Biomass – Cells

1.1 INTRODUCTION

All Earth's bio-energy originates from the Sun. Only a small proportion of the Sun's energy, incident on the Earth's surface, is fixed by organic matter and stored (see **Figure 1** below). This energy is recycled through a series of natural and chemical conversions. At some stage in the cycle we can intervene and use the bio-energy when it is optimally suited to act as a source of chemical energy and hence as fuel.

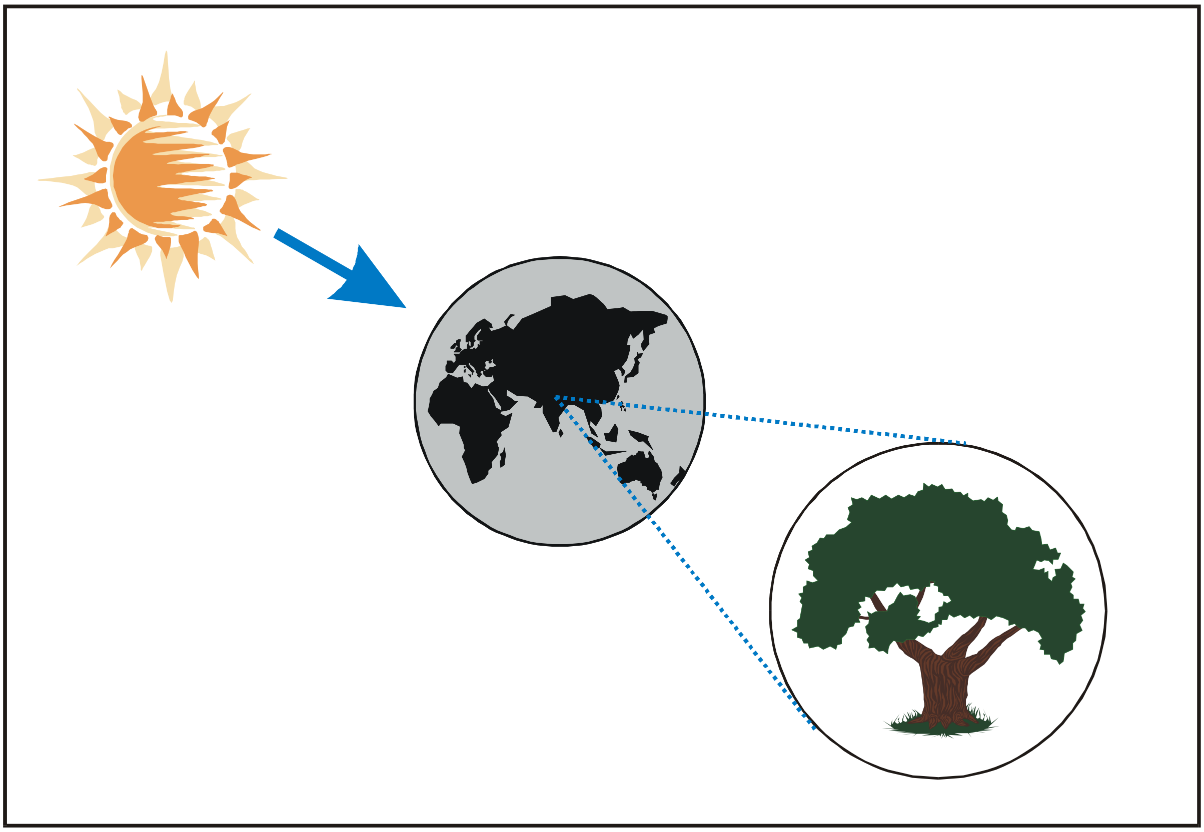


Figure 1. A schematic of the Earth's Bioenergy.

In order to gain a deeper insight into the energy that is stored in biofuels, it is essential to understand the basics of cell biology, cell chemistry and cell metabolism.

All the possible biomass energy conversion processes and products, which have been developed and used to date under the umbrella of "renewable energy" are shown overleaf in **Figure 2**. most of these processes will be introduced during the biomass module.

The overall biomass-to-fuel process generally consists of two stages:

1. Firstly, production of the biomass, i.e. photosynthesis, the conversion of solar energy to chemical energy, which is stored primarily as cellulose in plants.

