential, we can look at the four main ways of converting these fuels into energy of one kind or another and one treatment process.

4.1 Combustion

Biofuels such as wood, agricultural crop waste, or domestic waste, can be burnt to produce heat for:
- cooking
- space and water heating
- crop drying
- some industrial processes requiring heat or steam
- steam to drive a turbine to produce electricity.

At its most basic level, the process of combustion can take place in an open fire on the ground. However, very little of the heat from the fire (about 5%) will get into the cooking utensil. This is due to incomplete combustion, convection currents and radiant heat loss.

To improve on the low efficiency of such a process, stoves or closed containers with some control over the air intake, are increasingly used in domestic situations. Their efficiency is often 15-20% but can be as high as 60%. Boilers, with still more sophisticated controls over the rate of combustion, are used in industrial situations to produce process heat, steam and electricity. Here the combustion efficiency can be as much as 60-70%. Figure 6 shows the construction of a relatively efficient wood heater for domestic space heating. (Australia, by the way, is a world leader in the production of high efficiency, low pollution wood heaters.)

The efficiency of any combustion device will depend on the quality of the fuel used and the proper operation of the controls. For example, insufficient air will result in incomplete combustion; too much air will carry the heat away with the flue gases. Note that in Figure 6, the gases from the primary combustion chamber are burnt further in a secondary combustion chamber that induces turbulence and hence mixing of the gases to improve combustion.

Incomplete or partial combustion releases toxic gases into the atmosphere, leads to a build-up of sticky tars which will eventually block flues, - and produces much less heat. To ensure complete combustion, the fuel needs to be as dry as possible, and the oxygen supply should be sufficient.

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As well as drying, fuels may need to be reduced in size, e.g. woodchips, for ease of handling and fast, efficient combustion. Or they may need to be compressed in some way - such as sawdust, waste paper or domestic refuse made into pellets or briquettes - to produce fuel with a higher energy content that does not burn too quickly. This also enables the fuel to be easily transported and stored.

### 4.1.1 Land requirements

The yield of various crops measured in tonnes per hectare per year (t/ha.y) ranges widely depending on climate, soil type and farming practices. For natural Eucalyptus forest in Australia, the maximum yield is about 22 t/ha of green wood. For plantation Eucalyptus, it can be up to 55 t/ha of green wood using coppice harvesting. Note that these figures differ from Table 1 which gives oven dried weights.

The relationship between the required land area and the fuel demand is simply:

\[
\text{Land Area} = \frac{\text{Fuel Demand (t/y)}}{\text{Yield (t/ha.y)}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 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**Example 1**

The daily end use energy demand in a home with four people includes 20 MJ/day for cooking and 55 MJ/day for water heating. Calculate:

a) the mass of “dry” wood required daily, and

b) the mass of green wood required

c) the land area required for these energy services. Assume the NCV of wood is 13.7 MJ/kg at 20% moisture content (from Table 1).

(N.B. The figures in this example are based on typical gas consumption for cooking and water heating, and assume the same efficiency for wood (60%).)

**Solution:**

a) The mass of wood required can be calculated from Eq. 1.2e as follows:

\[
\text{Mass of Wood (kg)} = \frac{\text{Energy Demand (MJ)}}{\text{NCV of the Wood (MJ/kg)}}
\]

\[
= \frac{20 + 55}{13.7}
\]

\[
= 5.47 \text{ kg}
\]

Since the daily energy demand figure was used, the answer gives the mass of wood required per day.

b) Now we need to determine the mass of green wood required.

