Teaching Sustainability in High Schools:

Module 3 (Focus on Senior Chemistry)

Lessons 9-12

Chemistry Innovations in Sustainable Development

Teacher Supplement

Developed by:

The Natural Edge Project

Funded by:

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Student Supplement for Module 3:
Chemistry Innovations in Sustainable Development

Developed by: The Natural Edge Project

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In collaboration with the Sustainable Living Challenge

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Disclaimer

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Introduction – Using this Supplement

Overview

Are you a high school science, biology, chemistry, or physics teacher who wants to discover relevant and practical activities that engage students in sustainability in your classroom? This teacher supplement will help you address national curriculum requirements with regard to education for sustainability, and will also show how sustainability can provide context for STEM curriculum.

This Teacher Supplement provides teaching and assessment support for the *'Learning-by-Notes'* package for Senior School in chemistry related subjects, to support the use of these materials to address the requirement for education for sustainability in the national curriculum. It also aims to increase interest in Science, Engineering, Technology and Maths (i.e. STEM) through an interesting and current topic area. The teacher resource has been funded by Engineers Australia (QLD Division), as a companion to the existing 12 lessons (Grade 12, Senior Chemistry and Senior Physics) that have been previously developed with funding from the Port of Brisbane as part of the Sustainable Living Challenge.

As the third of three modules in this series, this module contains activity ideas, student handouts, and Summary Activities and Homework Ideas for four lessons on sustainable chemical innovations:

- **Lesson 9: Green Chemistry – An Introduction:** This lesson introduces the topic of 'Green Chemistry' and sets the context for the following three lessons. We introduce a number of key Green Chemistry principles that scientists and engineers can use to move towards sustainable development.
- **Lesson 10: Green Chemistry - Dealing with Greenhouse Gases:** This lesson highlights the potential role of Green Chemistry in helping to mitigate climate change through innovations in: 1) reducing greenhouse gas emissions, and 2) removing (sequestering) greenhouse gases from the atmosphere. We briefly discuss the types of greenhouse gas (GHG) emissions and exciting chemistry innovations in sequestering and mitigation.
- **Lesson 11: Green Chemistry - Reducing Toxicity:** This lesson aims to introduce the topic of reducing toxicity and the concept of 'benign by design', where products and services are designed so that they don't use or produce toxins in the first place. We provide examples of companies that are successfully delivering sustainable products and services.
- **Lesson 12: Green Chemistry - Making Better Batteries:** This lesson introduces students to the issues and possible opportunities within the field of batteries, as well as the role batteries will play in enabling sustainable development. In particular, we highlight the opportunities in hybrid-electric and electric vehicle applications, biodegradable batteries, and batteries that can support reliable renewable energy supply.

This curriculum draws on the text book: Hargroves, K. and Smith, M. (2006) *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, Earthscan, London. Teachers are encouraged to refer to this text for further explanation of related content, additional references and excerpts for use during training sessions. The text also has a supporting online companion at www.naturaledgeproject.net/NAON.aspx.

Structure of the Teacher Supplement

This 'Teacher Supplement' provides an activity pack for each of the four lessons described above. The content has been structured to enable a wide variety of teaching methods, from lesson-style teaching, to problem based learning. Teachers may choose to fully explore all of the material, or just take parts of the content as they support existing materials in the learning program. Each lesson supplement has the following structure to enable easy referencing and lesson preparation:

– **Educational Aim:** This text is the same as in the student materials, defining the educational objective for each lesson. The teacher may use this as an introduction to the class.

– **Alignment to National Curriculum:** This text provides a summary of how the lesson is anticipated to align with the future requirements of the Australian National Curriculum, in particular given the statements already provided for junior and middle schools.

– **Activity descriptions:** Here we provide 2 activities for each lesson, spanning exercises that require minimal resources or expenditure, to activities that may need some funds and/or preparation. Occasionally there are also pre-prepared student handouts that can be photo-copied or scanned, to assist with the lesson preparation.

– **Summary Activities and Homework Ideas:** Here we provide a number of ideas for assessment under three popular types including essay topics, mind map opportunities, and short answer questions. We also provide some sample answers to assist with assessing.

The activities suggested in this are meant to complement the content introduced in class. As such, they are do not cover extensive amounts of chemistry theory, rather they provide an application that demonstrates how theory learnt in class can be used to develop sustainable solutions to real world problems.

Structure of the Student Materials

This module has been designed as a base reference for Australian Science teachers to incorporate into lessons on the challenges and opportunities in sustainable development. The student materials comprise four lessons, as summarised on the previous page.

Each Lesson contains the following headings. It is intended that teachers can either use this structure directly, or be readily able to adapt it to their preferred class structure and format:

– **Educational Aims:** define the educational objective for each lesson. This text provides a snapshot of the key message.

– **Learning Points:** summarise key points to explain the message. This information can be transferred onto overhead or PowerPoint slides for teaching to the class. Alternatively, the points could be read out by students and discussed in a tutorial-style learning environment.

– **Brief Background Information:** This provides the teacher with a context within which to interpret the Learning Points. It also indicates the type of information contained in the recommended references and resources. This material often explains terminology in more depth, or provides background information to help further explain concepts in case students find the material difficult to understand. Note that the Brief Background Information should not be considered the only source of in-depth information – please also refer to the cited references.

- **Key References:** This list is essential as a summary of where key information has been sourced from, and where more information on related topics can be found.
- **Key Words for Searching Online:** This list is intended to encourage students to explore online resources related to the topic of interest. Specific pages are noted where appropriate, although at times only the home page is listed for general reading. A search of these key words will also list the most current material available on the topic of interest.

Additional Support for Teaching Education for Sustainability

In addition to the extensive reference list provided for each part in the 'Student Supplement' the following is a list of key resources for which teachers can use to access potential class activities:

TeachSustainability.com.au (http://www.teachsustainability.com.au/): A primary resource for teachers is the *TeachSustainability.com.au* web resource. An initiative of the Sustainable Living Challenge, this website is a resource sharing database to support Australian teachers who are exploring issues of sustainability in their classrooms. This database allows the open and free sharing of resources that have been developed or sourced by school teachers and educators.

Teaching and Learning for a Sustainable Future (http://www.unesco.org/education/tlsf/): *Teaching and Learning for a Sustainable Future* web resource is an award winning internationally renowned training toolkit for those who want to educate for a sustainable future. It consists of over 100 hours (divided into 25 modules) of professional development for use in pre-service teacher courses, as well as the in-service education of teachers, curriculum developers, education policy makers and authors of educational materials.

Education for Sustainability Portal (http://www.aries.mq.edu.au/portal/index.htm): Developed by the Australian Research Institute in Education for Sustainability (ARIES), the *EFS Portal* is a central source of information on education for sustainability. This includes information for community groups, local councils, government agencies, industry, non-government organisations, schools, colleges and universities.

Federal Government Resources: DEWHA, DCC and ORER:

- The Australian Government Department of Environment Water, Heritage and the Arts (http://www.environment.gov.au/education/publications/index.html) provides a range of resources that seek to develop sustainability skills, knowledge, values and behaviours.
- The Department of Climate Change website provides answers to frequently asked questions about Climate Change (http://www.greenhouse.gov.au/science/index.html).
- The Office of the Renewable Energy Regulator has been established to oversee the implementation of the Australian Government's mandatory renewable energy target. Their website has information on renewable energy options (http://www.orer.gov.au/index.html).

The Natural Edge Project – Engineering Sustainable Solutions Program (ESSP): Recognising that the engineering, scientific and design professions will play a significant part in moving society to a more sustainable way of life, together with the realisation that we have very little time to prepare, this program seeks to contribute open source peer reviewed education material to assist efforts globally to accelerate education for sustainable development in engineering and the built environment: All material is freely available, open-source and online, under a Creative Commons Attribute license: (http://www.naturaledgeproject.net/ESSP.aspx, see Curriculum & Course Content).

9: Green Chemistry - An Introduction

Educational Aims

The aim of this lesson is to introduce the topic of 'Green Chemistry' and to set the context for the following three lessons. This lesson introduces a number of key Green Chemistry principles that scientists and engineers can use to move towards sustainable development.

Alignment with Existing Curriculum Requirements

The activities and information presented in this lesson aligns to the federal government's national strategy for Education for Sustainability in schools. Furthermore, the federal government has already stated sustainability as a national curriculum cross curriculum priority, where 'Sustainability' is concerned with the ongoing capacity of the Earth to maintain life:[1]

Actions to improve sustainability aim to reduce our ecological footprint while simultaneously supporting a quality of life that is valued—the 'liveability' of our society. Sustainable patterns of living meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is both an individual and a collective endeavour often shared across communities and nations necessitating a balanced but different approach to the ways humans have interacted with each other and with their biophysical environment. Sustainability learning draws on and relates learning across the curriculum. It leads to students developing an overall capacity to contribute to a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations.

These activities can be integrated within a variety of topic areas specified by the Queensland Studies Authority (QSA) Senior School Syllabus for Chemistry, as summarised in the following table:[2]

Key concept S1: All matter is composed of atoms.	
S1.1	Matter is composed of atoms which, in turn, contain protons and neutrons in a nucleus, and electrons outside the nucleus.
S1.2	The number of positively charged protons is equal to the number of negatively charged electrons in a neutral atom, and determines all the chemical properties of an atom.
S1.3	An element is a substance in which all atoms have the same number of protons.
S1.4	Atoms of an element may contain different numbers of neutrons, and are known as isotopes.
S1.5	Every element is assigned a unique chemical symbol.
S1.6	The atomic mass of an atom is arbitrarily defined relative to the mass of the isotope carbon-12.
S1.7	In modern theories of atomic structure, electrons are viewed as occupying orbitals which are grouped in electron shells.
Key concept R1: Specific criteria can be used to classify chemical reactions.	
R1.1	Redox reactions involve a transfer of electrons and a change in oxidation number.
R1.2	Precipitation reactions result in the appearance of a solid from reactants in aqueous solution.
R1.3	Acid-base reactions involve transfer of protons from donors to acceptors.

[1] http://www.australiancurriculum.edu.au

[2] http://www.qsa.qld.edu.au/downloads/senior/snr_chemistry_07_syll.pdf

R1.4	Polymerisation reactions produce large molecules with repeating units.
Key concept R2: Chemical reactions involve energy changes.	
R2.1	All chemical reactions involve energy transformations.
R2.2	The spontaneous directions of chemical reactions are towards lower energy and greater randomness.
Key concept R3: The mole concept and stoichiometry enable the determination of quantities in chemical processes.	
R3.1	The mole, defined arbitrarily using the isotope carbon-12, is the basic quantity in stoichiometric calculations.
R3.2	Every chemical reaction can be represented by a balanced equation, whose coefficients indicate both the number of reacting particles and the reacting quantities in moles.
R3.3	A balanced equation can be used when determining whether reagents are limiting or in excess.
R3.4	The use of molarity for expressing concentration allows easy interconversions between volume of solution and moles of solute. R3.5—The ideal gas equation may be used to relate the volume of a gas at defined temperature and pressure to its quantity in moles.
Key concept R4: Specialised qualitative and quantitative techniques are used to determine the quantity, composition and type of reaction.	
R4.1	Techniques such as volumetric and gravimetric analysis are used to determine amounts of reactants and products.
R4.2	Specialised techniques and instrumentation are used in chemical analysis. R4.3—Qualitative and quantitative testing may be used to determine the composition or type of material.
Key concept R5: Chemical reactions are influenced by the conditions under which they take place and, being reversible, may reach a state of equilibrium.	
R5.1	Chemical reactions occur at different rates and changing the nature of the reactants, temperature, or concentration, or introducing a catalyst, may alter these.
R5.2	Life is maintained by chemical reactions, especially those catalysed by large molecules called enzymes.
R5.3	Chemical reactions may be reversible.
R5.4	Reversible chemical reactions may reach a state of dynamic balance known as equilibrium which, when disturbed, will be re-established.