2. Secondly, a conversion stage to change the biomass into a gross fuel product.

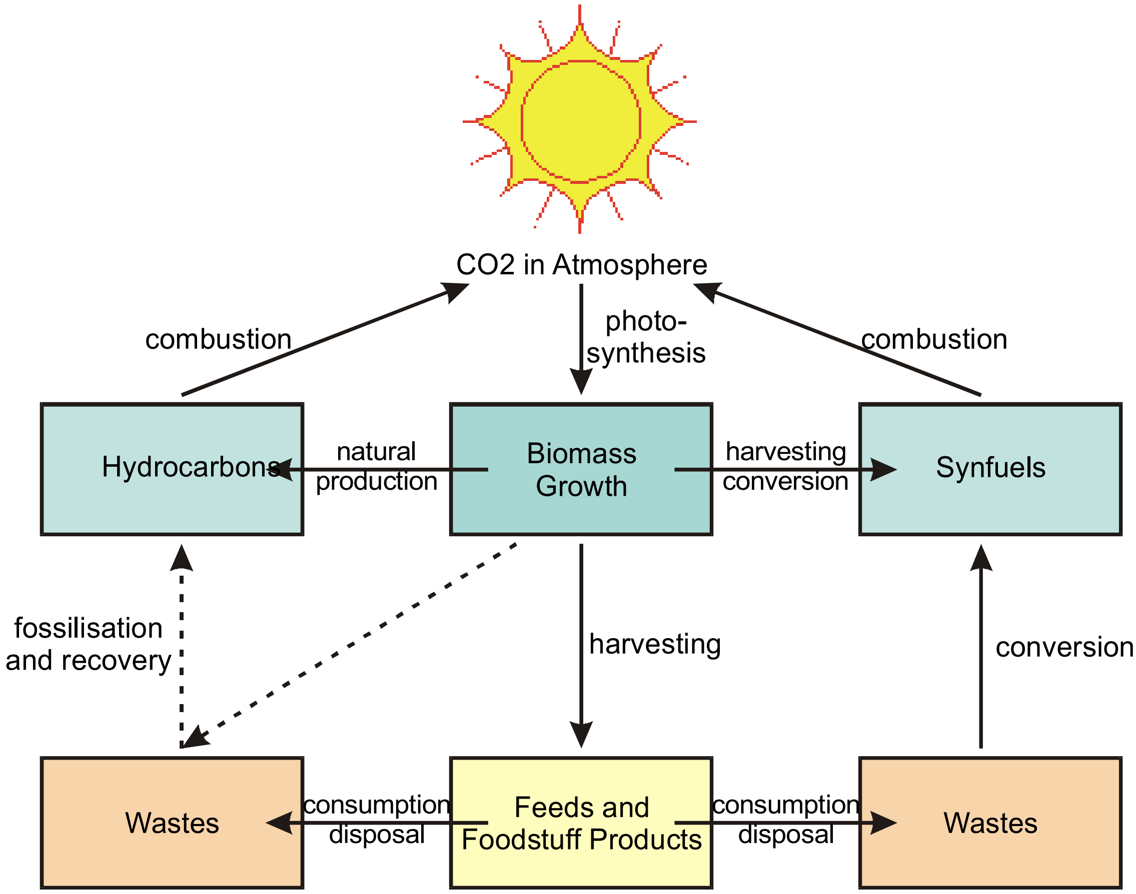


Figure 2. The main features of Biomass Energy Technology.

An exception to this is when biomass is directly combusted to produce heat, in which case no intermediate conversion process is required. The conversion process can be divided into dry and aqueous or "wet" processes. Generally, the dry chemical processes, such as combustion and gasification, are more efficient than the aqueous processes. However, one of the main criteria dictating the choice of biomass conversion process is the water content of the biomass. If this is over 70%, aqueous processing is usually the only conversion process that can be used without entailing exorbitant energy expenditure on drying.

With this is mind, this unit introduces students to the building blocks of biological activity that leads to the eventual production of biomass.

1.2 THE CELL AS THE BASIS OF LIFE

In 1838, it was realised, for the first time, that all plants and animals are composed of structures known as cells. Different types of cells vary greatly in size. A single human nerve cell can be as long as 3 to 4 feet. An ostrich egg cell is usually the size of a small grapefruit, but most cells of plants and animals are in the range of 10 to 100 micrometres in diameter. To get your bearings in this microscopic world, consider that 1 μm is one millionth of a metre. To put it another way, 10,000 μm corresponds to 1 cm.

