Learn Chemistry

Chemistry of Energy

Tutor Guide

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National HE STEM Programme

RSC | Advancing the Chemical Sciences

www.rsc.org/learn-chemistry

Table of Contents

Introduction

This resource is designed as contextualised introduction to the application of several key chemical concepts such as thermodynamics to real world situations.

The problem has been designed to be used with small groups of students (ideally of 4-6 members) studying chemistry, interdisciplinary science, natural sciences or sustainability at year one or year two level. The scenario places the groups in the roles of scientific advisory teams to the government of 'Northland' (a 'fictionalised' nation located in North West Europe with a population of 5 million and a wide-based installed power capacity – including fossil fuels, nuclear, hydro and wind). The assessment of this problem is rather varied. Students must work on a number of different types of submission, each of which targets different audiences including politicians other professional scientists, news agencies and members of the general public.

Delivery of the Problem

The problem has been designed as an integrated resource made up of three component units.

The three component units are:

1. Power Generation
2. Energy Conservation
3. Environmental Impact and Societal Issues

Criterion	Value
Intended level	Year 1-2
Subject area	Material Science, Thermodynamics, Sustainability,
Contact Hours	10 hours
Group size	4-6

Tutor text has been included in this version of the problem. The tutor text is shown in red; this text should not be shown to students.

Outline tutor answers have been provided for the facilitation questions. Please note that these are neither model answers nor guidelines to that amount of content that students should produce. These answers only provide a minimal outline of the concepts being asked and students should go into more detail and provide examples of each of these concepts.

We recommend that this problem is used with small groups of students (typically group sizes of 4-6 work best). We also recommend that each facilitator guides no more than 2 or 3 groups – if a facilitator has to work with any more groups than this, it is likely to mean that very little time is spent with each group.

We have found that postgraduate students can make good PBL/CBL facilitators if they are given guidance in this style of teaching and the nature of the problem before the start of the module. It is advisable to have at least one staff facilitator on duty during all sessions.

Dynamic nature of problems

The resource has been designed to give students the opportunity to focus their path through the problem in a way that will allow them to pursue the topics that interest them the most. In the first unit students are asked to read a number of different tenders submitted for the development of new processes or facilities which will help Northland develop a sustainable supply of energy. they are then tasked with preparing a short press release detailing why they are recommending government investment in their chosen technology. At the end of the unit all of the groups participate in a press conference where they are questioned about their choice of technology by a panel which includes staff members, members of the other groups and (if possible) students who are not currently working on this problem but have an interest in this area of research.

We have also created a number of news articles which may be of use during the problem solving process. These articles have been designed to be issued to groups working on certain parts of the problem. These articles may provide groups with additional information or insight on the part of the problem they are working on or may even result in a change of conditions which is going to require them to rethink their solution.

Transferable Skills Development

This resource makes use of a number of types of assessment which share a common theme of communication. The authors have found that the use of C/PBL resources can be an ideal way of teaching communication skills in a scientific context and it is hoped that this resource will raise awareness of the relevant issues when communicating science to a range of audience types. The following transferable skills are encountered in this problem:

- Working in a small group on a mini-project **- Relevant throughout the problem**
- Critical thinking, decision making and independent learning **– Relevant throughout the problem**
- Preparing concise written critiques of active areas of scientific research - **Sessions 1, 4 and 5.**
- Working within a group to critically evaluate a number of different courses of action and justifying the decision made in a short written report – **Session 1 and 3-5.**
- Writing a short presentation – **Session 3.**
- Orally communicate an understanding of an area of scientific research in a press conference scenario – **Groups prepare for this between sessions 1 and 2 and participate in a press conference in session 2.**

Mathematical Skills

Most parts of the problem incorporate some level of mathematical activity. The key focus is one encouraging students to make calculations based on reasonable approximations. We have also placed an emphasis on unit conversion as this is an important skill that students must gain experience of. In the later parts of the problem students are asked to use a spreadsheet model which has been developed by someone else.

An overview of the scenarios

- Power Generation

This unit will be based around the Northland government's requirement to end the nation's dependence on non-renewable power sources and develop a viable plan for sustainable energy development for the future. Groups will be asked to research one of four sustainable energy technologies and report back in the form of a short presentation to representatives of the press followed by questions.

Students will be given the choice of the following technologies:

1. A new biomass process, which will allows diesel to be produced from timber waste.
2. Carbon capture technology for absorbing and storing the CO_2 formed in coal power plants
3. Semi-crystalline photovoltaics that capture significant energy from the extended hours of sunlight found in summers at high latitude.
4. The opportunities and environmental issues created by a discovery of rare earth (Neodymium) ores – the basis of magnets used in wind turbines.
5. New generation of nuclear facilities, possibly involving the reprocessing of thorium/plutonium waste.

As part of this task students will be asked to include a number of key points. Each of the four options will include the calculation of a specified quantity which will require students to make reasonable estimates and manipulate units.

- Energy Conservation

Northland has the potential to develop extensive wave/tidal power resources in the inaccessible north of the country. It is therefore faced with upgrading its main North-South power connections. We have developed a problem based on the issue of transmitting power over large distances and the related losses (typically 7-10%). We would like students to understand the nature of power loss during transmission and other related phenomena (such as skin effect). The groups will then be asked to select an appropriate material for the construction of these new power lines designed to transmit power over hundreds of miles – students will be given a number of options, each of which will be issued with a summary of the key specifications as issued by the manufacturer – these specifications will include a variety of units which will make them harder to perform a like for like comparison.