Relating these concepts to example topic areas, this lesson could be integrated within the following possible chemistry units:

- Introduction to Chemistry;
- Matter and molarity (Atom Economy);
- Chemical Reactions; and
- The mole concept and stoichiometry.

Activity 1 – News Cast: Introducing Green Chemistry

In this activity, students apply their knowledge of the principles of green engineering to create a short film clip or PowerPoint presentation demonstrating why and how they would apply one of the green chemistry or engineering principles in their classroom.

Key Learning Point:

Chemists and chemical engineers have the potential to make a significant contribution to sustainable development by understanding and applying green chemistry principles.

Resources:

- Each group will need access to a recording device, which may be as simple as a mobile phone camera, a digital camera, or a video camera.
- Students may get examples for their project by viewing online examples.
- 'Industry Take Up and Interest' in Brief Background Information, Lesson 9 'Green Chemistry – An Introduction'

Teacher Preparation:

- The teacher and students will need to be familiar with the green chemistry and green engineering principles. These principles and background information are explained in the student materials (Lesson 9).
- For teachers who are not familiar with using video creation for learning and assessment, please see for example 'School Tube' (www.schooltube.com)

Activity Description:

1. Teachers may wish to provide students with a stimulus discussion on the principles of green chemistry prior to the activity.
2. Create groups of 2-3 students in the class.
3. Allocate each group to one of the 12 principles of green chemistry
4. Explain to the student groups that they will be creating a short you-tube clip (or other modern media presentation) to create a 'news cast' about their principle of green chemistry.

   Example conditions that might also be stipulated for this activity include the following:
   - A 1-minute creative video presentation
   - The presentation must include the appearance of all students
   - The presentation must cover one (or more) of the following:
     - the principle, its meaning and development
     - one application of the principle on a large scale (eg industry)
     - one application of the principle on a smaller scale (eg classroom or home)
     - the benefits of these kinds of applications (eg materials reductions, less toxic waste)
5. After the students have submitted their presentations, the teacher may review and then show-case examples for the rest of the class. Alternatively all of the presentations might be viewed by the rest of the class, then discussed with regard to insights into green chemistry opportunities.

Activity 2 – Experiment: Biosynthesis of Ethanol from Molasses

In this activity, the teacher (in a demonstration) or students (in groups) use chemistry laboratory skills to apply three green principles (the use of renewable resources, catalysis, and design for degradation) in a biosynthesis reaction. This experiment has been adapted from a 'Greener Education Materials for Chemists' publication.[3] (Note that part of this experiment needs to be prepared a week in advance!)

Key Learning Point:

Green chemistry principles can be applied to all kinds of chemical reaction processes, to lessen the environmental impact of reactions.

Resources:

- For an excellent support resource to this activity, visit http://greenchem.uoregon.edu/Pages/Overview.php?ID=86
- Students should be confident in the 12 principles of green chemistry and Green Engineering: 'Key Learning Point 8' in Lesson 9 'Green Chemistry – An Introduction'
- Materials (per demonstration): 70mL molasses, 70mL water, 0.5g yeast, Ca(OH)2 (to make limewater)
- Equipment (per demonstration): 250mL Erlenmeyer flask, One-hole rubber stopper, containing bent glass tube, Test tube, Simple Distillation Equipment, Fractional Distillation Equipment

Teacher Preparation:

Whoever is undertaking this experiment (i.e. as a demonstration or in student groups) will need to have sound chemistry knowledge and skills in distillation. The principles applied in this lab (the use of renewable resources, catalysis, and design for degradation) are described in detail in the student handout.

Activity Description:

The first part of the experiment (the fermentation) must be performed a week prior to the distillation (boiling).

Procedure 1: Week 1

1. Mix 70 ml of molasses with 70 ml of water in a 250 ml Erlenmeyer flask.
2. Add about 0.5 g of yeast to the flask and stir gently until well mixed.
3. Stopper the flask with a one-hole rubber stopper containing a bent glass tube.
4. Attach a short rubber hose to the bent glass tube and insert a short straight section of glass rube into the other end of the rubber tube.
5. Dip the straight glass tube into a test tube two-thirds full of limewater, $Ca(OH)_2$ solution. The test tube of limewater serves as a one-way vapor lock, keeping air from entering the flask

[3] Greener Education Materials for Chemists, http://greenchem.uoregon.edu/Pages/Overview.php?ID=86

while allowing the carbon dioxide to escape. If air were to enter the flask during the reaction, the ethanol produced would be further oxidized to acetic acid (vinegar).

6. Store this apparatus in a lab cabinet (in darkness) for one week while the fermentation reaction occurs.

Procedure 2: Week 2

1. Prepare a simple distillation, decanting the ethanol solution into a 250 ml round bottom (Florance) flask.
2. The simple distillation can be done fairly rapidly (one drop per second) and the alcohol fraction should be collected until just below the boiling point of water, 100ºC.
3. Prepare a fractional distillation, placing the mixed alcohol product from the simple distillation in another round bottom flask. Distill the ethanol slowly; record the temperature range for each fraction collected - stop collecting at 90ºC.
4. Fractons are identified by a rapid change in temperature and a concurrent increase/decrease in distillate production.
5. Determine the density of each fraction by massing a 10 ml sample collected with a volumetric pipette. If the collected fraction is less than 10 ml, use the available pipette that is closest in volume to the fraction.
6. Use the table below to determine the alcohol content in each fraction.

Determining the Aqueous Alcohol (EtOH) Content:							
Density g/ml	% EtOH by wt.	% EtOH by vol.	g EtOH per 100 ml	Density g/ml	% EtOH by wt.	% EtOH by vol.	g EtOH per 100 ml
0.989	5	6.27	4.95	0.856	75	81.30	64.17
0.982	10	12.44	9.82	0.843	80	85.49	67.48
0.975	15	18.54	14.63	0.831	85	89.48	70.63
0.969	20	24.54	19.37	0.828	86	90.25	71.23
0.962	25	30.45	24.04	0.826	87	91.02	71.84
0.954	30	36.25	28.61	0.823	88	91.77	72.43
0.945	35	41.90	33.07	0.821	89	92.53	73.03
0.935	40	47.40	37.41	0.818	90	93.27	73.62
0.925	45	52.72	41.61	0.815	91	93.99	74.19
0.914	50	57.89	45.69	0.813	92	94/72	74.76
0.903	55	62.89	49.64	0.810	93	95.44	75.32
0.891	60	67.74	53.47	0.807	94	96.11	75.86
0.880	65	72.43	57.17	0.804	95	96.79	76.40
0.868	70	76.95	60.74	0.789	100	100.00	78.90

7. Record your volume of "pure" ethanol collected and add your ethanol to the collection container.
8. Discuss with students the benefits of conducting chemical processes without the production of toxic by-products or the use of significant energy.

Student Handout – Biosynthesis of Ethanol from Molasses

Introduction[4]

Alcohols are often called green solvents because they have few human health and environmental risks, particularly when compared to solvents like methylene chloride or benzene. Ethanol may be a benign solvent, but what is its source? If the source is petroleum, all we have done is moved the hazard to another part of the process. In fact, until recently ethanol has been synthesized primarily from oil. A growing industrial source of ethanol is blackstrap molasses, a waste product of sugar production.

This experiment demonstrates three key green principles: the use of renewable resources, catalysis, and design for degradation.

Cheap petroleum led to its use for the synthesis of most organic compounds. Petroleum is renewable only on a geological timescale and is dwindling rapidly. In comparison, blackstrap molasses comes from a quickly renewable natural product. Sugar beets are harvested annually and sugar cane several times a year. While these crops are renewable, the practices used in growing them can vary from environmentally responsible to environmentally destructive. Even when well intentioned, our use of chemical products can still result in serious environmental harm. Sometimes the petroleum product may actually do the least amount of harm when considering the big picture. Analysing the choice of resource to used can be a challenging task!

Catalysts are important for reducing the energy consumption and the waste production in a chemical reaction. The reaction in this experiment takes advantage of two enzymes found in yeast. Enzymes are remarkable natural catalysts that are highly chemically selective and significantly reduce the activation energy of a reaction.

This reaction is an excellent example of design for degradation. Only a small amount of yeast is necessary to initiate the reaction and the yeast reproduces while the reaction is occurring. Once the reaction has reached completion, the yeast dies and the ethanol and all by-products are easily, rapidly, and harmlessly degraded in the environment.

Experimental Theory/Design

Fermentation is one of the oldest chemical arts. The fermentation of molasses is the process used to make rum (although the rum produced from blackstrap molasses is not fit for human consumption). In our experiment, the interest is the synthesis and purification of ethanol by a green reaction pathway.

Molasses is a mixture of monosaccharides and disaccharides and other miscellaneous flavoring agents naturally produced in the sugar cane or sugar beet. Approximately 50% of the molasses mass is sugar. Yeast has two enzymes that convert the saccharides to ethanol. Invertase converts dissacharides (sucrose) to monosaccharides (glucose) by a catalytic hydrolysis (addition of water) reaction. Glucose is then converted to ethanol and carbon dioxide by the enzyme zymase.

One mole of sucrose will produce four moles of ethanol and four moles of carbon dioxide. When the alcohol level becomes high enough, the yeast will die of alcohol poisoning. The reaction is

[4] This theory has been adapted from an experiment designed by Greener Education Materials for Chemists http://greenchem.uoregon.edu/Pages/Overview.php?ID=86.

vapour locked with limewater so that the reaction environment remains oxygen free, keeping the ethanol from further oxidizing.

Boiling occurs when the vapour pressure of a liquid is equal to atmospheric pressure. Distillations take advantage of this behaviour to separate liquid mixtures. Some mixtures of liquids do not behave in this ideal way and instead form azeotropes, solutions that boil at a temperature different from any specific liquid in the solution. Ethanol and water form a binary azetrope, making pure ethanol very difficult to obtain by distillation. At one atmosphere of pressure, pure water boils at 100^{o}C and pure ethanol boils at 78^{o}C. At one atmosphere of pressure, the ethanol-water azeotrope boils at 78.5^{o}C, producing a vapour that is 95.6% ethanol and 4.4% water.

Pre-Laboratory Questions

1. During the fermentation reaction, it is important to prevent air from entering the reaction chamber. Why?
2. Explain the advantage of fractional distillation over simple distillation
3. What is an azeotrope and why does it limit our ethanol purity eve when we are doing a fractional distillation?
4. Complete the following table:

Liquids	**Boiling Point (ºC)**	**Density (g/ml)**
Ethanol		
Water		

Laboratory Experiment

Materials (per experiment): 70mL molasses; 70mL water; 0.5g yeast; Ca(OH)2 (to make limewater).

Equipment (per experiment): 250mL Erlenmeyer flask; One-hole rubber stopper, containing bent glass tube; Test tube; Simple Distillation Equipment; Fractional Distillation Equipment..