There are two groups of organisms: **macro-organisms** and **micro-organisms**.

The organisms that are called macro-organisms (humans, animals, plants, insects, etc) are composed of numerous cells, which have specialised features. Groups of specialised cells are called tissues, for example, muscle tissue. Several different specialised tissues can then be further organised into structures known as organs, for example, animals hearts and livers; leaves and roots of plants.

> *The cells of macro-organisms cannot exist alone in nature but can only exist as part of multi-cellular organisms.*

The organisms we refer to as micro-organisms (bacteria, yeasts, fungi, algae and protozoa) consist as single cells or clusters of cells. The smallest of all the micro-organisms are the bacteria, which consist only as a single cell. However, the basic blueprint governing growth and development of bacteria is fundamentally the same as that of all other types of cells. Bacteria contain the same classes of essential biomolecules found in plant and animal cells, and all cells produce their constituents by the same kinds of biosynthetic pathways.

1.2.1 What is a Cell?

We now know that cells are the fundamental units of life, however, in order to understand the processes that occur at cellular level (e.g. photosynthesis, alcohol and methane formation), it is necessary to be familiar with both the chemical composition and physical structure of a cell.

A cell may be visualised as a complex collection of chemicals arranged in a systematic way so that they are capable of performing the various functions required to sustain life. In a more simplistic way, we may imagine a cell as a house in which simple chemical building blocks are connected in various ways to create more complex structures.

1.2.2 The Chemical Composition of a Cell

All matter is composed of chemical elements. Those of particular importance in biology are conveniently grouped into three categories based on the relative amounts present in typical cells of microbes and other organisms.

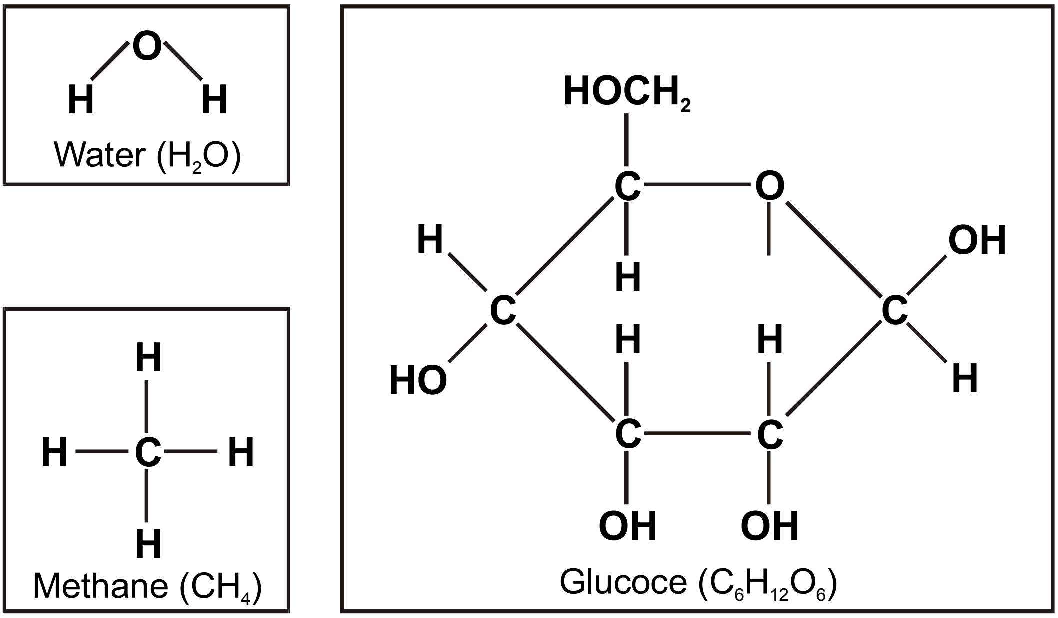
Category 1. These are the elements that account for the major part of living matter, namely, carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur (CHNOPS).

Category 2. These are the four elements that occur in smaller, but significant quantities, namely, sodium, potassium, calcium and magnesium.