In the answer to part a), the specified 20% mc means that:

\[
\text{Mass of Moisture} = \text{Gross Wood Mass } \times \text{mc}
\]

\[
= 5.47 \times 0.2
\]

\[
= 1.09 \text{ kg}
\]

\[
\text{Mass of Wood Fibre} = \text{Gross Wood Mass } \times (1-\text{mc})
\]

\[
= 5.47 \times 0.8
\]

\[
= 4.38 \text{ kg}
\]

The typical mc of freshly harvested timber is 50%. So with the same amount of wood fibre (4.38 kg), the total mass of green wood would be (from Eq. 1.2a):

\[
\text{Gross Wood Mass} = \text{Mass of Wood Fibre} + \text{Mass of Moisture}
\]

The trick now is to work out the mass of moisture in the green wood. From Eq. 1.2d

\[
\text{Mass of Moisture} = \text{Mass of Wood Fibre } \times \frac{\text{mc}}{(1-\text{mc})}
\]

\[
= 4.38 \times \frac{0.5}{(1-0.5)}
\]

\[
= 4.38 \text{ kg}
\]
4.2 Gasification

This term refers to the conversion of a solid fuel such as biomass into a gaseous fuel, via a process of staggered and partial combustion. In this instance, however, the partial combustion is deliberate, and the emissions relatively "clean". The process is based on pyrolysis, - that is, chemical decomposition by the action of heat. The easiest way to produce the heat is often to burn the fuel itself, but this is done in the near absence of oxygen so that most of the fuel just decomposes rather than burns. For example when making charcoal, the water and volatile components of the fuel are driven off leaving the char, which has a much higher energy content per unit mass than the original fuel and burns at much higher temperatures.

Gasification is simply pyrolysis adapted to maximise the amount of combustible gases released (and then captured) rather than the amounts of char or volatile compounds. Partly this is done by controlled use of forced air, steam or oxygen at different stages of the process.

The end product is known as "producer gas" and consists mainly of carbon monoxide, hydrogen and nitrogen. Small amounts of carbon dioxide, methane and other hydrocarbons may also be present, depending on the type of processing and whether air or oxygen is used.

There are distinct advantages to producer gas as a fuel:
- It is much cleaner than the original biomass, as pollutants can be removed during the process.
- It can be produced with efficiencies as high as 80-90%.
- As a gas, it is easier to handle and transport.
- It is a versatile fuel. It can be burned directly or used to power internal combustion engines or even gas turbines.

The simplest kinds of gasifiers produce gas with relatively little calorific value. This may still be worth doing for local use as the process is relatively cheap and clean. The more sophisticated processes, using oxygen instead of air, result in a product known as "synthesis gas" consisting almost entirely of carbon monoxide and hydrogen. This in turn can be used to make the very valuable fuels, methane and methanol. As with many other examples of developing biofuels technology, the waste disposal function is at least as important as the energy production.

Figure 7 (a) shows the stages in a pyrolysis system.

![Figure 7 (a) A small scale pyrolysis system](image)

4.3 Digestion

Like pyrolysis, digestion occurs in the relative absence of air, but this time the process relies on biological organisms rather than the external application of heat. It is called digestion because it is similar to the process which happens in the digestive tract of ruminant animals!

If you have ever kept a compost heap, you will be aware of how organic matter will rot down over time to produce an excellent fertiliser. The bacteria which aid this process
of decomposition will be a mixture of those that work best in the presence of air (aerobic) and those that will only work in the absence of air (anaerobic).

Digesters are designed to maximise the proportion of anaerobic decomposition taking place inside them. This is because anaerobic digestion will produce methane, usually in combination with carbon dioxide. This is known as "biogas".

Like the compost heap, conditions inside a digester need to be warm, wet and dark. The bacterial action itself will generate heat and help to keep the temperature up; the closed container keeps out daylight; and water is provided via the feedstock itself. The carbon to nitrogen ratio of the feedstock must be in the range of 20:1 to 30:1. Most digesters operate at temperatures around 35 degrees Celsius but higher and lower temperatures can be used as different bacteria will form to breakdown the feedstock. Higher temperatures promote more rapid conversion.

Only small amounts of the potential heat of combustion of the origin feedstock (e.g. 10%) need be lost in the digestion process. This equates to 90% energy conversion efficiency. However, this would require long retention times and so a typical, well managed digester will operate at a conversion efficiency of 60%. Figure 8 shows some various types of digesters.

