HEA & Teagasc

Crops for Energy

Over recent years there has been growing public awareness of the need to rationalise our use of fossil fuels and where possible to replace them with sustainable alternatives. A variety of crops can be used directly or indirectly as sources of fuel.

The Basic Principle

Plants need light; this is their ultimate source of energy. The living cells of a plant require a steady supply of energy but light is not available all the time and some cells never receive light (e.g. in the roots). Besides, very few of the thousands of biochemical reactions in plant cells can be 'powered' directly by light.

In the leaves of plants a process called photosynthesis takes place; in effect light energy is used to combine carbon dioxide and water to form glucose. Much of the glucose is distributed to other parts of the plant to power the complex life processes. What is not required immediately may be stored as starch. As plants grow new 'building materials' are required to form more roots, stems, leaves and fruit/seeds. These are composed of carbohydrates (such as cellulose), proteins and lipids (fats or oils). Over 90% of the dry mass of a plant is derived from the carbon dioxide it takes from the air.

If plant material is broken down (e.g., by digestion or combustion) the chemical energy 'stored' in the cellulose, oils etc. is released and may be used for heating or electricity generation.

Getting the Energy Back

Below are some of the methods used to retrieve the energy stored in plants.

Combustion

The plant material is dried, at least partially, and burned; the main products are carbon dioxide, water (steam) and ash. (If the material is not sufficiently dry then energy is 'wasted' in vaporising the moisture.)

Gasification of biomass

In this process the plant material is enclosed and heated to a high temperature; is undergoes pyrolysis, that is it is decomposed by heat, and gases such as CO, CO_2, H_2 and CH_4 are formed. Carbon monoxide, hydrogen and methane are combustible gases.

Cellulosic fermentation

This process can make use of most of the plant material (largely cellulose) to produce ethanol. Its ultimate usefulness depends on the development of bacterial strains that can break down cellulose and lignin at high temperatures. It is still under development.

Fermentation of starch

Plant parts with high starch content (grain, potatoes etc.) can be fermented to produce ethanol which is then separated by distillation. The ethanol can be used as a liquid fuel on its own or mixed with petrol.

Anaerobic digestion

This process employs anaerobic bacteria which break down organic material and release 'biogas'— methane and other gases.

Mechanical processes

Combustible oils can be extracted from certain crops by pressing them, effectively squeezing the liquid from them. The oils may need to be processed further before they can be used as transportation fuel. The remaining pulp may be treated using one of the techniques listed above.

Efficient Capture of Solar Energy

Not all the solar radiation landing on a leaf is used for photosynthesis. Less than half is in the visible part of the spectrum and only about half of that again is actually absorbed by chloroplasts; the rest just warms the leaf and is lost to the air by conduction and by evaporation of water (in transpiration) or is reflected or transmitted. So only about 25% of the incoming solar radiation is captured by the chloroplasts. Only one third of this energy is 'stored' as glucose and a third of the glucose is used to power part of the

photosynthesis cycle. Therefore the net efficiency is usually less than 6%. Other variables such as the planting density, weather and crop damage may reduce this to 1% – 2%. The photosynthetic efficiency of sugar cane is exceptional; it may be as high as 7% – 8%.

In effect only a small fraction of the sunlight shining on crops is 'captured' in biochemicals such as glucose, starch, cellulose etc. If only part of a plant is harvested for energy (e.g. rapeseed or wheat) then the energy stored in the rest of the plant may be wasted; this may be 75% – 90% of the total mass of the plant. This waste biomass might be allowed to decay and enrich the soil. It might also be harvested and used as fuel. Burning waste biomass to clear the land of weeds and pests brings its own problems and is not the most desirable option.

Rough Calculation

During the growing season in Ireland (say, April to September) the average solar radiation is about 400 W per square metre for about

10 hours a day. Over the six month period this amounts to 2600 MJ per square metre (400 × 60 ×60 ×10 × 6 × 30 = 2592 MJ)

The energy stored in sugar (or cellulose) is about 15.6 MJ/kg (1560 kJ per 100 g).

So, assuming 1% photosynthetic efficiency one might expect to obtain about 1.7 kg (2600 MJ × 1% ÷ 15.6 MJ/kg) of dried biomass per square metre or about 17 tonnes per hectare. For reasons stated earlier actual yields are closer to half that value (8 to 10 tonnes per hectare).

Energy Inputs

In calculating the overall energy potential of crops the energy expended in tilling, fertilising, planting, irrigating, pest control, harvesting, transporting, drying, processing (e.g. chopping) and waste disposal must all be taken into account. These can offset the perceived benefit of some energy crops.

Some plants are perennial, that is once they become established they grow again each year. This eliminates the tilling and planting and so reduces energy inputs.