Procedure 1 (Week 1)

1. Mix 70 ml of molasses with 70 ml of water in a 250 ml Erlenmeyer flask.
2. Add about 0.5 g of yeast to the flask and stir gently until well mixed.
3. Stopper the flask with a one-hole rubber stopper containing a bent glass tube.
4. Attach a short rubber hose to the bent glass tube and insert a short straight section of glass rube into the other end of the rubber tube.
5. Dip the straight glass tube into a test tube two-thirds full of limewater, Ca(OH)2 solution. The test tube of limewater serves as a one-way vapor lock, keeping air from entering the flask while allowing the carbon dioxide to escape. If air were to enter the flask during the reaction, the ethanol produced would be further oxidized to acetic acid (vinegar).
6. Store this apparatus in a lab cabinet (in darkness) for one week while the fermentation reaction occurs.

Procedure 2 (Week 2)

1. Prepare a simple distillation, decanting the ethanol solution into a 250 ml round bottom (Florance) flask.
2. The simple distillation can be done fairly rapidly (one drop per second) and the alcohol fraction should be collected until just below the boiling point of water, 100ºC.
3. Prepare a fractional distillation, placing the mixed alcohol product from the simple distillation in another round bottom flask. Distill the ethanol slowly; record the temperature range for each fraction collected - stop collecting at 90ºC.
4. Fractons are identified by a rapid change in temperature and a concurrent increase/decrease in distillate production.
5. Determine the density of each fraction by massing a 10 ml sample collected with a volumetric pipette. If the collected fraction is less than 10 ml, use the available pipette that is closest in volume to the fraction.
6. Use the table below to determine the alcohol content in each fraction. Record your volume of "pure" ethanol collected and add your ethanol to the collection container

Determining the Aqueous Alcohol (EtOH) Content:							
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0.945	35	41.90	33.07	0.821	89	92.53	73.03
0.935	40	47.40	37.41	0.818	90	93.27	73.62
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0.880	65	72.43	57.17	0.804	95	96.79	76.40
0.868	70	76.95	60.74	0.789	100	100.00	78.90

Summary Activities and Homework Ideas

1. Essay

This essay question provides students with an opportunity to consider the historic evolution of green chemistry principles. In answering the questions posed below, students will be tested on their appreciation of this evolution, and their ability to write a well-structured essay within the word limit set by the teacher.

Essay Statement:

Rachel Carson's famous publication 'Silent Spring'[5] demonstrated significant and disturbing links between 'everyday' chemicals that society took for granted, and serious environmental and human health concerns. However, when released in 1962, it encountered serious opposition from chemical companies and the media and government.

Write an essay that discusses some of the major contributions that Rachel Carson's text made to the world, from agricultural practices through to the manufacture of many of the goods and services that we rely on today.

Sample Answer:

Students may discuss key contributions including:

– A global awareness of the concept of bioaccumulation, where chemicals such as DDT accumulate within organisms.

– An increased appreciation of the adverse affects that widespread chemicals were having on important food chains.

– Catalysing research on human health impacts of widespread use of bio-accumulating chemicals.

– A demonstration of the difference that one person can make, in causing sustainable development.

[5] Carson, R. (1962) *Silent Spring*, Houghton Mifflin, Boston.

2. Mind Map

This mind map assessment item encourages students to recall the 12 principles of green chemistry, and consider how these principles might be applied in the classroom. In creating the mind map, students will be demonstrating their appreciation of the 12 elements, problem-solving skills in considering classroom applications, and their appreciation of the interconnectedness of these issues. This exercise could be undertaken individually or in a group.

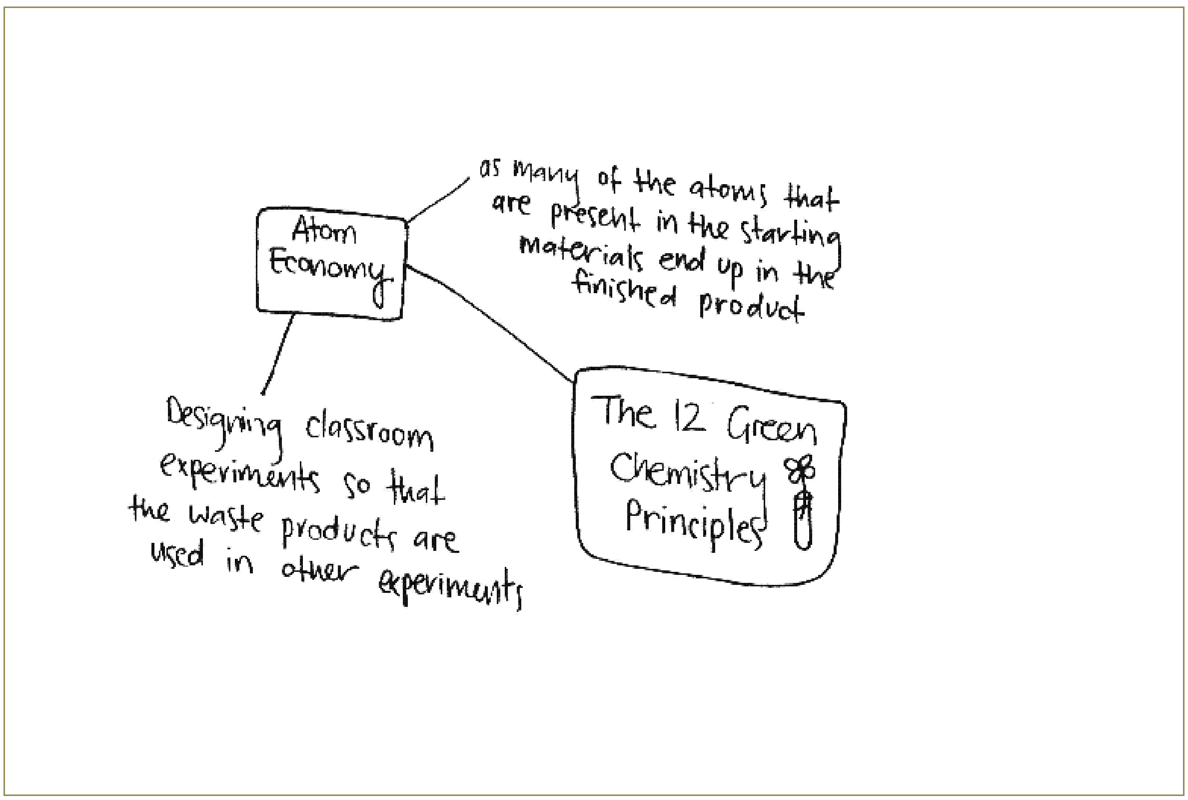
<u>Mind Map Briefing:</u>

Summarize the 12 Green Chemistry Principles in the form of a mind map. For each principle (which may be in the form of a single branch), provide an example of how chemistry lessons at school could be reconsidered to 'walk the talk' of each green chemistry principle.

Where you can see multiple benefits of certain classroom practices for more than one principle, show this by adding connections between the various nodes.

<u>Sample Answer (for one node):</u>

Key aspects of a mind map are noted here:



3. Short Answer Questions

<u>Question 1:</u> Describe why is it so important to think about the role of catalysts in green chemistry.

<u>Sample Answer:</u>

It is important to think about catalysts in green chemistry because chemical processes underpin most of our modern lifestyles, and these are often driven by catalysts that use a lot of energy, require a lot of resources, and which can create significant amounts of waste if they are not re-useable.

<u>Question 2:</u> List two international conventions that legally require nations to safely manage and use chemicals.

<u>Sample Answer:</u>

Any of the following:

- The Montreal Protocol on Substances that Deplete the Ozone Layer (1987)
- The Basel Convention on Trans-boundary Movements of Hazardous Wastes (1992)
- The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (2004)
- The Stockholm Convention on Persistent Organic Pollutants (2004)

<u>Question 3:</u> Briefly describe the green chemistry principle of the 'Atom Economy' and explain with examples how this concept could be used to reduce waste in chemistry classrooms.

<u>Sample Answer:</u>

The 'Atom Economy' refers to the principle that chemical reactions should be designed so as many of the atoms as possible that are present in the starting materials, end up in the product rather than in the waste stream.

This principle could be applied in the classroom, where:

- Students could make sure that the right quantities are used in experiments, rather than wasting chemical ingredients.
- Teachers could purchase catalysts for experiments that are reusable if such an option exists.
- Chemical experiments that result in large amounts of waste products could be undertaken as simulations (i.e. online) or as a demonstration by the teacher rather than by many groups in the classroom

10: Green Chemistry - Dealing with Greenhouse Gases

Educational Aims:

The aim of this lesson is to provide an overview of climate change and 'peak oil', and introduce ways of reducing our greenhouse gas emissions and reliance on fossil fuels like oil as an energy source. In particular, we will consider using energy more efficiently in everyday places like our homes, and using different forms of fuel and technology to power vehicles.

Alignment with National Curriculum

The activities and information presented in this lesson aligns to the federal government's national strategy for Education for Sustainability in schools. Furthermore, the federal government has already stated sustainability as a national curriculum cross curriculum priority, where 'Sustainability' is concerned with the ongoing capacity of the Earth to maintain life:[6]

Actions to improve sustainability aim to reduce our ecological footprint while simultaneously supporting a quality of life that is valued—the 'liveability' of our society. Sustainable patterns of living meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is both an individual and a collective endeavour often shared across communities and nations necessitating a balanced but different approach to the ways humans have interacted with each other and with their biophysical environment. Sustainability learning draws on and relates learning across the curriculum. It leads to students developing an overall capacity to contribute to a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations.

These activities can be integrated within a variety of topic areas specified by the Queensland Studies Authority (QSA) Senior School Syllabus for Chemistry, as summarised in the following table:[7]

Key concept R1: Specific criteria can be used to classify chemical reactions.	
R1.1	Redox reactions involve a transfer of electrons and a change in oxidation number.
R1.2	Precipitation reactions result in the appearance of a solid from reactants in aqueous solution.
R1.3	Acid-base reactions involve transfer of protons from donors to acceptors.
R1.4	Polymerisation reactions produce large molecules with repeating units.
Key concept R2: Chemical reactions involve energy changes.	
R2.1	All chemical reactions involve energy transformations.
R2.2	The spontaneous directions of chemical reactions are towards lower energy and greater randomness.
Key concept R3: The mole concept and stoichiometry enable the determination of quantities in chemical processes.	
R3.1	The mole, defined arbitrarily using the isotope carbon-12, is the basic quantity in stoichiometric calculations.

[6] http://www.australiancurriculum.edu.au

[7] http://www.qsa.qld.edu.au/downloads/senior/snr_chemistry_07_syll.pdf

R3.2	Every chemical reaction can be represented by a balanced equation, whose coefficients indicate both the number of reacting particles and the reacting quantities in moles.
R3.3	A balanced equation can be used when determining whether reagents are limiting or in excess.
R3.4	The use of molarity for expressing concentration allows easy interconversions between volume of solution and moles of solute. R3.5—The ideal gas equation may be used to relate the volume of a gas at defined temperature and pressure to its quantity in moles.
Key concept R4: Specialised qualitative and quantitative techniques are used to determine the quantity, composition and type of reaction.	
R4.1	Techniques such as volumetric and gravimetric analysis are used to determine amounts of reactants and products.
R4.2	Specialised techniques and instrumentation are used in chemical analysis. R4.3—Qualitative and quantitative testing may be used to determine the composition or type of material.
Key concept R5: Chemical reactions are influenced by the conditions under which they take place and, being reversible, may reach a state of equilibrium.	
R5.1	Chemical reactions occur at different rates and changing the nature of the reactants, temperature, or concentration, or introducing a catalyst, may alter these.
R5.2	Life is maintained by chemical reactions, especially those catalysed by large molecules called enzymes.
R5.3	Chemical reactions may be reversible.
R5.4	Reversible chemical reactions may reach a state of dynamic balance known as equilibrium which, when disturbed, will be re-established.