Category 3. These are the so-called trace elements, which are essential for all cell chemistry but are usually present in very small quantities.

1.2.3 Chemical Bonding to form Molecules/Compounds

Atoms are the smallest particles of an element that can enter into chemical combinations. The atoms in a cell combine as a result of chemical bonding to form larger molecules or compounds. The most simple way of visualizing chemical bonding is to imagine that each kind of atom has a certain number of "hooks", which can link with the "hook" of another atom. For example, if an oxygen atom has two hooks and a hydrogen atom one hook, it is possible to visualize the combination of oxygen and hydrogen atoms to form a molecule of water as shown below in **Figure 3**.



Water (H_2O)

Methane (CH_4)

Glucoce ($C_6H_{12}O_6$)

Figure 3. Chemical Bonding.

In diagrams, chemical bonds are usually depicted as a line (or a double line for a "double bond") that connects the symbols of two atoms. For example, the structure of water is shown as H-O-H. Glucose contains 24 atoms and is represented as shown in **Figure 3**.

From the diagrams in **Figure 3**, we can see that the Category 1 elements can form a limited and characteristic number of chemical bonds: one for H, two for O and four for C. It can also be seen that the element, carbon, is of central importance in biology, and it is necessary to distinguish between two classes of carbon compounds. Compounds, such as carbon monoxide, CO, and carbon dioxide, CO_2, are designated as **inorganic**. In contrast, **organic** compounds always contain chemical bonds between carbon and hydrogen atoms, as well as other kinds of bonds. Since one carbon atom can form only four bonds (and hydrogen can form only one) the simplest organic compound is methane, CH_4 (see **Figure 3**).

Humans, animals and most microbes cannot use inorganic carbon as a source of nutritional carbon. As we will see later in this unit, one of the most important aspects of plant photosynthesis is that it allows the conversion of inorganic carbon (which is of no nutritional value to humans etc.) to organic carbon compounds, which can be used as a source of nutrition.

This unit is primarily concerned with biochemistry, that is, the **organic chemistry of cells**.

When atoms combine by chemical bonding, small molecules known collectively as monomers are formed. The four types of monomers, which are important in cell biochemistry, are:

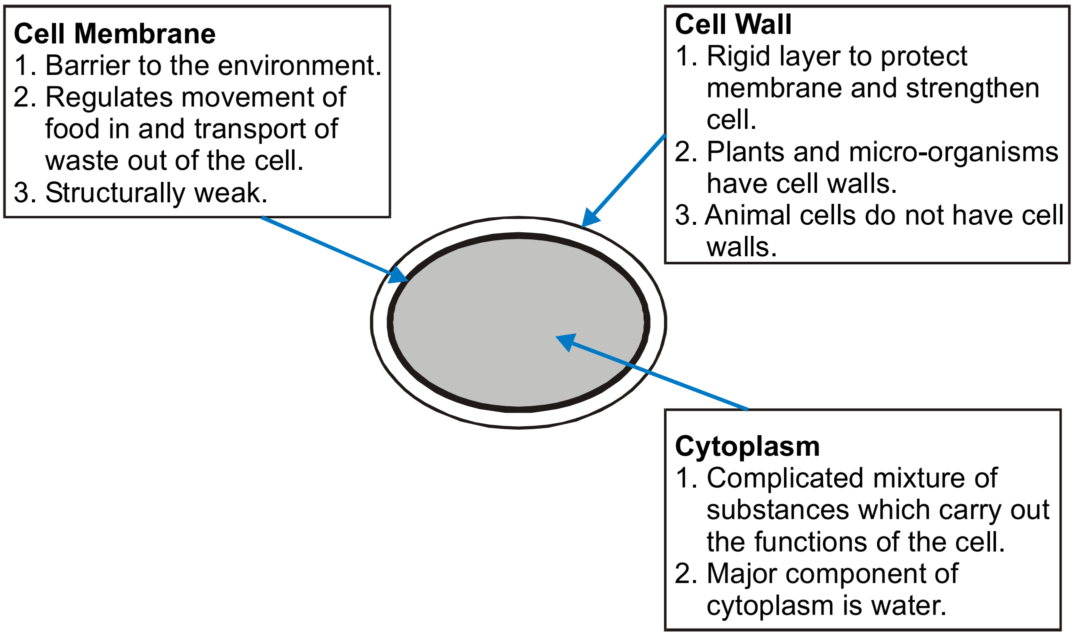
1. **Sugars**, e.g. glucose.
2. **Fatty acids**, e.g. the volatile fatty acids such as acetic acid (vinegar), which is an important intermediate product of anaerobic digestion.
3. **Nucleotides**, e.g. Adenosine Triphosphate (ATP), which is important in cell energetics**.**
4. **Amino** acids.