Typical feedstocks for digesters are sewage sludge and farmyard slurry, and one of the major benefits of this process is that it will treat particularly noxious and unpleasant wastes. The residue is a useful fertiliser and while not completely free of all pathogens, is much more palatable than the original. Digestion is most appropriate in situations where there is a substantial flow of waste material already present and in need of treatment and disposal. Typical manure production rates and biogas yields are shown in Table 4 below.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Equiv. dry matter production (kg/animal.day)</th>
<th>Yield per unit dry matter (m³/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig manure</td>
<td>0.68</td>
<td>0.35 - 0.5</td>
</tr>
<tr>
<td>Cow manure (India)</td>
<td>4.5</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>Chicken manure</td>
<td>0.05</td>
<td>0.35 - 0.8</td>
</tr>
<tr>
<td>Conventional Sewage</td>
<td>0.14</td>
<td>0.35 - 0.55</td>
</tr>
</tbody>
</table>

Table 4 Manure production and Biogas yields. (Source: Stoner)

We have already discussed landfill gas as a producer of methane (again mixed with carbon dioxide). Here however the conditions are less desirable and less controllable, and so the process takes much longer - years rather than weeks. Typical yields are about half those of yields from a digester.
Figure 8  Various types of methane digesters
(a) Oil drum batch digester  (b) Typical Indian gobar gas digester
(c) Chinese pit design (from Van Buren, 1970)  (d) high rate farm digester for cooler climates
where heating is necessary (from Maynell, 1976)
(Source: Twidell and Weir, pp. 302 - 303)
Example 2

Calculate the number of cows and digester size required to provide energy for cooking and water heating in a home with four people. Assume the daily end use energy demand is 20 MJ/day for cooking and 55 MJ/day for water heating.

The following additional information is required and typical values are given:
- Biogas Yield per unit dry mass input = 0.24 m³/kg
  1. This depends on the type of fuel and the conversion efficiency of the digester
  2. Typical range is 0.2 to 0.4 m³/kg at STP (Standard Temperature and Pressure)
- Dry matter input per cow = 2 kg per day
  1. This is dried manure from the cow available for input to the digester
  2. Depends on source of raw materials (e.g., cows, humans, chickens)
- Density of dry matter in the digester fluid, ρd = 50 kg/m³
- Retention time of the digester fluid, t_r = 20 days (range 8 to 20 days)
- GCV of Methane (per unit volume at STP), GCV_methane = 28 MJ/m³
- Fraction of Methane in biogas, f_m = 0.7
- Mass of dry input material, m_d - to be calculated (kg)

Solution:
The following calculations are based on daily figures.

\[
\text{Volume of Gas required (m}^3\) = \frac{\text{Energy Demand (MJ)}}{\text{GCV_methane (MJ/m}^3\) \times f_m} \quad (\text{Eq. 4.3a})
\]
\[
= \frac{20 + 55}{28 \times 0.7}
\]
\[
= 3.83 \text{ m}^3 \quad \text{(per day)}
\]

\[
\text{Mass of dry input required (kg)} = \frac{\text{Volume of Gas (m}^3\)}{\text{Biogas yield (m}^3/\text{kg})} \quad \text{(4.3b)}
\]
\[
= \frac{3.83}{0.24}
\]
\[
= 16 \text{ kg} \quad \text{(per day)}
\]

\[
\text{Number of Cows} = \frac{\text{Mass of dry input}}{\text{Dry Mass input per cow}}
\]
\[
= \frac{16}{2}
\]
\[
= 8 \text{ cows}
\]

(continued next page)
4.4 Fermentation

It might seem that this has nothing to do with energy, but in fact alcohol is a kind of fuel and some types of alcohol, notably ethanol, can be used to power vehicles. It requires further distillation after fermentation and can then be used directly in suitably adapted engines, or as a gasoline extender. "Gasohol" contains 20% ethanol; 80% gasoline (petrol). The feedstock for the fermentation process is often sugar cane, though other crops can be used. Brazil, with its huge resources of sugar cane, has led the way in ethanol production and has all its vehicles running on either pure ethanol or gasohol.