Relating these concepts to example topic areas, this lesson could be integrated within the following possible chemistry units:

- Introduction to Chemistry;
- Matter and molarity (Atom Economy);
- Chemical Reactions; and
- The mole concept and stoichiometry.

Activity 1 – Discussion: A Family of Greenhouse Gases?

In this activity, students are encouraged to discuss the science around greenhouse gases and their various contributions to atmospheric heating.

Key Learning Point:

It is an important skill to be able to discuss the science behind climate change, with regard to the role of greenhouse gases in affecting atmospheric systems.

Resources:

– ‘Overview of the range of GHG Emissions’ in Brief Background Information, Lesson 10 ‘Dealing with Greenhouse Gases’

– Depending on the time available to cover this topic, we recommend viewing *An Inconvenient Truth.* Hosted by ex-Vice President of the United States, Al Gore, this documentary provides a well considered introduction to climate change. The documentary explains in easy-to-understand terms the latest scientific evidence of global warming and its potential impacts on our civilisation. To learn more about the documentary or to preview the trailer, visit www.climatecrisis.net.

Teacher Preparation:

– Depending on the level of understanding about this topic, teachers may want to do some preparatory research, following up on the references provided in ‘Brief Background Information’ in the student materials.

– Students should be given time to prepare for the activity, and class time should be allocated for the actual discussion.

Activity Description:

1. Divide students into five groups. Provide each group with one of the gases listed in Table 10.1 of the student materials, not including carbon dioxide.
2. Ask each group to discuss:
   a) The natural, and human-derived sources of this gas;
   b) The atmospheric lifetime and global warming potential, compared with CO_2.
   c) The percentage of American emissions
   d) An example of where this gas emission is being addressed (see background reading)
3. After allowing discussion time, ask the groups to – in turn – present their considerations to the rest of the class.
4. After each presentation, or after all of the presentations, bring the various topics together by reconsidering the Key Learning Point above.
5. Highlight the complexity of atmospheric systems, the need to be cautious about any gaseous emissions, and the many opportunities for chemists to reduce the emission of very powerful greenhouse gases to the atmosphere.

Activity 2 – Creating Low Carbon Glue

This activity introduces students to the concept of biomimicry as an alternative to the 'beat, heat and treat' approach to materials manufacture commonly employed by industry. Students complete a biomimicry matching game, adapted from the Beyond Benign Project to discover some biomimicry concepts.

Key Learning Point:

Biomimicry is an alternative way of manufacturing materials that can reduce greenhouse gas emissions and reduce energy use and the production of toxins.

Resources:

– 'Background Information' provided in Lesson 10 'Green Chemistry – Dealing with Greenhouse Gases'

– Student Handout (1 per student, provided below)

Teacher Preparation:

– Students should understand the basic idea of biomimicry. They should also be aware of the currents materials production methods, which mainly are extremely energy intensive and produce harmful by-products.

Activity Description:

– Use the background information in Lesson 10 (starting with the sections 'Creating Low Carbon Manufactured Materials' to introduce the importance of biomimicry in reduce greenhouse emissions.

– Distribute copies of the handout provided.

– Assist students with completing the table.

Answers:

Glue Innovation	Answers
Gorilla Glue	Barnacles
Epoxy	The Velvet Worm
Elmer's Glue	Land Snail Mucus
Rubber Cement	Setae of Leaf Beetles
Superglue	Marine Worm Sand Tubes
Liquid nails	Body Lice
Silicone Adhesives	Australian Mistletoe Berries

Student Handout – Creating Low Carbon Glue

This activity has been modified from an activity developed by Beyond Benign[8] Biomimicry Matching Activity, considering how we can imagine new possibilities for nature-inspired materials that do not rely on fossil fuels.

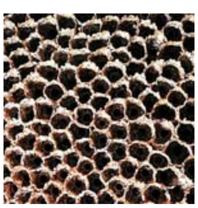
The following glues have been inspired by a variety of natural organisms over millions of years. Can you match the inspiration with the glue?

Using the information about various organisms provided on the following pages, match the organism to the low carbon glue solution in the table:

Glue Innovation	Properties of the Glue	Nature's Inspiration	Explanation
Gorilla Glue	– Expands as it cures, filling gaps – Is waterproof – Takes a few hours to dry so you can reposition things if you need to		
Epoxy	– Comes in two parts, resin and catalyst – Is sold in different drying times – Once cured can be drilled, sanded or painted		
Elmer's Glue	– Non-toxic – Can be cleaned up with water – Good for wood and paper gluing		
Rubber Cement	– Easy damage free removal – Favored in arts and crafts projects – Will not shrink or swell paper fibers		
Superglue	– Fast Drying – Creates an almost invisible bond – Can stick human skin together – Dries out easily if not stored properly		
Liquid nails	– Withstands temperatures from -60° to 300°F, indoor & outdoor – Acid free / Low odour – Flexible & shock absorbing – Works on wet surfaces – Can fill gaps up to 1/4" (6mm) – Does not adhere to polyethylene or polypropylene		
Silicone Adhesives	– Reacts with moisture in the air – Used around water as in gasket sealants and caulking – Used in electronics		

[8] [8] beyond bengin, 2007-2010 http://www.beyondbenign.org/index.html, acessed 23 December 2010

Match the examples from nature in the following table, with the design inspiration on the previous page:

	**The Velvet Worm:** They shoot at prey with an adhesive liquid ejected by two nozzles next to the mouth. The nozzles move from side to side as they fire, causing the stream of glue to crisscross in a lasso-like motion. The glue travels nearly 3 feet (1 m) and dries in seconds, ensnaring the prey in multiple strands. Fast drying glue for housing, medical emergency or everyday use.
	**Barnacles**: have the capability for tenacious underwater adhesion to the surfaces by a proteinaceous cement substance. Three major proteins had been identified in a previous study and this study adds a fourth. It is suggested that each cement protein fulfills a distinct and specific role in underwater adhesion, and that firm barnacle adhesion is achieved cooperatively by these cement proteins. Understanding the specific role of each cement protein helps provide a better understanding of barnacle settlement and of synthetic polymer mimics, including underwater adhesives.
	**Setae of Leaf Beetles:** The thousands of setae (pads on the bottom of the feet) of leaf beetles enhance their ability to adhere to various, sometimes irregular surfaces thanks to the resulting multiple contact points. These feet are designed to temporarily stick but also peel off at will without damaging the surface underneath. There is also no wetting process so there is no residue or liquid involved.
	**Australian Mistletoe Berries:** For some reason, the mistletoe bird digests mistletoe berries with remarkable speed, in less than half an hour. When it emerges the seed still has considerable residual stickiness and so remains fastened to the bird's rear. The defecating bird then turns so that its body is aligned along the twig and carefully wipes its bottom on the bark beneath! This fixes the seed to the tree but threads of the seed's glue still remain attached to the bird's rear and it has to make three separate sideways jumps along the twig before the connection is finally broken. Scientists believe it could be used to seal pipes or cables, and for use in gluing pre-fabricated building products or furniture, bonding applications for electronics.
	**Land Snail Mucus:** The trails of land snails are non-toxic and water soluble. There are specific proteins in the adhesive mucus in the slug Arion subfuscus and the land snail Helix aspersa. Such a mechanism may be common among invertebrates, and it may guide biomimetic approaches in the development of glues and gels. Glues and gels without harsh chemicals
	**Marine Worm Sand Tubes:** The colonies built by Sabellaria worms on seashore rocks look like very untidy honeycombs. The worms construct tubes of sand grains stuck together with mucus. Sabellaria worms are marine worms about 30 mm long which build tubes by cementing together particles of sand and rock. The cement they create is extremely strong and it is imagined that there might be an application in the construction industry. Could be used in Biolubricants and construction glue.
	**Body Lice:** Eggs of body lice, commonly called 'nits', are attached to the body hairs of the host by a cement-like substance. They form a cement-like structure that resists moisture and high temperatures.

Summary Activities and Homework Ideas

1. Essay

This essay question highlights the role of chemistry in considering solar energy solutions, and requires students to identify an innovative ways of delivering energy to society. In answering the questions posed below, students will be tested on their ability to describe green chemistry innovations, and their ability to write a well-structured essay within a word limit set by the teacher.

Essay Statement:

Chemistry and Solar Opportunities: Reducing society's dependence on fossil fuels will result in major reductions to greenhouse gas emissions. A huge possibility for achieving this is improving the amount of energy we use from solar radiation. However, a major barrier is the current efficiency of solar cells.

Using your knowledge of biomimicry, write about some examples of current research into the way plant process sunlight. What is this process called? What are some current projects that attempt to mimic this process to develop more efficient solar cells?

Sample Answer:

Key points that students could include in their essay:

- The process that plants use to convert solar radiation into useful energy is called photosynthesis.
- There has been significant research into mimicking this very complex process of making energy from sunlight.
- Innovations include a new technology called 'Dye Solar Cell' of 'Dyesol' that mimics the photosynthesis process using dye and nanotechnology.
- … (refer to Lesson 10 in the student materials).
- This technology is just one of the many kinds of developments that are helping to make solar cells more efficient.