These four types of monomers form the basis of larger molecules known as polymers. That is, sugars combine to form carbohydrates such as cellulose; fatty acids combine to form lipids (fats); nucleotides combine to form nucleic acids and amino acids combine to form proteins.

1. **Polysaccharides** are high molecular weight carbohydrates containing hundreds or sometimes thousands of monomeric sugar units. Polysaccharides are important carbon and energy reserves in bacteria, plants and animals. Cellulose (consisting of a chain of glucose units) is the principal carbon reserve in plants, produced via photosynthesis.
2. **Lipids** are formed from fatty acids and have interesting chemical properties such as being both hydrophobic (water repelling) and hydrophilic (water soluble). This makes lipids ideal structural components of cell membranes; the hydrophobic characteristics enable the membrane to act as a barrier to diffusion of substances into and out of the cell.
3. The **nucleic acids** (DNA and RNA) are polymers of monomers called nucleotides. DNA contains the genetic blueprint for the cell and RNA acts as an intermediary molecule to convert this blueprint into defined amino acid sequences in proteins.
4. **Proteins** are composed of amino acid monomers. Proteins play key roles in cell function. Two kinds of proteins are recognised in cells, the catalytic proteins (enzymes) and the structural proteins. Structural proteins are those which become integral parts of the structures of cells, in membranes, walls and cytoplasmic components. In essence, a cell is what it is because of the kinds of proteins it contains.

1.2.4 The Physical Structure of a Cell

The next logical step is to investigate the basic structure of a cell, which is the result of innumerable combinations of polymers to form physical structures. The basic structure of a cell is shown overleaf in **Figure 4**.



Cell Membrane
1. Barrier to the environment.
2. Regulates movement of food in and transport of waste out of the cell.
3. Structurally weak.

Cell Wall
1. Rigid layer to protect membrane and strengthen cell.
2. Plants and micro-organisms have cell walls.
3. Animal cells do not have cell walls.

Cytoplasm
1. Complicated mixture of substances which carry out the functions of the cell.
2. Major component of cytoplasm is water.

Figure 4. The Basic Structure of a Cell.

The first point to note is that a cell is a complete single entity, isolated from other cells and the environment by a cell membrane and, in some cases, a cell wall.

All cells have a **cell membrane**, its role is protective in that it forms a barrier to the external environment and also regulatory. The cell membrane regulates the movement of food in and the transport of waste out of the cell. However, the cell membrane does not provide much structural support for the cell.

The **cell wall** is a structure external to the cell membrane, which exists in plant and microbial cells only. Animal cells do not have cell walls. It is a rigid layer, which provides structural support to the cell and protects the inner membrane.

The **cytoplasm** is the collective term for everything internal to the cell membrane. It is a complex mixture of substances, bathed in water, which carry out the functions of the cell. Apart from water the major components of a cell are polymers, ribosomes (the site of protein synthesis) and inorganic ions (e.g. magnesium, sodium, potassium).

1.2.5 Prokaryotic and Eukaryotic Cells

Types of prokaryotic and eukaryotic cells are shown below in **Table 1**.

Table 1. Types of Prokaryotic and Eukaryotic Cells.

	Prokaryotic	**Eukaryotic**
Macro-organisms	None known	Animals Plants (photosynthesis)
Micro-organisms	Bacteria (anaerobic digestion and ethanol)	Algae (photosynthesis) Fungi including yeasts (important for ethanol production)

The characteristics of prokaryotic and eukaryotic cells are summarised below in **Table 2**.

Table 2. The Characteristics of Prokaryotic and Eukaryotic Cells.

Prokaryotic Cell	**Eukaryotic Cell**
1. No true nucleus. 2. Single molecule of DNA which contains the genetic blueprint of the cell. 3. No organelles (besides ribosomes).	1. Has a true membrane-enclosed nucleus within which DNA is located. 2. Cytoplasm is organised into distinct structures called organelles.

