Practical Biofuel Activities for School Engagement and Outreach

Second Edition

Willow leaves © BBSRC

Safety checked, but not trialled, by CLEAPSS.

BBSRC bioscience for the future

Research Councils UK Energy For a Low Carbon Future

The Biofuel Researcher Practical Guide

Who this is for:

Researchers - This guide will enable you to communicate and engage young people with the scientific principles and research in the fields of bioenergy and biofuels through outreach activities.

Bioenergy science and research are ideal topics to engage young people and support teachers in delivering the curriculum. Delivering a number of small public engagement activities across the UK to young people and families increases awareness of research and the issues that it raises whilst also providing opportunities for dialogue. Stimulating discussion within families raises the level of interest in science and provides an effective means of promoting further study in science subjects. By engaging with young people you will be able to consider the relevance of your research to the needs of future generations and potentially refine the direction of research you undertake to meet those needs.

What is in the practical guide:

The background information on these pages will cover the basic science involved in the field of bioenergy and biofuels and links to the curriculum and further information on the research being conducted. There are also a range of practical activities with instructions. The activities can be carried out in universities and research institutes with visiting students as well as school science laboratories and classrooms, and with modifications most can be demonstrated at science fairs or other engagement activities. The topics cover plant science, microbiology, chemistry and a range of other areas of science and technology.

Each activity has background science, further reading and links to research groups to enable you to become familiar with the important developments that have occurred in the field of biofuel research. There are learning objectives, keywords, suitable age ranges, extension activities and curriculum links to help plan activities that will meet the needs of teachers and young people. Before carrying out activities, try to find out the audience's existing knowledge or understanding of science concepts. You may want to consult teachers or parents prior to the activity. To help with this, suggested prior knowledge is included for each activity.

Activities take between 10 and 60 minutes depending on the age and ability of the participants. Some of the activities require incubation periods which can be carried out in advance or as part of a series of engagement activities with schools or young people. The time taken can be reduced if materials are prepared in advance or parts of the activities carried out as a demonstration. It is recommended that sufficient time before or after the activity is arranged and planned in advance so that the outcomes can be observed.

Many of the activities in this guide are suggested by exam boards to cover the knowledge, understanding or practical skills content required for GCSE, A-level or Higher examinations.

The activities can be carried out with equipment available in most school science laboratories.

Equipment and consumables can be obtained from Sigma-Aldrich, the National Centre for Biotechnology Education (NCBE), Philip Harris Education, Blades Biological Ltd, Mindsets, Sciento, Timstar Laboratory Suppliers Ltd, Bio-Rad and Edvotek.

Key to abbreviations: Association for Science Education (ASE), Biotechnology and Biological Sciences Research Council (BBSRC), Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS®), Control of Substances Hazardous to Health (COSHH), Department for Education and Employment (DfEE), National Centre for Biotechnology Education (NCBE), Royal Society of Chemistry (RSC), Science and Plants for Schools (SAPS), Society for General Microbiology (SGM), Scottish Schools Equipment Research Centre (SSERC), Scottish Qualifications Authority (SQA), Oxford, Cambridge and RSA Examinations (OCR), Assessment and Qualifications Alliance (AQA).

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These pages can be downloaded as pdf's from www.bbsrc.ac.uk/biofuelsactivities

About

BBSRC

The Biotechnology and Biological Sciences Research Council (BBSRC) invests in world-class bioscience research and training on behalf of the UK public. BBSRC supports research and training in universities and strategically funded institutes to further scientific knowledge, to promote economic growth, wealth and job creation and to improve quality of life in the UK and beyond. BBSRC supports a total of around 1600 scientists and 2000 research students in universities and institutes in the UK. BBSRC research and the people we fund are helping society to meet major challenges, including food security, green energy and healthier, longer lives. Our investments underpin important UK economic sectors, such as farming, food, industrial biotechnology and pharmaceuticals.

BBSRC has a commitment to inspiring young people and provides a number of resources to support researchers, teachers and school pupils. This set of resources has been produced following consultation with a wide range of organisations and stakeholders to enable researchers to engage young people with the science and issues surrounding Biofuels and Bioenergy.