2. Mind Map

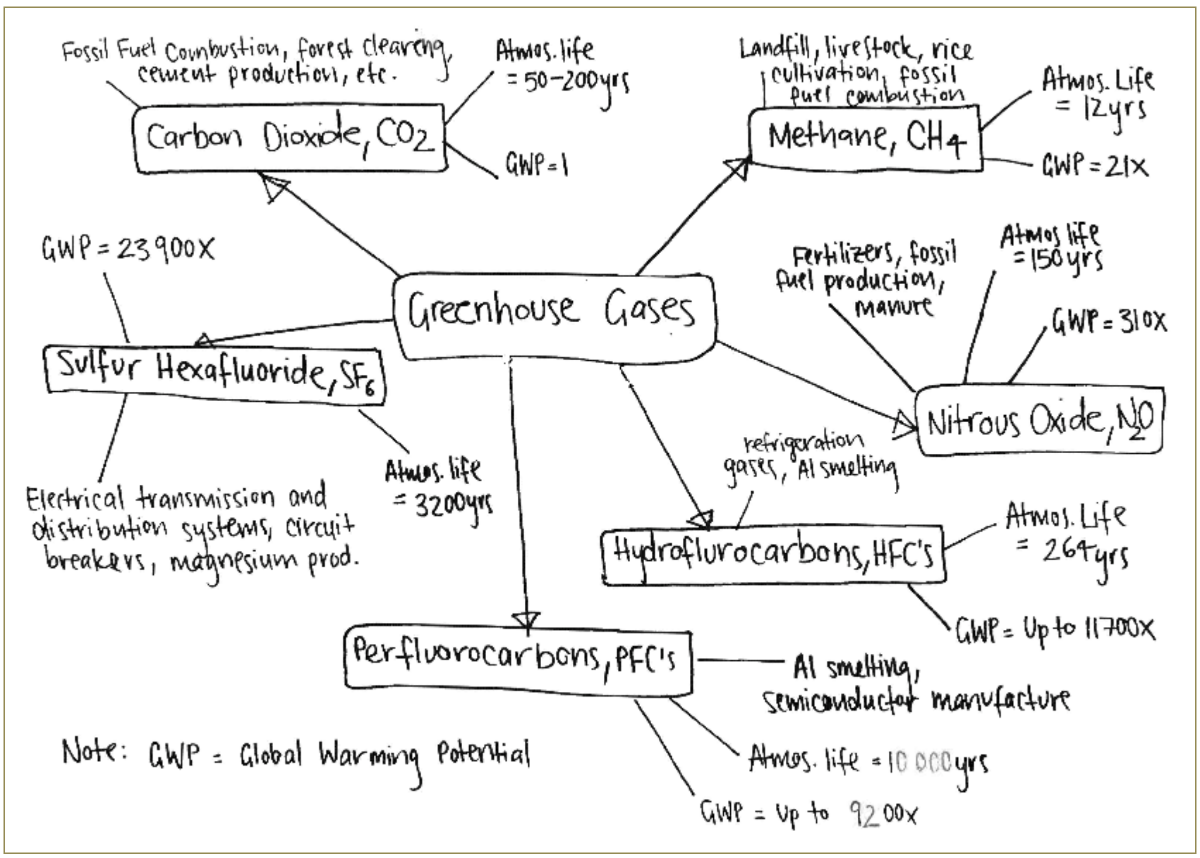
This mind map assessment item highlights the variety of greenhouse gases that contribute to atmospheric warming. In creating the mind map, students will be demonstrating their understanding of the variety of natural and human-derived contributions to greenhouse gas emissions, and their appreciation of the interconnectedness of these issues. This exercise could be undertaken individually or in a group.

<u>Mind Map Briefing:</u>

Create a mind map of the six major greenhouse gas emissions. In your mind map, include the name, common sources, atmospheric lifetime, global warming potential and the percentage of worldwide emissions created by each GHG

<u>Sample Answer:</u>

Key aspects of a mind map are noted here:



3. Short Answer Questions

<u>Question 1:</u> Briefly explain the concept of biomimicry and why it can be used for innovations in reducing greenhouse gas emissions.

<u>Sample Answer:</u>

Biomimicry is the term given to innovations that are inspired by nature. If we think about the process of photosynthesis that nature uses chemistry to create energy, there is significant opportunity to develop new chemical processes that can deliver ‘clean’ energy, rather than relying on just burning fossil fuels.

We can also look to nature to find examples of where chemical processes are using carbon dioxide for other tasks. Such examples could inspire us to design chemical processes for things that everybody needs, which consume (or ‘sequester’) carbon dioxide and other greenhouse gases from the atmosphere, helping to reduce the excess amounts that we currently have.

<u>Question 2:</u> What is a ‘low carbon’ manufactured material? Give an example.

<u>Sample Answer:</u>

A low carbon manufactured material is one that has a reduced amount of greenhouse gas emissions in its production. For example, a locally grown and manufactured bamboo flooring may be a ‘low carbon’ floor compared with a concrete floor, given the amount of greenhouse gas emissions involved in creating cement, and transporting the input materials for concrete production.

<u>Question 3:</u> Briefly describe two ways that can chemists and chemical engineers help to reduce and capture the GHG entering the atmosphere.

<u>Sample Answer:</u>

Students could provide any of the examples from key learning point 6 in the student materials for Lesson 10.

11: Green Chemistry - Reducing Toxicity

Educational Aims

The aim of this lesson is to provide an overview of the challenges that Australia and the rest of the world are facing with maintaining our most precious resource: water. This lesson will introduce various ways we can use water more efficiently, clean water more effectively, and help major users of water, like agriculture, reduce their reliance on drinking-quality (i.e. potable) water.

Alignment with Existing Curriculum Requirements

The activities and information presented in this lesson aligns to the federal government's national strategy for Education for Sustainability in schools. Furthermore, the federal government has already stated sustainability as a national curriculum cross curriculum priority, where 'Sustainability' is concerned with the ongoing capacity of the Earth to maintain life:[9]

Actions to improve sustainability aim to reduce our ecological footprint while simultaneously supporting a quality of life that is valued—the 'liveability' of our society. Sustainable patterns of living meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is both an individual and a collective endeavour often shared across communities and nations necessitating a balanced but different approach to the ways humans have interacted with each other and with their biophysical environment. Sustainability learning draws on and relates learning across the curriculum. It leads to students developing an overall capacity to contribute to a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations.

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R1.4	Polymerisation reactions produce large molecules with repeating units.
Key concept R2: Chemical reactions involve energy changes.	
R2.1	All chemical reactions involve energy transformations.
R2.2	The spontaneous directions of chemical reactions are towards lower energy and greater randomness.
Key concept R3: The mole concept and stoichiometry enable the determination of quantities in chemical processes.	
R3.1	The mole, defined arbitrarily using the isotope carbon-12, is the basic quantity in stoichiometric

[9] http://www.australiancurriculum.edu.au

[10] http://www.qsa.qld.edu.au/downloads/senior/snr_chemistry_07_syll.pdf

	calculations.
R3.2	Every chemical reaction can be represented by a balanced equation, whose coefficients indicate both the number of reacting particles and the reacting quantities in moles.
R3.3	A balanced equation can be used when determining whether reagents are limiting or in excess.
R3.4	The use of molarity for expressing concentration allows easy interconversions between volume of solution and moles of solute. R3.5—The ideal gas equation may be used to relate the volume of a gas at defined temperature and pressure to its quantity in moles.
Key concept R4: Specialised qualitative and quantitative techniques are used to determine the quantity, composition and type of reaction.	
R4.1	Techniques such as volumetric and gravimetric analysis are used to determine amounts of reactants and products.
R4.2	Specialised techniques and instrumentation are used in chemical analysis. R4.3—Qualitative and quantitative testing may be used to determine the composition or type of material.
Key concept R5: Chemical reactions are influenced by the conditions under which they take place and, being reversible, may reach a state of equilibrium.	
R5.1	Chemical reactions occur at different rates and changing the nature of the reactants, temperature, or concentration, or introducing a catalyst, may alter these.
R5.2	Life is maintained by chemical reactions, especially those catalysed by large molecules called enzymes.
R5.3	Chemical reactions may be reversible.
R5.4	Reversible chemical reactions may reach a state of dynamic balance known as equilibrium which, when disturbed, will be re-established.

Relating these concepts to example topic areas, this lesson could be integrated within the following possible chemistry units:

- Toxicology;
- Moles and Molarity;
- Green Chemistry; and
- Industry Applications of Chemistry.

Activity 1 – Discussion: Chemistry by Design

In this activity students will consider areas where some of the 12 principles of green chemistry are already occurring.

Key Learning Point:

Around the world there are some industries where the 12 principles of green chemistry are already occurring.

Resources:

- ‘Case Study 1: McDonough-Braungart Design Chemistry’ in Lesson 11: ‘Green Chemistry: Reducing Toxicity’
- Students will need to have existing knowledge of the 12 principles of green chemistry (i.e. from Lesson 9). They will build on this knowledge in considering an industry case study.

Teacher Preparation:

- Study ‘Case Study 1: McDonough-Braungart Design Chemistry’ in Lesson 11.
- Prepare to discuss the examples discussed in the case study, particularly ‘Design Tex’.

Activity Description:

1. Ask students to read the case study presented in the student handout (taken from ‘Case Study 1: McDonough-Braungart Design Chemistry’ in Lesson 11).
2. Individually or as a class, identify examples of the 12 principles of green chemistry.
3. At the conclusion of the discussion, highlight for students the opportunity to use this type of thinking to transform the chemical industry into a more environmentally aware industry.

Student Handout: Chemistry by Design

Case Study: MacDonough-Braungart Design Chemistry

The McDonough-Braungart Design Chemistry Group (MBDC) are working with many of the US Fortune 500 companies to implement green chemistry, including Nike, BASF, Volvo, and the City of Chicago. Bill McDonough and Michael Brangart argue that it is time for effective designs that are in harmony with nature and based in green chemistry type principles. McDonough and Braungart call their approach 'Cradle to Cradle', as Bill McDonough explains:

Cradle-to-cradle design (which aligns with the principles of green chemistry and green engineering) offers hope for an entirely different world. Cradle-to-cradle design begins with the proposition that the effective, regenerative cycles of nature – the cyclical flows of energy, water and nutrients that support life – provide an unmatched model for wholly positive human designs.

In the natural world, one organism's 'waste' cycles through an ecosystem to provide nourishment for other living things; its productivity is beneficial and regenerative – waste equals food. Just so, cradle-to-cradle products are designed to circulate in closed-loop cycles that virtually eliminate waste and provide 'nutrients' for nature and industry. The cradle-to-cradle framework developed by my colleague Michael Braungart and myself recognizes two metabolisms within which materials flow as healthy nutrients.

First, nature's nutrient cycles constitute the biological metabolism. Materials designed to flow optimally in the biological metabolism are biological nutrients. Products conceived as these nutrients, such as biodegradeable fabrics, are designed to be used and safely returned to the environment to nourish living systems. Second, the technical metabolism, designed to mirror earth's cradle-to-cradle cycles, is a closed-loop system in which valuable, high-tech synthetics and mineral resources – technical nutrients – circulate in perpetual cycles of production, recovery and remanufacture. Ideally, all the human artefacts that make up the technical metabolism, from buildings to manufacturing systems, are powered by renewable energy.

Working within this framework we can, by design, enhance humanity's positive impact on the world. Rather than limiting growth or reducing emissions or using brute force to overcome the rules of the natural world, we can create economies worldwide that purify air, land and water; that rely on current solar income and generate no waste; that support energy-effectiveness, healthy productivity and social well-being. In short, sound, regenerative economies that enhance all life.

McDonough illustrates their cradle to cradle methodology with the following example:

In 1993, we helped to conceive and create a compostable upholstery fabric, a biological nutrient. We were initially asked by Design Tex to create an aesthetically unique fabric that was also ecologically intelligent, although the client did not quite know at that point what this would (tangibly) mean. The challenge helped to clarify, both for us and for the company we were working with, the difference between superficial responses such as recycling and reduction and the more significant changes required by the Next Industrial Revolution.

For example, when the company first sought to meet our desire for an environmentally safe fabric, it presented what it thought was a wholesome option: cotton, which is natural, combined with PET (Polyethylene Terephthalate) fibres from recycled beverage bottles. Since the proposed hybrid could be described with two important ecobuzzwords, 'natural' and 'recycled,' it appeared to be environmentally ideal. The materials were readily available, market-tested, *durable, and cheap. But when the project team looked carefully at what the manifestations of such a hybrid might be in the long run, we discovered some disturbing facts. When a person sits in an office chair and shifts around, the fabric beneath him or her abrades; tiny particles of it are inhaled or swallowed by the user and other people nearby. PET was not designed to be inhaled. Furthermore, PET would prevent the proposed hybrid from going back into the soil safely, and the cotton would prevent it from re-entering an industrial cycle. The hybrid would still add junk to landfills, and it might also be dangerous.*

The team decided to design a fabric so safe that one could literally eat it. The European textile mill chosen to produce the fabric was quite ‘clean’ environmentally, and yet it had an interesting problem: although the mill’s director had been diligent about reducing levels of dangerous emissions, government regulators had recently defined the trimmings of his fabric as hazardous waste. We sought a different end for our trimmings: mulch for the local garden club. When removed from the frame after the chair’s useful life and tossed onto the ground to mingle with sun, water and hungry micro-organisms, both the fabric and its trimmings would decompose naturally.