And it seems Australia could follow suit! It has been estimated that in Queensland, if all the sugar cane was converted to alcohol, then this could provide 50 percent of the liquid fuel transport requirements assuming 1990 energy use. Of course, if you wanted sugar as well, you would have to grow more cane. (See Table 5).

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Yield L/t (a)</th>
<th>Yield L/ha.y (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane (harvested stalks)</td>
<td>70</td>
<td>400 - 12000</td>
</tr>
<tr>
<td>Corn (maize, grain)</td>
<td>360</td>
<td>250 - 2000</td>
</tr>
<tr>
<td>Cassava (roots)</td>
<td>180</td>
<td>500 - 4000</td>
</tr>
<tr>
<td>Sweet potatoes (roots)</td>
<td>120</td>
<td>1000 - 4500</td>
</tr>
<tr>
<td>Wood</td>
<td>160</td>
<td>160 - 4000</td>
</tr>
</tbody>
</table>

(a) This figure depends mainly on the proportion of the raw material which can be fermented.
(b) The ranges of values reflect worldwide differences in yield.
(c) The upper figure represents the theoretical maximum.

Table 5 Ethanol yields. (Source: Boyle)
Figure 9 shows the steps in the production of ethanol from sugars and starches.

![Diagram of the production of ethanol from sugars and starches]

**Figure 9  Production of ethanol** *(Source: Twidell and Weir, p.299)*

**Example 3**

Calculate the land area required to grow sugar cane for alcohol production to fuel a car on straight alcohol. The car travels 20,000 kilometres per year. Assume the following typical values:

- Fuel consumption of the car using petrol = 10 km/L
- Alcohol yield = 3500 L/ha y
- Energy content of alcohol = 25 MJ/L
- Energy content of petrol = 32 MJ/L

**Solution:**

The following calculations are based on annual figures.

\[
\text{Fuel volume}_{\text{petrol}} (\text{L}) = \frac{\text{Distance traveled (km)}}{\text{Fuel consumption}_{\text{petrol}} (\text{km/L})} \quad \text{(Eq 4.4a)}
\]

\[
= \frac{20 000}{10} = 2000 \text{ L} \quad \text{(per year)}
\]

\[
\text{Energy Demand (MJ)} = \text{Fuel Volume}_{\text{petrol}} (\text{L}) \times \text{Energy Content}_{\text{petrol}} (\text{MJ/L}) \quad \text{(Eq 4.4b)}
\]

\[
= 2000 \times 32 = 64 000 \text{ MJ} \quad \text{(per year)}
\]

*(continued next page)*
**Example 3 (cont’d)**

\[
\text{Fuel Volume}_{\text{pellet}} (L) = \frac{\text{Energy demand (MJ)}}{\text{Energy Content}_{\text{pellet}} (MJ/L)} \quad \text{(Eq 4.4c)}
\]

\[
= \frac{64,000}{25} = 2,560 \text{ L} \quad \text{(per year)}
\]

However, the thermodynamic efficiency of an internal combustion engine improves significantly when using straight alcohol, by up to approximately 30%. To be conservative, assume a 15% improvement in city / country driving.

Then,

\[
\text{Fuel Volume}_{\text{pellet}} = 2,560 \times (1 - 0.15) \]

\[
= 2,176 \text{ L} \quad \text{(per year)}
\]

Finally, the land area can be calculated from a modified form of Eq 3.1.1a

\[
\text{Land Area (ha)} = \frac{\text{Fuel Demand}_{\text{pellet}} (L/yr)}{\text{Yield (L/ha.y)}}
\]

\[
= \frac{2,176}{3,500} = 0.62 \text{ ha}
\]

### 4.5 Pelletising

To solve some of the problems of transportation and storage of solid biofuels, biomass can be compacted at high pressures and temperatures to produce briquettes and pellets. These are significantly smaller in volume and have a higher energy density than the original organic material.