BBSRC Sustainable Bioenergy Centre (BSBEC)

BSBEC was launched in 2009 to provide focus for research underpinning sustainable bioenergy and biofuels in the UK. It represents the largest UK public investment in bioenergy, with £20M from BBSRC and around £5M from industry. BSBEC is a virtual centre, integrating activities across six UK research hubs led by Rothamsted Research (RRes) and the Universities of Cambridge, Dundee, Nottingham (two hubs) and York.

BSBEC is part of the Research Councils UK Energy Programme, aimed at helping the UK move towards a low carbon future.

Research Councils UK Energy Programme

The Research Councils UK Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £530 million in research and skills to pioneer a low carbon future. This builds on an investment of £360 million over the past 5 years.

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

Health and Safety

The practical activities outlined here are for guidance only.

Provided appropriate equipment and facilities are used and safety precautions are made the experiments do not pose a health and safety risk to participants. It is essential that you check safety policies and procedures with your place of work, venues or school and follow the guidance provided before carrying out activities. Modifications to the procedures outlined here may be required to accommodate the circumstances under which the activity is conducted. When carrying out activities in laboratories ensure that good laboratory practice is followed by demonstrators and students. A copy of the Good Laboratory Practice with Young People (from CLEAPSS®) is provided.

Risk assessments should be carried out for all activities and it is recommended that CLEAPSS® guidelines are followed (or, in Scotland, SSERC). CLEAPSS® www.cleapss.org.uk is the school science and technology safety advisory service. BBSRC has membership of CLEAPSS® and further advice can be obtained from CLEAPSS® through BBSRC by contacting the Inspiring Young Scientists Coordinator on 01603 255017 or email external.relations@bbsrc.ac.uk. In Scotland, SSERC www.sserc.org.uk has a similar role to CLEAPSS® and there are some reciprocal arrangements. Further advice is also available from the Association for Science Education (ASE) www.ase.org.uk, which BBSRC is a member of, or consult the individual responsible for Health and Safety in your organisation.

COSHH Regulations (2002) and the Management of Health and Safety at Work Regulations (1999) require risk assessments for any hazardous procedure or activities with harmful microorganisms. Use of chemicals should adhere to COSHH regulations and some chemistry based activities should only be carried out in a suitable location such as a school science laboratory.

For activities involving microorganisms, suitable disposal and decontamination procedures should be planned prior to carrying out the activity. None of the practical activities suggested in this guide involve pathogenic microorganisms, however, they can be cultured by mistake and it is important to note that COSHH Regulations apply to activities involving pathogenic microorganisms. Further advice can also be sought from the Society for General Microbiology and the Microbiology in Schools Advisory Committee.

It is important to check for any relevant medical conditions, such as allergies, that young people or members of the public may have before carrying out these activities. It is recommended that participants are provided with nitrile gloves or made to wash their hands at the start and end of activities.

Further reading

CLEAPSS® laboratory handbook

- section 13.2.1 Fossil Fuel Experiments (Distillation of coal, the distillation of crude oil, 'cracking' experiments) pages 1305-1309.
- section 14.9 Fermenters (Safety, Practical considerations) pages 1443-1451.
- section 15.2 Microbiology (COSHH, good practice and safety precautions, levels of practical work, using microorganisms in practical work, equipment and materials, sterilisation and disinfection) page 1505.
- section 15.5 Plants and seeds (choosing suitable plant material, growing and cultivating plants, sources and suppliers of plants) pages 1540-1567
- section 20.3.1 Carbohydrate tests page 2006.

Health and Safety

CLEAPSS® Recipe book RB1 (Agar), RB3 (Alginate beads), RB11 (Benedict's qualitative reagent),

RB12 (Benedict's quantitative reagent), RB17 (Bromine water), RB19 (Calcium chloride and nitrate(V) solutions), RB21 (Carbon dioxide), RB26 (Chromatography solvents and locating agents), RB32 (Crude oil alternative), RB37 (Enzymes), RB40 (Fehling's solutions), RB48 (Indicators-carbon dioxide), RB50 (Iodine solution), RB71 (Potassium hydroxide), RB73 (Potassium manganate(VII)) RB93 (Stains for plant material), RB99 (Testing for gases), RB102 (Testing for organic functional groups).