The team decided on a mixture of safe, pesticide-free plant and animal fibres for the fabric (ramie and wool) and began working on perhaps the most difficult aspect: the finishes, dyes, and other processing chemicals. If the fabric was to go back into the soil safely, it had to be free of mutagens, carcinogens, heavy metals, endocrine disrupters, persistent toxic substances and bio-accumulative substances. Sixty chemical companies were approached about joining the project, and all declined, uncomfortable with the idea of exposing their chemistry to the kind of scrutiny necessary. Finally one European company, Ciba-Geigy, agreed to join. With that company’s help the project team considered more than 8000 chemicals used in the textile industry and eliminated 7962. The fabric – in fact, an entire line of fabrics – was created using only 38 chemicals.

The resulting fabric has garnered gold medals and design awards and has proved to be tremendously successful in the marketplace. The non-toxic fabric, Climatex®Lifecycle™, is so safe that the fabric’s trimmings can indeed be used as a mulch by local garden clubs. The director of the mill told a surprising story after the fabrics were in production. When regulators came to test the effluent, they thought their instruments were broken. After testing the influent as well, they realized that the equipment was fine – the water coming out of the factory was as clean as the water going in. The manufacturing process itself was filtering the water. The new design not only bypassed the traditional three-R responses to environmental problems but also eliminated the need for regulation.[11]

[11] McDonough, W. and Braungart, M. (2002) *Cradle to Cradle: Remaking the Way We Make Things*, North Point Press, New York

Activity 2 – Experiment: Toxicology Testing

This activity will introduce students to an environmental monitoring technique called a 'bioassay', using plant material. The activity has been adapted from Environmental Inquiry, a collection of ideas and resources to support student projects on a wide range of topics in the environmental sciences produced by Cornell University through an American National Science Fund grant.[12]

Key Learning Point:

Many household products and common bodies of water contain chemicals that are harmful to plant and animal life. The sensitivity of food crops to common pollutants and products can be tested through simple tests using plant material.

Resources:

– Materials (per group of 4 students): lettuce seeds, bleach, deionized water, petri-dishes, samples of suspected contaminated water, soils, solutions of household substances

Teacher Preparation:

– For this activity, the teacher will need to become familiar with the process of doing a plant-based bioassay, which involves use of plant material to test for chemical toxicity. For environmental testing, plant bioassays can provide an integrated picture of overall toxicity of an effluent or a sample of water, sediment, or soil from a contaminated site.

– The experiment runs over 5 days, so if the class timetable does not match, the teacher may need to prepare a demonstration experiment 5 days prior to the class with students.

Activity Description:

Preparation:

1. Soak lettuce seeds for 20 minutes in a 10% bleach solution (add 1 part household bleach to 9 part deionized or distilled water). Then rinse five times. This kills fungal spores that can interfere with seed germination. Note: Tap water can be used if you do not have access to deionized or distilled water, but it will introduce more variability into your experiment because of the varied minerals and other compounds it contains.
2. For water samples, place a 7.5-cm paper filter in each 9-cm petri dish. Add 2 ml of water sample to each dish
3. For sediment or soil samples, place 3 grams of sample in the bottom of each petri dish and cover with filter paper. If the sample does not contain enough moisture to saturate the filter paper, add up to 2 ml deionized water as needed.
4. Prepare a control by setting up dishes using 2 ml deionized or distilled water as your test solution.
5. To each dish, add 5 lettuce seeds, spaced evenly on the filter paper so that they do not touch each other or the sides of the dish.

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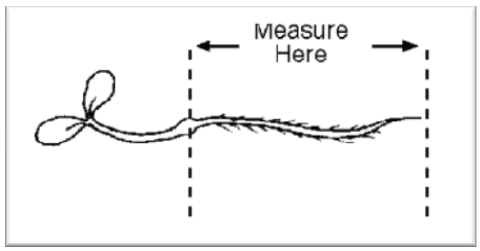
[12] Environmental Inquiry – Authentic Scientific Research for High School Students, http://ei.cornell.edu/index.html

6. Place the dishes in a plastic bag, and seal it to retain moisture. Incubate in the dark at constant temperature (preferably 24.5 degrees C) for 5 days (120 hours).

Measurement:

7. Collect and Interpret the Lettuce Seed Bioassay Data:

   At the end of the 5-day growth period, count and record how many seeds in each dish have germinated. For each sprout, measure the radicle (the embryonic root) length to the nearest mm. Instruct students to look carefully at the plants to make sure they are just measuring the radicle, not the shoot as well. For example, in the picture below, you would measure just the part between the two arrows, not the shoot and cotelydons to the left.



8. Compare the data with the Control:

   Count and record how many seeds in the control dish have germinated. The purpose of the control is to identify how well the seeds will grow without any added contaminants. Would you expect all of the seeds in your control dishes to germinate? Probably not, just like a gardener does not expect all the seeds in a garden to sprout.

   If fewer than 80% of the seeds in the control dishes sprouted, something may have gone wrong in the experiment. Perhaps the seeds were too old or stored improperly, so they were no longer viable. Or maybe something went wrong with the conditions for growth. Did the dishes get too hot, too dry, or contaminated in some way? Did students use tap water for your control, rather than deionized or distilled water? In many cases this works fine, but since tap water is highly variable from source to source, it gives less predictable results.

9. Consider the variability of results:

   Within each treatment, how much variability did students find in their results? Did the replicate dishes show similar numbers of seeds sprouting, and similar average radicle lengths? If you think the data are much more variable than you would expect, you might want to explore the potential sources of variability for this type of experiment.

10. Relating to toxicology:

    How might water and soils become contaminated? How can chemists and chemical engineers prevent this from occurring? If soils and water are contaminated, how can we remediate the soils?

Summary Activities and Homework Ideas

1. Essay

This essay question highlights a number of companies who are using green chemistry to achieve significant environmental milestones. In writing about one of the companies listed below, students will be tested on their ability to evaluate the performance of a company with regard to its sustainability credentials, and their ability to write a well-structured essay within a word limit set by the teacher.

Essay Statement:

Green Chemistry and green engineering are now being practised and promoted by a number of major international companies. Choose a company from the list below and describe the 'green chemistry' initiatives that have been undertaken and which are underway:

- 3M
- Dupont
- Dow
- Herman Miller
- Interface Ltd

In your essay, provide your perspective on how these measures might lead to significant progress in the larger context of global sustainable development.

Sample Answer:

For example for Dupont, example aspects that students may discuss include:[13]

- The U.S. Environmental Protection Agency (EPA) recently presented its Presidential Green Chemistry award to DuPont for the company's innovation that uses corn – instead of conventional petroleum-based processes – to produce the latest polymer platform for use in clothing, carpets and automobile interior.
- Since the early 1990s, DuPont has been recognized as a leader in sustainability, earning a number of awards including the World Environment Centre's Gold Medal.
- As part of its sustainable growth mission, DuPont has set four goals for 2010, supplementing existing goals:
    - To derive 25 percent of revenues from non-depletable resources.
    - To reduce global carbon-equivalent greenhouse gas emissions by 65 percent, using 1990 as a base year. The company has already surpassed this goal with a 68 percent reduction.
    - To hold energy use flat using 1990 as a base year.
    - To source 10 percent of the company's global energy use in the year 2010 from renewable resources.

[13] DuPont Sustainability Blog, http://www.scienceblog.com/community/older/2003/D/20032116.html

2. Mind Map

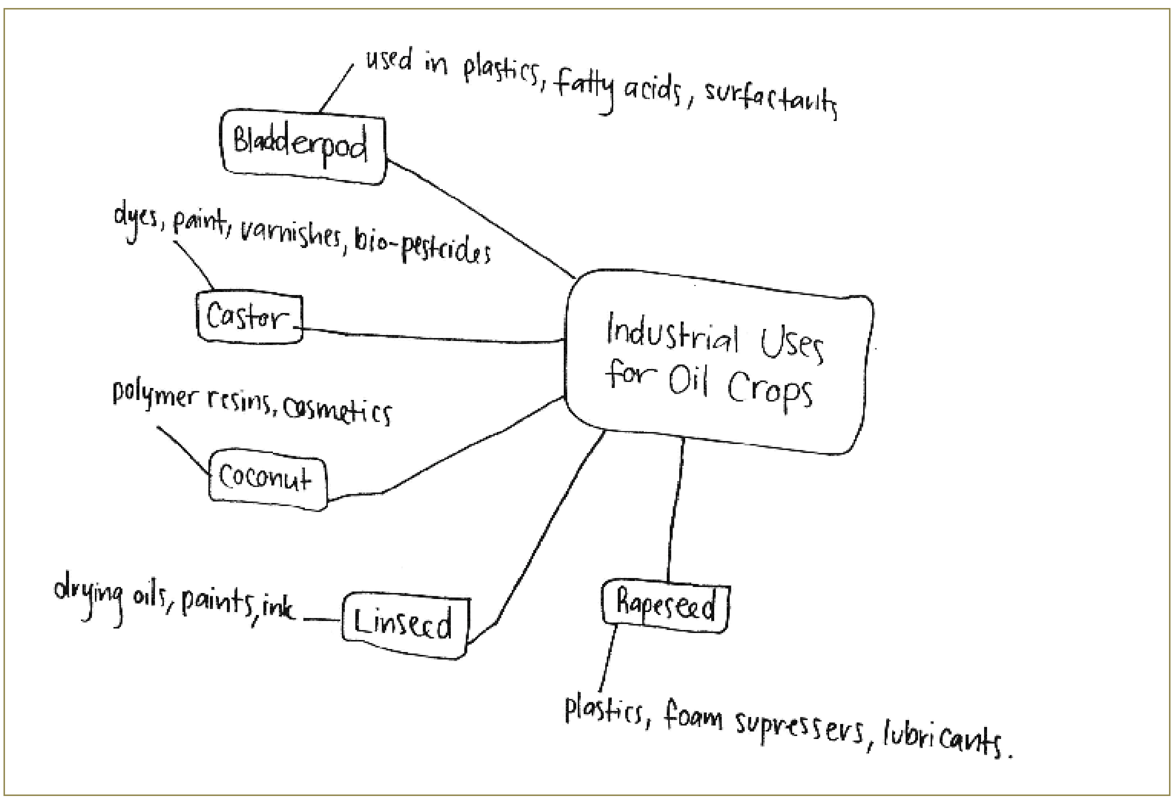
This mind map assessment item highlights a variety of options for using plant based innovations rather than petroleum based products and services, to support our lifestyles. In creating the mind map, students will be demonstrating their understanding of systemic opportunities for creating chemicals, and their appreciation of the interconnectedness of these issues. This exercise could be undertaken individually or in a group.

Mind Map Briefing:

Many feedstocks and crops in the US can be used to create industrial organic chemicals after the need for food has been met. For this mind map, you will research 2-3 renewable crops that could be used for biomass to create oil, and possible community considerations with regard to potential challenges with food supply. On the mind map, include the crop, the industry it could serve, the uses for the oil, and local and global social considerations with regard to meeting food needs.