Short rotation willow (also called 'Short Rotation Coppice'), once it has become established, can be harvested every two years and may last 25 to 30 years. *Miscanthus* (a type of large grass) can be harvested every year. These two plants are considered suitable for cultivation in Ireland as fuel crops.

Other Costs

The cost of specialised equipment for harvesting is likely to remain a significant factor, especially in the case of willow, until the crop area is large enough to make such investment worthwhile. It is likely that grant aid for such purchases will be necessary, at least in the start-up phase of the development of crops for energy.

Liquid Fuel Crops

There will be a need for liquid fuels for the foreseeable future. For example corn or potatoes can be fermented to produce 'bioethanol' which can be substituted, at least in part, for petrol. Oil from plants such as rapeseed or soybeans can be used to produce 'biodiesel'. However the final fuel yield of these crops is only about 5% of that of combustible crops and two or three times as much energy is used in the production process (e.g. distillation).

Teagasc

Teagasc is Ireland's agricultural and food development authority. As such Teagasc provides research, advisory and training services for the agriculture and food industry in Ireland. The organisation also works in close co-operation with their counterparts in other countries around the world.

Teagasc employs over 200 scientists and 300 technicians in research, and many other specialist staff in training and advisory roles. In total, over 1,500 staff are employed at over eighty locations throughout the country. The research carried out by Teagasc is essential to the development of competitive and sustainable agricultural and food industries. It also researches the potential use of crops for energy.

HEA

The Higher Education Authority (HEA) is the national agency with responsibility for allocating funding to our universities, institutes of technology and other designated higher education institutions. In addition, the HEA advises Government on all aspects of higher education and research.

Research is vital to Ireland's future economic and social development and the HEA is committed to putting in place the buildings and the support mechanisms that will allow researchers and their ideas to flourish. There are increasing opportunities in higher education institutions and in business and industry for those who wish to pursue a career in research.

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Teaching Notes

Syllabus References

The relevant syllabus references are:

Leaving Certificate Biology

The Sun as the primary source of energy for our planet.

Feeding as a pathway of energy flow.

Development of grazing food chain, food web and pyramid of numbers.

Leaving Certificate Agricultural Science

Propagation of plants by vegetative means.

Photosynthesis, translocation, food storage.

Farm Crops – Cereal and Roots

Measurement of output of grassland in terms of total weight, dry matter, meat and milk.

Leaving Certificate Chemistry

Exothermic and Endothermic Reactions

Heat of combustion.

Learning Outcomes

On completion of this lesson, students should be able to:

- understand the basic principle of biofuels.
- outline the main methods of producing energy from crops.
- estimate an ideal crop yield assuming a particular level of photosynthetic efficiency (e.g. 1%) and sunlight.
- list energy inputs/costs involved in producing energy from crops.

General Learning Points

The following information can be used to revise the lesson's main learning points and inform discussion.

- The finite reserves of fossil fuels and the growing demand for energy make alternative sources essential.
- The Sun is the ultimate source of almost all alternative energy schemes, including crop energy.
- If more land is used to grow energy crops less land is available for food crops.
- Many methods are used to extract useable energy from crops, e.g. combustion, fermentation and anaerobic digestion.
- Only a small percentage (~1%) of the available solar energy on a field of crops is 'captured' as carbohydrates, oils etc.
- Not all the energy absorbed by a leaf is captured by chloroplasts.
- Leaves use about a third of the glucose they produce to power part of the photosynthesis cycle.
- Energy can be produced quite efficiently by physical means but the initial costs are high.

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Student Exercises

Student Activity

1. The heat of combustion of ethanol is 1300 kJ mol^{-1}.

The molecular formula for ethanol is C_2H_5OH.

Calculate the molar mass of ethanol.

Calculate the heat of combustion of ethanol in MJ kg^{-1}.

2. Calculate the energy yield from a hectare of *Miscanthus* assuming

- the dry mass yield of a *Miscanthus* crop is 10 tonnes per hectare
- the dry mass is cellulose/glucose
- the heat of combustion of glucose is 15.6 MJ kg^{-1} (2805 kJ mol^{-1}).

3. Assuming that the yield of ethanol from fermentation of corn or potatoes is 350 litres per hectare calculate the energy yield per hectare (using the result obtained in part 1 above).

How does this compare with the energy yield per hectare for combustion of *Miscanthus* (using the result obtained in part 2 above).

4. (Exercise suitable for groups)

Each group examines the potential of a specific energy crop, preferably one that is grown locally. The findings should be summarised under the headings: estimates of the energy output per hectare per annum, the initial setup costs, pest control, harvesting, processing, and other costs. The summary might usefully be presented in poster format.