CLEAPSS® Hazcard 12 (Benzene diols and triols), 15A and B (Bromine), 18 (Calcium oxide), 19A (Calcium salts), 20 (Carbon dioxide), 27C (Copper salts), 28 (Dichloromethane), 33 (Enzymes), 37 (Ethane-1,2-diol and other polyols), 40A (Ethanol), 40B (Methanol), 40C (Carbohydrates), 45 and 46 (Hydrocarbons), 54 (Iodine), Student Safety Sheet 48 and Hazcard 81 Potassium manganate(VII), 85 (Propanone), 91 (Sodium hydroxide), 92 (Sodium and potassium metabisulphate), 95C (Sodium and Potassium salts).

CLEAPSS® Guidance leaflets G5p (Using chemicals safely), PS 04 (COSHH: risk assessments in situations where microorganisms might be involved), PS 15 (Ventilation and levels of carbon dioxide and other gases in the laboratory & prep room), PS 67-01 (Testing for unsaturation), PS 67-05 (The viscosity of motor oils), PS 67-10 (Making bio-diesel), PS 67-14 (Chromatography), PS 89 (Measurement of anaerobic respiration in yeast).

CLEAPSS® Guides R57 (Colorimeters), R101 (Steam sterilisation: Autoclaves & pressure cookers).

CLEAPSS® Model Risk Assessment 3.002 (Chemical testing of food), 3.015 (Enzymes), 3.026 (Microorganisms used in food production).

Practical Fermentation – A guide for Schools and Colleges. 1999. National Centre for Biotechnology Education (NCBE) and Society of General Microbiology (SGM).

Burdass, D., Grainger, J.M. and Hurst, J. (editors) 2006, Basic Practical Microbiology – A Manual and Grainger, J. M. and Hurst, J. (editors) 2007, Practical Microbiology for Secondary Schools. available free from the Society for General Microbiology (SGM)

Royal Society of Chemistry (RSC) Transporting chemicals for lecture demonstrations & similar purposes January 2008.

Association for Science Education (ASE) Be Safe! 4th Edition, 2011, pages 16-17 (microorganisms), 18-19 (plants), 34-36 (chemicals).

Association for Science Education (ASE), Safeguards in the school laboratory, 11th edition, 2006. www.ase.org.uk/resources/health-and-safety-resources/

Association for Science Education (ASE) Topics in Safety, Third edition, 2001, College Lane, Hatfield, Herts. AL10 9AA. ISBN: 0 86357 104 2.

Department For Education and Employment (DfEE) Safety in Science Education, 1996. HMSO, London. ISBN: 011 270915 X.

Scottish Schools Equipment Research Centre (SSERC) Limited, 1997, Hazardous Chemicals, A Manual for Science Education, ISBN 0 9531776 0 2.

CLEAPSS guidance on Good Laboratory Practice with young people

It is expected that every university, research institute or school will have rules governing behaviour in the laboratory. No eating or drinking (or indeed smoking or the application of cosmetics) should be allowed in laboratories. Interference with mains services or equipment should be strictly forbidden, as should running or foolish behaviour generally.

Good hygiene is needed at all times, but especially when chemicals or living organisms are being used. Benches need to be wiped down after such activities and hands washed.

Suitable eye protection must be worn whenever the risk assessment requires it, ie, whenever there is a recognised risk to the eyes. This will certainly include activities in which chemicals are heated, heat is generated in a chemical reaction or any activities involving chemicals with a hazard classification. Eye protection is also necessary where there are mechanical hazards, eg when stretching wires to breaking point or evacuating vessels.

Many accidents occur during heating activities. Long hair should be tied back and ties, cardigans, scarves, baggy shirts, etc should not be allowed to hang freely. It is assumed that demonstrators (i.e. you) and teachers will show and remind students how to heat safely small quantities of solids in test tubes and liquids in boiling tubes (wide diameter test tubes), using small quantities so that the tube is not more than 1/5th full, and pointing the tube away from their own faces and other peoples' faces. The tube should be sloping so that the holder is not in a flame. For liquids, tubes should be gently shaken or a water bath used where appropriate. Students should stand, not sit, for most operations in which chemicals (and especially liquids) are handled.

Students need to be shown how to pour safely from bottles, pouring away from the label (so that it is not damaged by drips). Spills of chemicals should be wiped up at once. Some may require chemical treatment (eg, neutralisation) but, in the quantities normally handled by students, a damp cloth is usually sufficient. The cloth should then be rinsed. Students should be trained to use a spatula or similar device and never to handle chemicals with their fingers. Wherever possible, teat pipettes should be avoided. Even with well-behaved classes, too many accidents occur when liquids are squirted from them, eg, when clearing up at the end of a lesson. Except sometimes in the sixth form, work in schools rarely requires the use of protective gloves. However, when chemicals have been used or living organisms handled, students should be trained to wash their hands afterwards.