Sample Answer:

For example: Bladderpod: plastics, fatty acids, surfactants. For a full list of possible opportunities, see Lesson 11.



3. Short Answer Questions

Question 1: Briefly describe the concept of moving the design 'up the pipeline', and explain why this is useful in green chemistry.

Sample Answer:

Considering the design and commercialisation process for a product as a pipe, conventional 'environmental management' is largely about cleaning up the pollution at the 'end of pipe', once all of the design and production processes have been completed.

This concept is useful in green chemistry as our challenge is to reduce toxicity in the product and in the waste stream, by designing out the toxicity in the first place - i.e. moving back up the pipe to the beginning and designing products that are 'benign by design'.

Question 2: What does 'source reduction' mean?

Sample Answer:

Source reduction is about reducing or eliminating the use or generation of hazardous substances in the design, manufacture and application of chemical products.

With increased regulation of the chemical industry, a high priority is now placed on developing solutions to avoid chemical treatment and remediation costs through waste prevention. Many chemical and related industries realise that re-designing waste out of the initial process will not only save significant costs but can also result in greater profits.

Question 3: Briefly explain the concept of reducing risk by addressing the hazard, not just exposure.

Sample Answer:

Ideally, we can avoid coming into contact with any toxic material during our day to day life. The concept of reducing risk by addressing the hazard, not just exposure, is about working to remove the hazard in the first place.

At its most basic level, risk can be described by the formula '*Risk = f [hazard, exposure]'* (i.e. risk is a function of - or related to - hazard and exposure). The conventional way that society has dealt with reducing risk is by fixing the hazard at some specific level, and managing exposure. In contrast, we can work to reduce the hazard as much as possible, before we then consider the potential for exposure.

12: Green Chemistry - Making Better Batteries

Educational Aims

The aim of this lesson is to introduce the significance of waste that comes from our everyday practices, and the extent to which waste-to-landfill impacts on the health of our society and the environment. This part will introduce the benefits of reducing and eliminating waste, and highlights some examples of what companies and governments around the world are doing to achieve 'zero waste' goals.

Alignment with Existing Curriculum Requirements

The activities and information presented in this lesson aligns to the federal government's national strategy for Education for Sustainability in schools. Furthermore, the federal government has already stated sustainability as a national curriculum cross curriculum priority, where 'Sustainability' is concerned with the ongoing capacity of the Earth to maintain life:[14]

Actions to improve sustainability aim to reduce our ecological footprint while simultaneously supporting a quality of life that is valued—the 'liveability' of our society. Sustainable patterns of living meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is both an individual and a collective endeavour often shared across communities and nations necessitating a balanced but different approach to the ways humans have interacted with each other and with their biophysical environment. Sustainability learning draws on and relates learning across the curriculum. It leads to students developing an overall capacity to contribute to a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations.

These activities can be integrated within a variety of topic areas specified by the Queensland Studies Authority (QSA) Senior School Syllabus for Chemistry, as summarised in the following table:[15]

Key concept R1: Specific criteria can be used to classify chemical reactions.	
R1.1	Redox reactions involve a transfer of electrons and a change in oxidation number.
R1.2	Precipitation reactions result in the appearance of a solid from reactants in aqueous solution.
R1.3	Acid-base reactions involve transfer of protons from donors to acceptors.
R1.4	Polymerisation reactions produce large molecules with repeating units.
Key concept R2: Chemical reactions involve energy changes.	
R2.1	All chemical reactions involve energy transformations.
R2.2	The spontaneous directions of chemical reactions are towards lower energy and greater randomness.
Key concept R3: The mole concept and stoichiometry enable the determination of quantities	

[14] http://www.australiancurriculum.edu.au

[15] http://www.qsa.qld.edu.au/downloads/senior/snr_chemistry_07_syll.pdf

in chemical processes.	
R3.1	The mole, defined arbitrarily using the isotope carbon-12, is the basic quantity in stoichiometric calculations.
R3.2	Every chemical reaction can be represented by a balanced equation, whose coefficients indicate both the number of reacting particles and the reacting quantities in moles.
R3.3	A balanced equation can be used when determining whether reagents are limiting or in excess.
R3.4	The use of molarity for expressing concentration allows easy interconversions between volume of solution and moles of solute. R3.5—The ideal gas equation may be used to relate the volume of a gas at defined temperature and pressure to its quantity in moles.
Key concept R4: Specialised qualitative and quantitative techniques are used to determine the quantity, composition and type of reaction.	
R4.1	Techniques such as volumetric and gravimetric analysis are used to determine amounts of reactants and products.
R4.2	Specialised techniques and instrumentation are used in chemical analysis. R4.3—Qualitative and quantitative testing may be used to determine the composition or type of material.
Key concept R5: Chemical reactions are influenced by the conditions under which they take place and, being reversible, may reach a state of equilibrium.	
R5.1	Chemical reactions occur at different rates and changing the nature of the reactants, temperature, or concentration, or introducing a catalyst, may alter these.
R5.2	Life is maintained by chemical reactions, especially those catalysed by large molecules called enzymes.
R5.3	Chemical reactions may be reversible.
R5.4	Reversible chemical reactions may reach a state of dynamic balance known as equilibrium which, when disturbed, will be re-established.

Relating these concepts to example topic areas, this lesson could be integrated within the following possible chemistry units:

- Electro-chemistry
- Chemical Reactions
- Electrochemical Series
- Electrolysis

Activity 1 – Video: Battery Innovations

In this activity students will research an environmentally friendly battery innovation and prepare a short video proposal to the government to fund further research into this battery.

Key Learning Point:

There is significant research already underway to find more environmentally friendly battery designs, however much more work and funding is need to reduce manufacture and disposal impacts on the environment and improve efficiency.

Resources:

- Each group will need access to a recording device, which may be as simple as a mobile phone camera, a digital camera, or a video camera.
- Brief Background Information, Lesson 12 'Making Better Batteries'
- Research time and facilities (computer and internet) - Students may get examples for their project by doing some internet-based research.

Teacher Preparation:

- The teacher and students will need to be familiar with batteries and battery applications before beginning this task. These principles and background information are explained in the student materials (Lesson 9).
- For teachers who are not familiar with using video creation for learning and assessment, please see for example 'School Tube' (www.schooltube.com)

Activity Description:

1. Create groups of 3-4 students
2. Explain to the groups that the task is to prepare a short 2-minute 'bid' for funding to a new innovation fund.
3. Provide each group with a battery innovation from the following list (alternatively, you may like to allow students to select their own): Hybrid-Electric and Electric Vehicles – Lithium-Ion Battery Innovation, Combined Battery Technologies, 'Virus' Battery Technology, or Solar-Thermal Battery-Style Technology.
4. Each bid must address the following aspects: Battery Technology; Limitations; Research required; Expected Developments; and Uses and expected profits.
5. Once the groups have submitted their 'bids', the class can then act as the panel of assessors, and can 'score' the bids.
6. At the end of the screening of all bid presentations, the teacher can discuss with the students aspects of their presentations.

Activity 2 – Experiment: Sea Water Batteries

In this activity students (or a teacher in a demonstration scenario) will create a battery using salt water. This activity has been adapted from an activity by Creative Science.[16]

Key Learning Point:

Landfills are complex scientific systems. What we put into landfills affects all parts of the landfill and surrounding land through leaking liquids (i.e. leachate), leaking gases (i.e. off-gasing) and leaking contaminants (i.e. soil contamination). We can improve landfill use by properly designing the landfill, reducing the amount we put in, and sorting the waste before disposal.

Resources:

- Students should have a sound understanding of the chemistry behind batteries (including ionic chemistry, electrolysis and the electrochemical series)
- Materials (for each group of 3-5 students): Salt (NaCl), Ice- cube trays, Flat piece of wood (ply or balsa, same size as icecube tray) for electrode support, Galvanised screws (about 5 cm long) for each battery, 12 pencil leads (2B or softer), or better still, school lab carbon rods or ones salvaged from old worn out batteries, Tinned copper wire, Alligator Clips, LED lights.

Teacher Preparation:

The teacher may wish to create a demonstration model to use with the class.

Activity Description:

A very brief background to the experiment:[17]

The voltage created in a battery is due to ionic chemistry. When a metal electrode is immersed in an electrolyte a rather complex dynamic process occurs. Let us assume that the metal electrode is initially uncharged (the atoms from which the electrode is made are neutral - they have equal numbers of electrons and protons). When the metal is immersed in the electrolyte, positive metal ions are formed on the surface of the electrode. These ions pass into solution, making the electrode progressively more negative, as the positive ions move away. There will come a time, however, when the negatively charged electrode will start to attract back the oppositely charged ions. So a dynamic equilibrium is thus formed between those ions leaving and those returning to the metal surface. How far the equilibrium goes one way or the other is dependent on the reactivity of the metal.

A battery must have two electrodes, so meanwhile on the other electrode, a similar process must be taking place. If this second electrode is of the same metal as the first, then each electrode will charge to the same extent (voltage), and there will be no resulting difference between them. There will thus be no attractive force (electromotive force EMF) between them, and so no current will flow.

[16] http://www.creative-science.org.uk/sea1.html accessed 10/01/11

[17] This section has been adapted from Creative Science , for more detail on the chemistry of batteries, see 'Brief Background Information' in Lesson 12 'Making Better Batteries'

A pair of electrodes can produce a voltage when immersed in an electrolyte. In the following experiments we use of galvanised (zinc- plated) screws and carbon rods as the electrodes and salt water as the electrolyte. While carbon is a good conductor of electricity, the chemistry that takes place at the carbon electrode is more complicated than would be the case when simply using metals. However, larger potentials are produced with carbon and zinc than with copper and zinc, so it is worth the complication. Carbon is a good conductor of electricity. In these cells the metal (zinc) electrode is negative (-) while the carbon becomes positive (+).

To increase the limited voltage and current of such a simple cell, we can join up cells to make a battery of cells - thereby increasing the power. An effective arrangement will be discussed. Household ice- cube trays are used to hold the electrolyte, and wood supports the multiple pairs of electrodes, a set for each ice cube tray.

Make the battery:

1. Fill each of the ice cube trays ¾ full with salt solution (sea water or a solution of table salt in water).
2. On the wood, mark the divisions of the ice cube tray.
3. In each division, insert one nail and and one carbon rod, as seen in the figure:

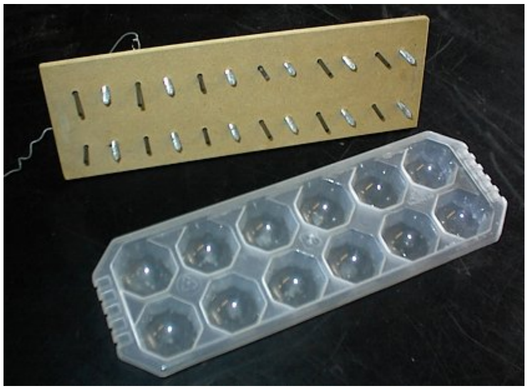


Figure 1. Tray and Wood[18]

4. Use the tinned copper wire to connect each electrode appropriately. This completes the construction of the battery!

   So what is the best way to wire up the 12 cells to get useful power from the battery – in series, or in parallel? Consider a single cell - it can produce a voltage of V volts and a maximum current of say I amps. Wiring a number (n) of these cells in series (one after the other in a sort of daisy chain) will multiply the voltage giving n x V volts. However, the maximum current produced by this arrangement will be the same as that of a single cell - I. On the other hand wiring all the cells in parallel will increase the curent n-fold but maintain the voltage equivalent to that of a single cell (i.e. V). Combinations of series and parallel cells with produce combination of possible total V and I.