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**Return to Learning Guide**

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### 5. Environmental, economic, social and political impacts

Very rarely is a technology entirely environmentally benign. The large scale generation of energy from biofuels carries with it a set of potential environmental dangers as well as potential environmental advantages. Even though the use of biofuels may offset far worse damage from the burning of fossil fuels, responsible industry and government should still be aware of the environmental impact of any technology, and act to minimise it.
In the case of biofuels, their use may impact in a number of ways.

**Atmospheric pollution** from combustion products is a serious concern and has lead to the banning of the use of wood stoves at certain times of the year in some regions. Emissions can be controlled in a number of ways e.g.:
- ensuring complete combustion
- fitting filters or scrubbers to the flues of combustion vessels
- incorporating some kind of heat or energy recovery into the system, which displaces some fuel use
- maximising the efficiency of the system.

**Land use issues** needing consideration include:
- Large scale, intensive, mono-culture agriculture, such as those that may be necessary for energy crops to become economically viable, can threaten natural eco-systems through land clearing and chemical pollution.
- Repeated harvesting could lead to soil erosion and fertility decline (using coppiced crops avoids this problem).
- The use of chemical fertilisers, herbicides and pesticides, if required for the energy crops, create a further burden on soil vitality, and their production is dependent on fossil fuels.
- Use of arable land for energy crops as opposed to food production. For example, in Brazil, 8.5 million square kilometres is harvested to supply 30 percent of its motor fuel requirements. To meet the U.N.'s predicted possible biomass contribution to world energy supply, (see Section 3.2, page 12), enormous amounts of productive land and water would be needed - resources which themselves may be in short supply and needed for food production.

Biomass should not be seen, however, as necessarily detrimental to land use issues. Clever 'partnerships' between energy companies and farmers can often provide innovative solutions for a number of environmental problems. For example, in the south of Western Australia where the wheat belt is suffering from severe salinity problems, the native mallee is being planted in alleys (hedgerows) to
- rejuvenate the land by lowering the water table
- provide a significant carbon sink (it has a significant root system)
- provide an ideal coppicing crop for the energy company
- provide an additional source of income through the distillation of eucalyptus oil from the leaves.

Our whole manner of resource use and consumerism needs to be taken into account. Will the establishment of facilities that require waste products as a fuel source encourage society to continue to be wasteful instead of developing technologies and practices to reduce the amount of waste produced?

The energy consumed to produce the biofuel product (**embodied energy**) also needs to be considered. We could end up with a situation whereby biofuels are developed using so much energy for ploughing, irrigation, weed and pest control, harvesting and processing, and for transporting raw materials or products, that there is little, if any, net reduction in fossil fuel use. In order to achieve a net energy gain, sometimes it is essential that the biofuel production process use waste biomass as its energy input or
alternatively solar collectors to generate heat. For example, solar energy might be used to control the temperature in a methane digester or for distillation in alcohol production.

Improving energy efficiency is also a key component to the equation. For example, doubling the average fuel efficiency of the present vehicle fleet is easily achievable with existing technology. Super light weight, hybrid vehicles have the potential to improve fuel economy of present vehicles by a factor of 4 to 10 times (e.g. from 10 L / 100 km to 5 L / 100 km).

The technological solutions, however, are only part of the equation. They need to be backed up by a political determination to give them high priority. This in turn can result in economic incentives for industry and consumers to choose a more environmentally benign product or process. “Green” electricity schemes are an example of this where markets have responded to consumer pressure for cleaner electricity production.

Often the whole economics of a particular industry or sector has been historically weighted in favour of the use of fossil fuels through incentive schemes such as the diesel rebate scheme for rural users in Australia. For any alternative energy source to compete on a “fair playing field”, the economic imbalance will have to be redressed. Some governments have responded with incentives and subsidies for the use of renewable energy and energy efficient technologies. For example, in the U.K., there are tax reductions on unleaded petrol and a government subsidy on energy efficient central heating boilers. In Australia, there are tax concessions for unleaded fuel and rebate schemes for solar water heaters and photovoltaic panels.

Another example of government intervention to level the playing field is the Non Fossil Fuel Obligation in the U.K. In this case, government has sought to guarantee a favourable price for all energy produced by fuels other than fossil fuels, for an initial period. This helps to offset the capital costs of setting up renewable energy systems. Since the scheme began in 1990, contracts for renewable energy systems have been dominated by biofuels projects.