If the risk assessment requires the use of a fume cupboard, then this should meet the standard of *Building Bulletin 88, Fume Cupboards in Schools* (Architects and Buildings Branch, DfEE, 1998, HMSO) (previously *Design Note 29*).

If safety screens are required for a demonstration, then they should be sufficient in number to protect both the teacher and all the students. They should be sufficiently tall and sufficiently close to the apparatus to prevent objects going over the top. There should be a gap of 2 m or more between any demonstration and the students.

If microorganisms are in use, teachers unfamiliar with modern techniques may need training (see for example, *Topics in Safety*, *Safety in Science Education* or the *CLEAPSS Laboratory Handbook*). In any work in micro-biology, risks can be reduced to an acceptable level by observing good practice and following simple precautions. Sterile technique is needed to prevent cultures from becoming contaminated and to stop microorganisms escaping from cultures. This will involve ensuring that materials which will contact microbes are sterile before and afterwards; a pressure cooker or autoclave is essential, complemented by the use of appropriate chemical disinfectants to deal with spills and to clean working surfaces. By choosing appropriate organisms and growth media, avoiding the culture of microbes from dangerous sources and incubating at room temperature, together with the correct handling and sealing of cultures, exposure to pathogens can be minimised or eliminated. The culture of organisms that will be consumed, eg, yoghurt bacteria or baker's yeast, should not take place in a science laboratory.

Introduction

Fossil fuels are declining and in order to maintain the current levels of energy use and the transport systems we depend on we need to find alternatives. There are also environmental concerns about the effects of using fossil fuels such as pollution and climate change. Bioenergy may be part of the solution to these problems

Bioenergy is the energy derived from harvesting biomass such as crops, trees or agricultural waste and using it to generate heat, electricity or transport fuels.

The benefits of bioenergy include, sustainable and renewable fuels, decreased carbon dioxide release into the atmosphere and turning the problem of waste into a source of energy. Biofuels can be 'effectively' carbon neutral and in some cases may use emissions from power plants as a carbon source.

Biofuels could power our cars, heat our homes and fuel our planes. Liquid biofuels represent the only sustainable alternative to current transport fuels. BBSRC research is focusing on advanced biofuels from inedible and non-food crops as well as waste. Currently biofuels are blended with mineral oil-based fuels so that typical UK petrol is composed of 3-4% biofuel. At present much of this biofuel comes from sources that directly or indirectly compete with land and resources that could otherwise be used to grow food.

Biomass can be burned directly to generate heat and/or power either on its own or 'co-fired' alongside conventional fuels such as coal. Alternatively, biomass can be treated to create gaseous or liquid biofuels which can be used on their own or in conjunction with conventional fuels such as coal or natural gas. For the transport sector the initial emphasis is on motor vehicle fuels, but the same principles apply to aviation fuels, where bio-products provide the only sustainable alternative to kerosene.

Biofuels, biofuel feedstocks and the technologies involved in producing them can be considered in terms of current bioenergy and advanced bioenergy. There are a wide range of sources of biomass used in producing biofuels commonly referred to as feedstocks. The procedures used to convert these feedstocks are equally varied as are the potential fuels produced. A number of terms have been used to describe this variety of approaches, the research being undertaken and developments that are taking place including 1st, 2nd, 3rd and 4th generation. These terms are in common use and have therefore been used on occasion in this document. However, this doesn't reflect the complex nature of the field and cannot completely describe the differences between biofuels.

Current or conventional bioenergy is often referred to as first generation whereas advanced bioenergy refers to second and third generation biofuels. First generation biofuel refers to established technologies used to produce biofuels, in particular the use of food crops such as sugar cane and maize, but also including biogas. Second and third generation biofuel refers to bioenergy solutions that either make use of waste, residues or rely on non-food crops that can be grown on non-prime agricultural and marginal land and thus does not compete with food production.

Advanced bioenergy solutions hold the unique promise of being able to provide a sustainable alternative to current oil-based liquid fuels, particularly for aviation, shipping and haulage.