The exact structure of the cytoplasm depends primarily on whether the cell in question is a **prokaryotic** or **eukaryotic** cell. Even single-cell micro organisms show different degrees of complexity with respect to arrangement of the cytoplasm, and this is the basis for separating cells into two major groups.

The separation is based mainly on whether or not the cell contains a well-defined nucleus. The nucleus of an eukaryotic cell is easily observable under a microscope as a distinct compartment of the cell that contains the genetic material in the form of filamentous structures called chromosomes.

Prokaryotic cells do not contain a true nucleus, only a single molecule of DNA, which is organised in a different way rather like a fuzzy blob floating in the cell interior! In addition to the issue of the “true nucleus”, in eukaryotic cells the cytoplasm is organised into distinct structures called organelles, which perform certain functions, rather like the organs of a human body.

Bacteria are the only known prokaryotic cells, all other micro- and macro-organisms consist of eukaryotic cells (see **Figure 5** overleaf).

The diagram, **Figure 5**, is a plant cell. The nucleus is a highly organised structure central to the cell. There are a number of organelles, such as the mitochondria in which the energy-generating functions of the cell occur.

What is important to remember, with respect to prokaryotic cells (see **Figure 6** overleaf) is that the cytoplasm, i.e. everything internal to the cell membrane is simple. There is no true nucleus, just a single, circular strand of DNA. Proteins, carbohydrates etc. are free with in the cytoplasm because the reactions that occur in organelles of eukaryotic cells occur in the cytoplasm (or on the cell membrane) of the prokaryotic cell.