True/False Questions

a) Plants produce proteins by photosynthesis.

b) Global energy needs can be met by biofuels.

c) Ethanol can be produced by fermentation of carbohydrates.

d) Ethanol production by cellulosic fermentation is still under development.

e) All the light energy entering a leaf is captured in carbohydrates such as glucose.

f) The photosynthetic efficiency of most plants is about 10%.

g) Chloroplasts absorb all the light energy that shines on a leaf.

h) About half of the glucose produced during photosynthesis is used to power other parts of the photosynthesis cycle.

i) Plants absorb carbon dioxide during photosynthesis.

j) The Sun is the ultimate source of energy for the Earth.

Check your answers to these questions on www.sta.ie

Examination Questions

Leaving Certificate Agricultural Science (HL) 2009, Q. 8 (a)

(i) With the aid of a labelled diagram briefly describe the carbon cycle.

(ii) Suggest one practice farmers could adopt to reduce the carbon footprint of agriculture.

Leaving Certificate Agricultural Science (HL) 2008, Q. b (b)

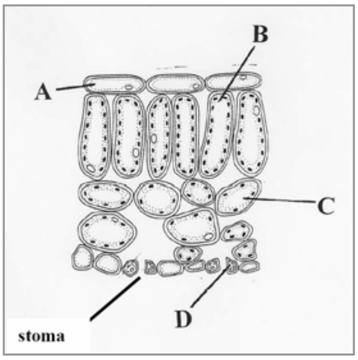
The diagram shows a section through part of a leaf.

(i) Name the cells labelled A, B, C, D.

(ii) Give two features of the leaf that are related to its role in photosynthesis.

(iii) Name two gases that may leave the leaf through the stoma.

(iv) Write a balanced chemical equation for the process of photosynthesis.



Leaving Certificate Agricultural Science (OL) 2008, Q. 9

In cereal production, farmers have a choice of sowing winter or spring varieties.

a) Give any two disadvantages of sowing spring varieties.
b) Give two reasons why winter varieties are sown.
c) What are the main benefits of sowing certified seed?
d) Name one pest of cereal crops. Explain how it affects the plant and how it is controlled.
e) Describe three procedures followed to ensure proper storage of cereal grain.
f) State the expected yield in tonnes per hectare of a named spring cereal crop.

Leaving Certificate Agricultural Science (HL) 2009, Q. 5 (a)

Describe the cultivation of spring barley or main-crop potatoes under the following headings:

(i) Soil requirements
(ii) Rotation
(iii) Weed control
(iv) Yield (tonnes per hectare)

Did You Know?

Solar radiation

About 52% of solar radiation is infrared and about 4% ultraviolet. The remaining 44% is visible light. About a quarter of the visible sunlight that shines on plants is reflected – mainly green light. Therefore only about 33% of the solar radiation on plants is absorbed or transmitted, and only part of this is likely to be intercepted and used by chloroplasts in the process of photosynthesis.

Comparison with photovoltaic cells

The efficiency of electricity generation using photovoltaic cells is currently about 15% and newer types are over 30% efficient. Set-up costs are relatively high but are likely to drop as uptake and efficiencies increase. Once installed the maintenance costs are relatively low.

Biographical Notes

Melvin Ellis Calvin (1911 – 1997)

Melvin Calvin's parents were Jewish emigrants from the Soviet Union. He was born in St. Paul, Minnesota in 1911 and a few years later the family moved to Detroit.

He studied science in what is now Michigan Technological University and earned his B.Sc. in 1931. He completed his doctorate in chemistry in 1935 and did further research in Manchester (UK).

In 1937 he was invited to join the faculty in the University of California at Berkeley. There he was introduced to Ernest Lawrence who had set up a Radiation Laboratory. Calvin was among the first to join the radiation team and in 1946 he undertook the study of photosynthesis using radioactive carbon. In this work he was joined by Andrew Benson and James Bassham. They mapped out the complete pathway taken by carbon from carbon dioxide to glucose via various intermediates. For this work he was awarded the Nobel Prize in Chemistry in 1961.

Calvin died in 1997 and is survived by two daughters, Elin and Karole, and a son, Noel. His wife Genevieve Elle, to whom he was married for 36 years, died in 1987.

Revise the Terms

Can you recall the meaning of the following terms? Reviewing terminology is a powerful aid to recall and retention.

anaerobic, anaerobic, bacterial strains, biodiesel, bioethanol, biomass, carbohydrate, carbon dioxide, cellulose, chloroplast, coppice, corn, distillation, energy, ethanol, fermentation, fossil fuel, fuel, glucose, glucose, hectare, hydrogen, irrigating, lignin, lipid, methane, Miscanthus, MJ, perennial, photosynthesis, photosynthetic efficiency, photovoltaic cell, protein, pyrolysis, solar radiation, spectrum, starch, sugar cane, sustainable, tilling, tonne, transpiration, transportation fuel, vaporise, W, willow

Check the Glossary of Terms for this lesson at www.sta.ie