There are also social impacts such as the effects on local employment opportunities (particularly in rural areas) if a local biomass resource is being harvested and utilised. Health improvements may occur through reduced air pollution from vehicles, especially in urban areas.

So we can see that many factors need to be considered carefully in the application of biofuel technologies and systems. Overall, energy derived from biofuels is only as sustainable as the methods which are used to produce it. Any large scale development in the provision of biofuels will need to be accompanied by thorough environmental, social, political and economic impact assessments. Indeed, "the long-term, sustainable use of biomass fuels might require a virtual re-invention of agriculture and society".
6. Summary

The amount of useful energy from a biofuel is largely dependent on the moisture content of the fuel. To maximise this, it is necessary to dry the fuel to reduce the moisture content to less than 20% of the fuel's "wet" mass. The energy content can be measured by either the Gross Calorific Value (after drying) or the Net Calorific Value (wet mass).

Currently about 14% of total world primary energy consumption is supplied from biomass. The potential resource is about 8 times the current world primary energy consumption. However, its use as a fuel must be balanced against other needs such as human food and fodder production, fibres and construction materials, as well as maintaining an essential ecological life support system for all animals including humans.

Biofuels are available from a wide range of sources including wood, agricultural production, animal and domestic and commercial wastes. Already there are many examples of biomass wastes being put to use for heat and electricity generation. For example, methane gas from landfill sites is being tapped to generate electricity. As well, special energy crops can be grown and harvested. Examples include coppicing of fast growing trees such as willows or eucalypts, or sugar cane grown for alcohol production.

There are four main methods of conversion of biofuels into energy. They are:

- Direct combustion to heat such as in a wood stove or boiler. This can be a high efficiency process if combustion is carefully controlled.

- Gasification by pyrolysis. This process converts biomass into producer gas, a clean burning, high energy content fuel consisting mostly of carbon monoxide, hydrogen and nitrogen.

- Anaerobic digestion of liquid wastes such as human and animal manures. This produces biogas, which consists of about 70% methane and 30% carbon dioxide.

- Fermentation of sugars or starches to produce ethanol. This can be used as a vehicle fuel either at 100% alcohol in modified engines, or mixed with petrol (20% alcohol to 80% petrol) in unmodified engines. Alternatively, it can be burnt directly for heat or converted to electricity.

Solid biofuels can also be compacted into smaller, more energy dense pellets and briquettes, aiding in transportation and storage of biofuels.

There are a range of potential negative impacts from the use of biofuels. These include localised atmospheric pollution from combustion products, land deterioration due to intensive, large scale agriculture for biofuel production and land use conflicts. There are also potential social, economic and environmental benefits such as improved health through reduced air pollution in cities when using alcohol fuels in vehicles, job creation opportunities particularly in regional areas with good biomass resources and the reduction in global greenhouse gas emissions.
There are also a range of barriers to the extended use of biofuels. These include market distortions and lack of political will. Some governments are leading the way with addressing these issues such as through subsidies to "level the economic playing field". As with any technology, we need to weigh up the pro's and con's of its use as best we can. Finally, although biofuels are renewable energy sources, they are often produced and used in ways that are neither renewable nor sustainable.
6.1 Summary of equations used

Gross Fuel Mass = Mass of Fibre + Mass of Moisture ........................................ (Eq 1.2a) .... 11

Mass of Moisture = Gross Fuel Mass × mc .................................................. (Eq 1.2b) .... 11

Mass of Fibre = Gross Fuel Mass × (1-mc) ........................................... (Eq 1.2 c) .... 11

\[
\frac{\text{Mass of Moisture}}{\text{Mass of Fibre}} = \frac{mc}{(1-mc)} \hspace{1cm} \text{(Eq 1.2d)} .... 11
\]