[18] http://www.creative-science.org.uk/sea1.html accessed 10/01/11

The ice cube tray used in these experiments has 12 compartments (i.e. 12 holes for ice cubes) and so to get useful power from the battery two combinations of wiring could be used (see Figure 2).

a) Configuration a) consists of two sets of six cells wired in series and these two sets are then wired in parallel - giving a total of 6 x V and 2 x I.

b) Configuration b) consists of two sets of six parallel cells which are wired in series - giving a total of 2 x V and 6 x I.

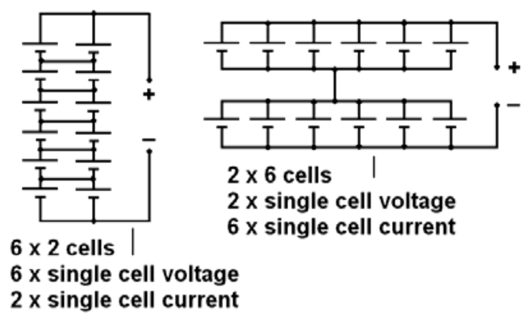


Figure 2. Combination of series and parallel[19]

5. Connect the ends of the circuit to the LED with alligator clips. Remember to check that the device you are powering is correctly wired to the – and + connection of the battery (metal (zinc) = -, carbon = +).

   We now have a sea water power plant! A pocket LCD calculator, an LED (and series resistor), and possibly a pocket radio, will work well using this arrangement.

   The first battery circuit provides a relatively higher voltage than the second and so it can therefore be used to power devices that need 'higher voltages' but low currents.

   In the demonstrations, you may use a simple flashing LED circuit to dramatically show the battery working. This circuit requires about 3V, but only about 1 or 2 mA to work.

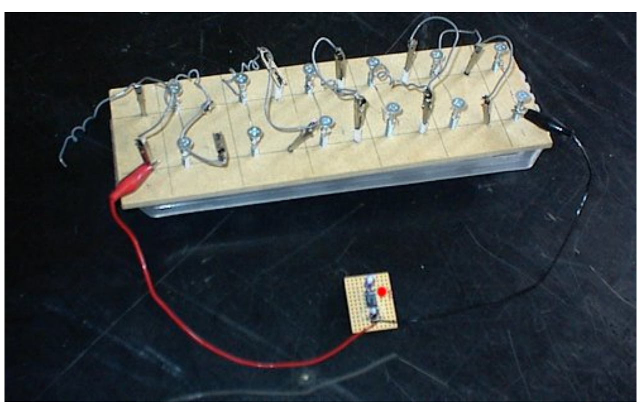


Figure 3. The complete 'high' voltage, 'low' current sea water battery connected to an LED flasher circuit[20]

[19] http://www.creative-science.org.uk/sea1.html accessed 10/01/11

Summary Activities and Homework Ideas

1. Essay

This essay question highlights issues associated with the global demand for battery storage of energy, and the escalating demand for all sorts of batteries. In discussing the topics stated below, students will be tested on their understanding of innovative battery storage opportunities, and their ability to write a well-structured essay within a word limit set by the teacher.

Essay Statement:

Batteries play an important role in developing a sustainable future. In this essay, discuss ways in which batteries will reduce fossil fuel use, greenhouse gas emissions and pollution. Specifically, consider:

- the use a batteries in harnessing renewable energy sources;
- batteries providing base load power; and
- battery design and materials.

Sample Answer:

Some key points that students may include in their essay include:

- Batteries play a vital role in storing the energy of renewable energy sources. They help to provide a reliable source of stored chemical energy for use when the direct source of energy (for example, wind or solar) are not available.
- Batteries can provide society with a consistent supply – 'baseload' – of energy that has been sourced from renewable sources
- Battery materials may include a number of heavy metals which may be highly toxic to humans, animal and plant and harmful for groundwater and soil.
- It is vital then, that future battery designers ensure that materials used to make batteries are safe, plentiful and easily recyclable and that the processes involved are low energy.

[20] http://www.creative-science.org.uk/sea1.html accessed 10/01/11

2. Mind Map

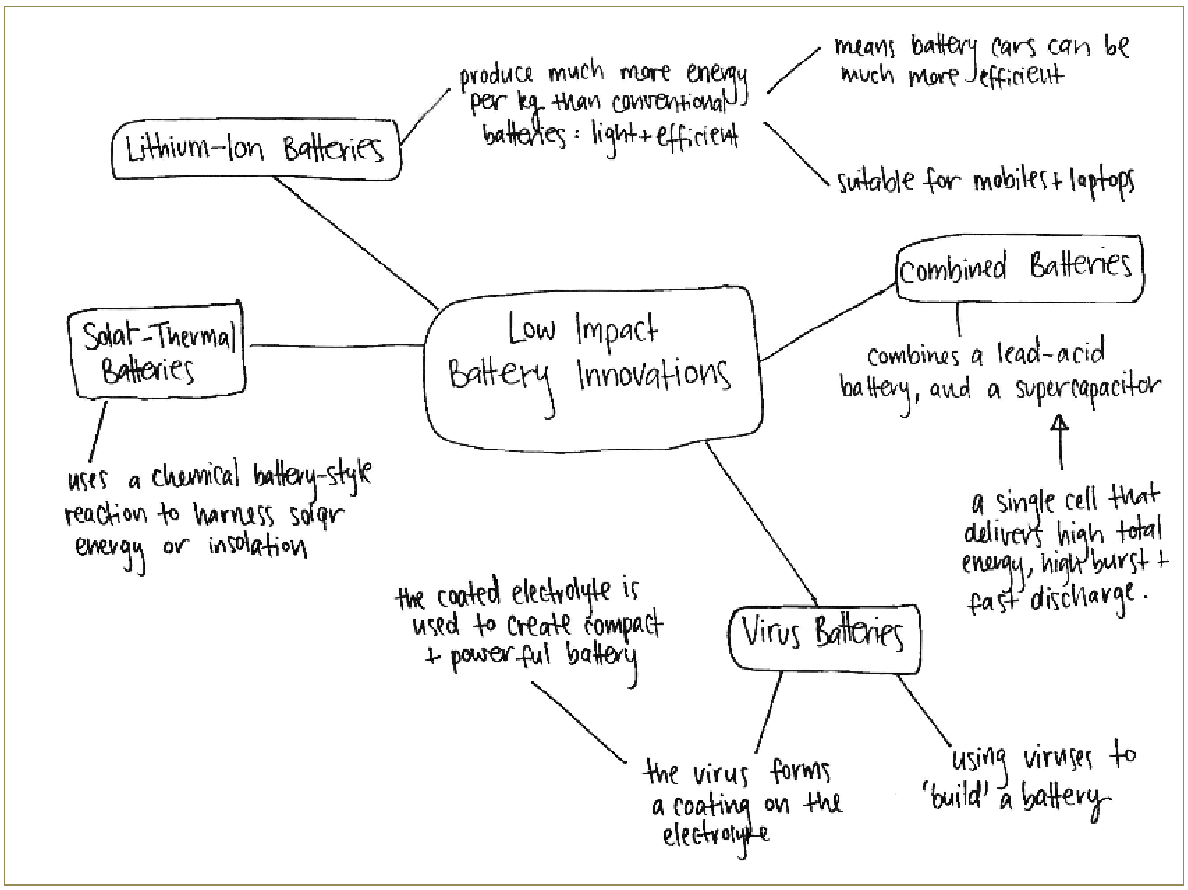
This mind map assessment item highlights the variety of battery innovations that may contribute to a sustainable future with reliable and environmentally friendly battery storage. Through this exercise, students will be demonstrating their understanding of opportunities for sustainable battery innovations, and some potential opportunities for innovations combining to provide integrated solutions. This exercise could be undertaken individually or in a group.

<u>Mind Map Briefing:</u>

There are many new batteries innovations occurring all over the world. Create a mind map of some of these innovations, detailing the materials, processes, green innovations and future research potential.

<u>Sample Answer:</u>

This mind map begins to document the technologies summarised in Lesson 12, however the inter-linkages between the technologies are not yet shown.



3. Short Answer Questions

Question 1: How does a battery cell work?

Sample Answer:

Batteries are made up of one or more electrochemical cells, which are devices that generate electricity as direct current (DC) via an electrochemical process. Each electrochemical cell, or simply cell, is comprised of an anode (negative electrode), a cathode (positive electrode), an electrolyte, and an external electric circuit (technically not part of the cell).

The electrochemical process in a cell is called an oxidation-reduction reaction which involves two half-reactions, comprising an oxidation half-reaction at the anode, which releases electrons; and a reduction half-reaction at the cathode, which accepts electrons.

The full reaction can be completed only when there is an external electric circuit connected to the electrodes, which is why batteries can retain their charge when they are not in use. The specific half-reactions, voltage produced (called the characteristic voltage) and 'rechargeability' of the battery depends on what materials are used to make the anode, cathode and electrolyte.

Multiple batteries are often used in devices that require more voltage or current than a single battery can provide, where parallel batteries are arranged next to each other, with the external electric circuit connecting to every battery's anode and cathode terminal (The currents add up and the voltage stays the same), and series (serial) batteries are arranged end-to-end, with the external electric circuit connecting to the first battery's anode and last battery's cathode (the voltages add up and the current stays the same).

Question 2: What are the major differences between the two common types of batteries – alkaline and lead acid batteries?

Sample Answer:

1. Alkaline batteries belong to a family of batteries that are used once and then thrown away, also called 'disposable' or 'primary' batteries (also lithium, saline etc). Unfortunately alkaline batteries can contain a number of heavy metals including Aluminium, Cadmium, Mercury, Nickel, Lead, Iron, Zinc, Calcium, Magnesium, and Lithium, which can be highly toxic for humans, animals and plants, polluting soil and groundwater.
2. Lead acid batteries belong to a family of batteries that can be recharged, commonly known as 'rechargeable' batteries (also lithium-ion, and nickel metal hydride). With regard to environmental impact, the process used to create the lead for the batteries (i.e. lead smelting operations) is quite toxic and energy intensive, and continuous improvement in battery recycling plants and furnace designs is required to keep pace with emission standards for lead smelters. Lead acid batteries pose a potential threat to human health and the environment if improperly discarded, as the two main components of these batteries are sulfuric acid and lead which can contaminate soil and ground water.

Question 3: What is a lithium-ion battery and what industry will make major use of developments of this kind of battery?

Sample Answer:

The reactions in lithium-ion batteries differ from the reactions in alkaline and lead-acid batteries in that they don't involve the electrolyte. The reactions in lithium-ion batteries represent a simple exchange of lithium ions and electrons between the graphite anode and the cobalt oxide cathode.

Although lithium-ion batteries contain an ionic form of lithium they contain no lithium metal and are classified as non-hazardous waste. However, the larger problem is the throwing away of more than 2 billion batteries a year, when this material that could be recovered through recycling. For example, each lithium-ion battery contains between 10 to 13 per cent cobalt by weight and it is estimated that between 8,000 and 9,000 tons of cobalt is used in the manufacture of lithium-ion batteries each year. While the market does not factor in the social cost of disposal, or the lower economic and environmental cost of recycling rather than mining raw materials such as cobalt, these batteries are still being thrown away by the millions.