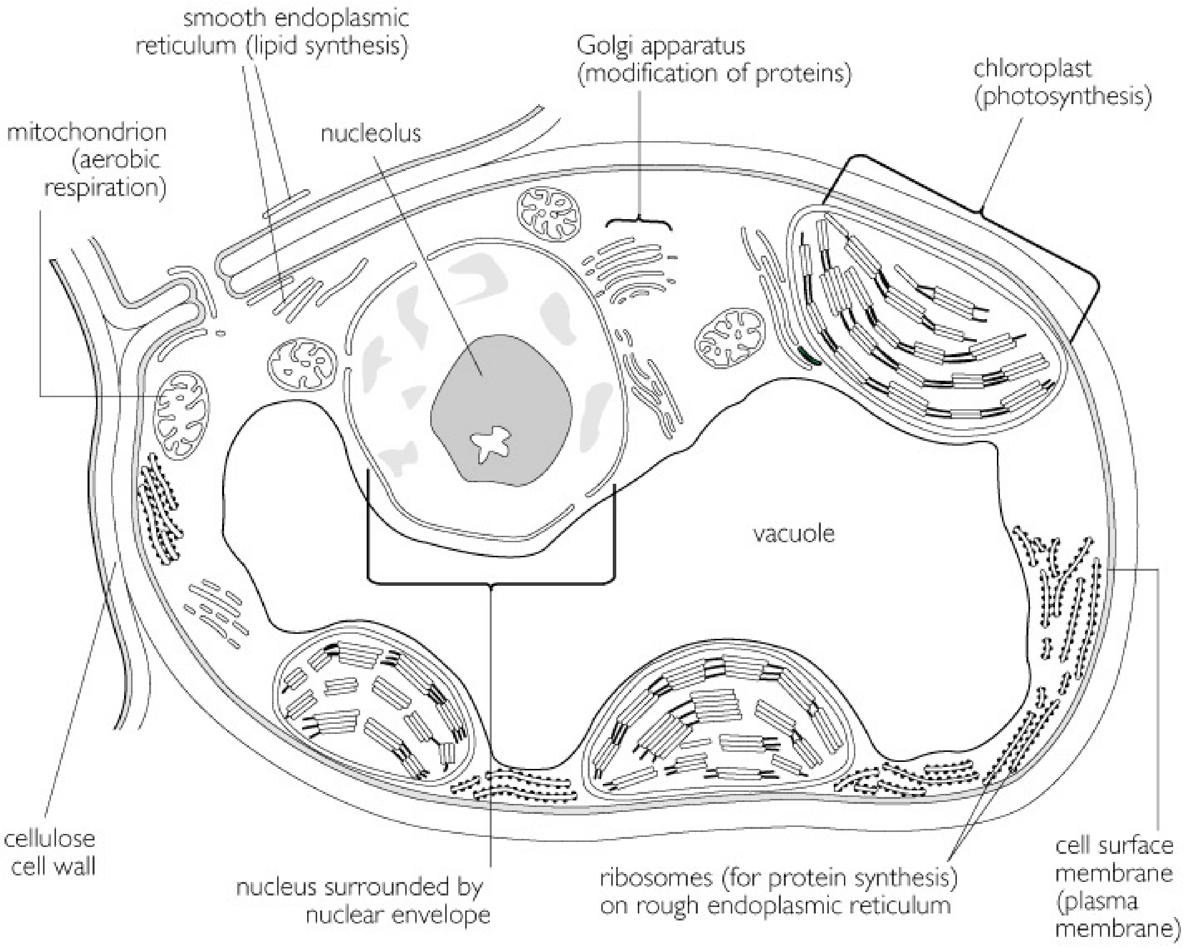


Figure 5. Diagram of an Eukaryotic Cell.

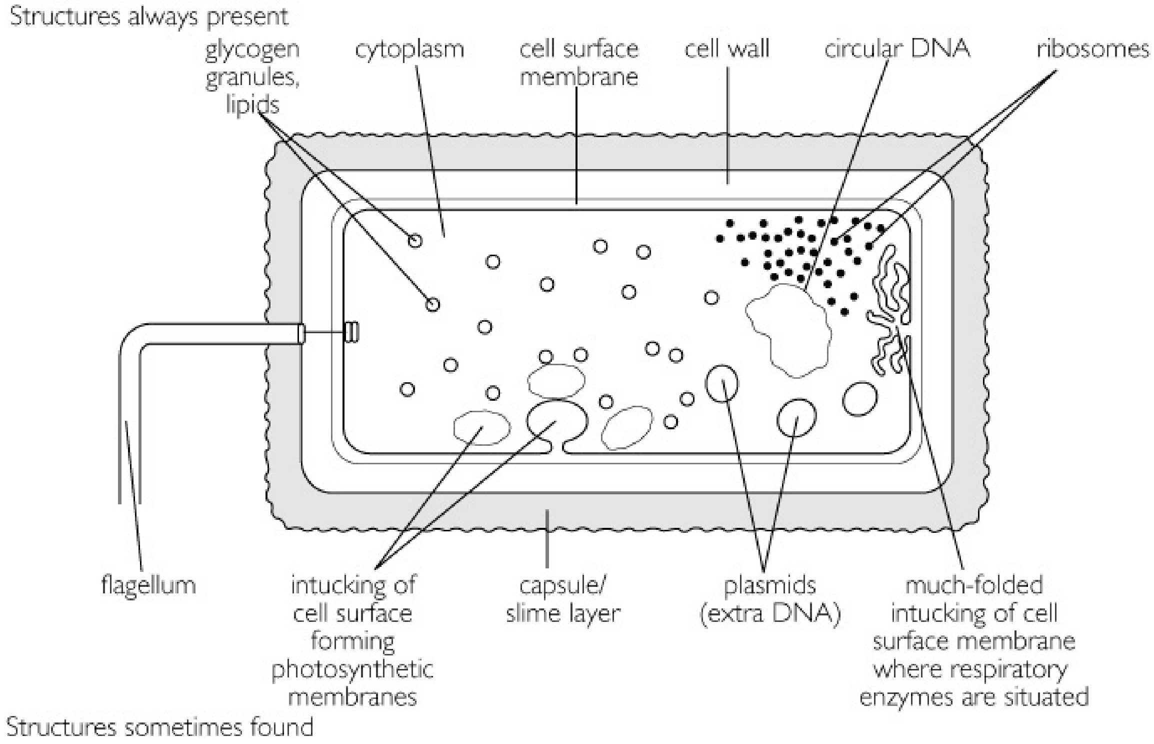


Figure 6. Diagram of a Prokaryotic Cell.

If you want to have a go at dissecting a cell, a *virtual cell* can be found at the following web site address:

http://www.life.uiuc.edu/plantbio/cell/

As well as being fun, this site gives good information on the structure and functions of all cell parts, and even includes animated clips on ATP generation and photosynthesis.