Mass of Fuel (kg) = \( \frac{\text{Energy Demand (Mj)}}{\text{NCV of the Fuel (MJ/kg)}} \) ........................................ (Eq 1.2e) .... 11

\[
\text{Land Area} = \frac{\text{Fuel Demand (t/ha.y)}}{\text{Yield (t/ha.y)}} \hspace{1cm} \text{(Eq 3.1.1a)} .... 14
\]

Volume of Gas required (m³) = \( \frac{\text{Energy Demand (Mj)}}{\text{GCVmethane (MJ/m³) × f_m}} \) ................. (Eq 4.3a) .... 20

Mass of dry input required (kg) = \( \frac{\text{Volume of Gas (m³)}}{\text{Biogas yield (m³/kg)}} \) ........................................... (4.3b) .... 20

Fuel volume_{petrol} (L) = \( \frac{\text{Distance traveled (km)}}{\text{Fuel consumption_{petrol} (km/L)}} \) ................. (Eq 4.4a) .... 22

Energy Demand (Mj) = Fuel Volume_{petrol} (L) × Energy Content_{petrol} (MJ/L) ........................................ (Eq 4.4b) .... 22

Fuel Volume_{alcohol} (L) = \( \frac{\text{Energy demand (Mj)}}{\text{Energy Content_{alcohol} (MJ/L)}} \) ........................................... (Eq 4.4c) .... 23
### 7. Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description/Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biodiesel</strong></td>
<td>a fuel produced by adding methanol or ethanol to most vegetable or animal fats and oils. It is a petrochemical diesel equivalent.</td>
</tr>
<tr>
<td><strong>Biofuel</strong></td>
<td>any solid, liquid or gaseous fuels produced from organic materials, either directly from plants, or indirectly from industrial, commercial, domestic or agricultural wastes</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td>The material of plants and animals. It is organic carbon based material that reacts with oxygen in combustion and natural metabolic processes to release heat</td>
</tr>
<tr>
<td><strong>Combustion</strong></td>
<td>This is the process of burning biofuels. As heat is applied, volatile compounds are force out. If enough heat and oxygen is available, carbon and hydrocarbons oxidise to form carbon dioxide and water. Heat is released in the processes, assisting the breakdown of more biomass tissue.</td>
</tr>
<tr>
<td><strong>Ethanol</strong></td>
<td>An alcohol that is formed during the fermentation of organic materials that contain sugars, starches or cellulose.</td>
</tr>
<tr>
<td><strong>Gross Calorific Value (GCV)</strong></td>
<td>the total amount of energy contained in the material that is theoretically available for use in an oven dried sample (also known as Heat of Combustion). Units: Giga Joules per oven dried tonne (GJ/odt)</td>
</tr>
<tr>
<td><strong>Heat of Combustion</strong></td>
<td>See Gross Calorific Value</td>
</tr>
<tr>
<td><strong>Landfill gas</strong></td>
<td>Gas generated from decomposing organic materials in buried in landfill sites. It mostly consists of methane and carbon dioxide</td>
</tr>
<tr>
<td><strong>Net Calorific Value (NCV)</strong></td>
<td>the actual amount of energy which can be recovered after evaporation, and depends largely on the moisture content of the feedstock. Units: GJ per green tonne (GJ/gt)</td>
</tr>
<tr>
<td><strong>Producer Gas</strong></td>
<td>The end product of pyrolysis and consists mainly of carbon monoxide, hydrogen and nitrogen. Small amounts of carbon dioxide, methane and other hydrocarbons may also be present, depending on the type of processing and whether air or oxygen is used.</td>
</tr>
<tr>
<td><strong>Pyrolysis</strong></td>
<td>Combustion in the near absence of oxygen.</td>
</tr>
<tr>
<td><strong>retention time</strong></td>
<td>The length of time the feedstock of a methane digester will remain in the digester before being removed.</td>
</tr>
<tr>
<td><strong>Volatile components</strong></td>
<td>Compounds within the biofuel which evaporate at relatively low temperatures.</td>
</tr>
</tbody>
</table>
8. Bibliography


Natural Resources Canada (2001) *Discover the Uses of Landfill Gas*. Quebec, Canada.