While other technologies, such as electric or hydrogen vehicles, may someday replace the need for liquid fuels, they are not viable alternatives at present. Electric vehicles may be excellent for short journeys, but the range provided by current battery technologies, and lack of infrastructure, make them impractical for longer journeys, haulage or aviation use. Hydrogen-based vehicles likewise still require significant technological and infrastructural developments to become viable.

Liquid biofuels, to replace petrol, diesel and aviation kerosene, can come from:
(a) breaking down the structures that plant cell walls are made of (lignin and celluloses) then converting them into energy using thermochemical and biochemical technologies
(b) harnessing the capabilities of algae and microbes to produce liquid fuels from simple molecules

Introduction

BBSRC bioenergy research focuses on sustainable energy (liquid fuels, heat and electricity) either from non-food feedstocks or from inedible elements and waste from agriculture, food crops or food processing. Research suggests that there is enough land in the UK to grow the biomass required to meet government targets by 2020 and produce renewable electricity that would provide16.6% of the total electricity used in the UK without affecting food production. Changes in land use will inevitably affect the environment, for instance biodiversity, soil structure or water availability. Some changes may be positive while others may have negative impacts. The farmed and natural environment provide vital ecosystem services and it is important that proper assessments of environmental risks are carried out throughout the development of crops and new technologies before they make it to the farm.

New and better sources of bioenergy may come from: non-food crops, inedible parts of food crops, waste, residues, microbial and algal metabolism, and biomass processing into biogas. Advanced bioenergy (rather than current or conventional bioenergy) solutions either make use of waste, agricultural residues or rely on non-food crops that can be grown on non-prime agricultural or marginal land. For instance, research focuses on improving yields and conversion efficiencies for producing biofuels from miscanthus, willow and barley straw.

Sustainably produced biofuels offer the only mid-term option for replacing liquid transport fuels such as petrol, diesel and kerosene. Crude oil is a finite resource and production is expected to eventually decline, though at present analysis by the International Energy Agency suggests there are ample supplies for the forseeable future. Even without the pressing environmental reasons for reducing the ‘carbon footprint’ of transport and manufacturing, the eventual depletion of fossil fuel reserves means that we need to find alternative sources of energy and raw materials. Plant-based industrial biotechnology provides a viable route to achieve this. Industrial biotechnology can substitute for dwindling fossil fuel stocks by providing fuel and other high value products such as plastics, pigments and antioxidants.

Scientists are using biotechnologies to carry out their research and these include:

- Plant breeding
- Systems biology
- Genetic modification
- Metabolic engineering
- Directed evolution
- Anaerobic digestion
- Synthetic biology

While some of today’s research can be applied in the near future, much of it is working towards longer term goals that will take 10 or or more years to achieve. These longer term research projects may lead to the discovery of new technologies and techniques in areas such as synthetic biology, with the possibility that plants may be able to produce fules and other products directly.

Introduction

KEYWORDS

Bioenergy, biofuel, biodiesel, sustainable, renewable, biomass, biogas, yield, waste, food security, second generation, bioethanol, lignocellulose, lignin, cellulose, cell wall, microbes, yeast, enzyme, fermentation, gribbles, photosynthesis, algae, varieties, electricity, heat, transport, crops, straw, miscanthus, willow, barley, oilseed rape, wheat, maize, wood, sugar, starch, aerobic, anaerobic, oil, catalyst, carbon dioxide, combustion, chlorophyll, fossil fuels, glycerol, genetic modification, hydrolysis, synthetic, saturated, viscosity, arable land, biodiversity, advanced plant breeding, feedstock, environment, agriculture, biodegradable, biorefinery.

Keywords courtesy of www.wordle.net/

FACTS and FIGURES

- To help combat climate change the UK has a target to reduce carbon emissions by 80% by 2050.
- 30% of the UK renewable energy could come from biomass heat and electricity by 2020.
- To meet the European Renewable Energy Directive, the UK's is aiming for 10% of transport energy to be from renewable sources by 2020.
- 18% of the sustainable renewable road transport fuel used in the UK between April 2012 and April 2013 came from UK feedstocks.
- Photosynthesis is only 6% efficient and it may be possible to improve this to produce higher yielding plants or develop novel ways of capturing solar energy.

Statistics from BBSRC Bioenergy position statement, Climate change Act 2008 and Renewable Transport Fuel Obligation report 2013