- Environmental Impact & Societal Issues

We have so far devised two activities for this unit. One requires students to produce a simple model of the carbon footprint of the nation based on a provided Excel template. The other will be to assess the incremental power generation requirements of rail electrification and a major shift to electric vehicles.

More Background Information

The MacKay text listed below provides a very useful and easy to understand review of sustainable energy approaches. Students and instructors may both find it useful to take a look at the relevant chapters before discussing the problem. This book is freely available to download from the author's website.

Atkins P. & de Paula J., **Atkins' Physical Chemistry**. Oxford University Press.

MacKay, J. C., **Sustainable Energy – without the hot air**. UIT.

Feedback from Trials

This resource has been used in three trial implementations during the 2011/12 academic year:

- The University of Edinburgh
- The University of Huddersfield
- The University of Leicester

Due to time constraints the trials focussed on sessions 1-3 only. Feedback from instructors indicated that the students found the resource engaging but indicated that one of the key difficulties was the amount of research that students have to do in order to attempt the problem. In order to address this, the trial at the University of Huddersfield took the form of a one day workshop (which ran from 10:00 – 16:00). Students were introduced to the problem at the start of the session and were told that the day would end with a series of presentations. Each group was assigned one of the technologies and given access to computer facilities. Groups were given $3^{3}/_{4}$ hours to research their assigned proposal. After $3^{3}/_{4}$ hours, students were told that the presentations would take the form of a press conference and each group was divided into two – one half of each group would give the presentation and the other half would act as members of the press and ask the presenters questions. The press conference ran in the last $1^{1}/_{2}$ hours of the day, questioning was student led. It is worth highlighting that post session evaluation revealed that students engaged very well with the resource and agreed that they had developed a range of scientific and transferable skills.

Student feedback comments indicated that they find the scenario relevant to their studies *"The content was addressed well to a group of chemists, the exercises all had a relevant context"* and that they appreciated the opportunity to improve their communication skills: *"Activities like the press conference helped to practice useful skills but were not too intimidating to those involved."*

Acknowledgements

The authors would like to thank Dr Christine Lamont (University of Huddersfield) for trailing the resource and for providing some additional discussion questions and alternative strategies for running the problem. We would also like to thank Dr Jason Love (University of Edinburgh) for organising the first trial of this resource and providing insightful feedback. The authors would also like to thank Professor Simon Belt for providing feedback on the draft version of this resource. Finally we would like to thank the project managers at the Royal Society of Chemistry.

Tutor text

The red text in this version of the guide is meant to be seen by the tutor only. This text includes guidance on how the problem can be run, marking criteria, feedback from the trials and some (where appropriate) example answers.

Week	Session	Topics	Transferable Skills	Assessment	Pre-session Prep./Feedback
1	1 (90-120 mins)	• Sustainability • Power generation technologies • Rare Earth chemistry • Nuclear chemistry • Semiconductors • Thermodynamics • Unit conversion	• Team working • Group discussion – discussion of proposals • Independent learning • Critical thinking • Decision making – choosing a single proposal to back • Written communication – preparing the one page summary	• Each group must chose to back one of the proposals and write a one page summary which justifies their decision (deadline - between session 1 and 2). • Groups must spend the first session and the time between sessions 1 and 2 to prepare for the press conference in the next session (deadline – the press conference in session 2)	<u>Before session:</u> Issue students with the following: - The 'session 1' summary which includes the ILOs. - The Introductory email from the science minister and the accompanying 'Welcome to Northland' information. - The five summary proposals. <u>In session:</u> - Toward the end of the session, provide students with the relevant news articles for their technology. - Give each group the press stories on their related technology in the second half of the session. - In the second half of the session make the email and information about the press conference available. - Towards the end of the session ask groups to describe their approach to you and give some oral feedback on this. <u>Before next session:</u> Students receive brief written formative feedback on the one page summary prior to the next session.
2	2 (90-120 mins)	• Sustainability • Power generation technologies • Rare Earth chemistry • Nuclear chemistry • Semiconductors • Thermodynamics • Unit conversion	• Team working – the group should present as a coherent unit rather than a group of individuals • Science communication to a non-expert audience. • Time management – ensuring points are expressed in the time available for the presentation.	This session will take the form of a series of press conferences. Each group will be given up to 5 minutes to give an opening statement; this is followed by a longer period of questioning from the non-expert (journalists) audience.	<u>Before next session:</u> Students should receive formal feedback on the press conference. This will usually be written feedback which is issued within a week of the session.
Opt. Task	Suggest between sessions 2 and 3	• Sustainability • Power generation technologies • Photovoltaics • Biomass • Semiconductors • Unit conversion	• Team working – the group should present as a coherent unit rather than a group of individuals • Science communication to a non-expert audience. • Time management – ensuring points are expressed in the time available for the presentation.	Groups must make a more detailed direct comparison of two different technologies: photovoltaics and biomass. The groups will write a short report	<u>Before session:</u> Issue students with the following: - The emails and the data for this part of the problem. <u>In session:</u> - Towards the end of the session ask groups to describe their approach to you and give some oral feedback on this. <u>After session:</u> Students receive full written formative feedback on their report.
3	3 (90-120 mins)	• Materials chemistry • Power transmission	• Team working • Group discussion • Independent learning • Critical thinking • Decision making • Written communication	Groups must research a number of alternative approaches that may be used to transmit power over long distances. Groups must prepare short (around 3 slides) presentations on one or more of these approaches which are suitable for an audience of politicians.	<u>Before session:</u> Issue students with the following: -The 'session 3' summary which includes the ILOs. -The research funding applications <u>Before next session:</u> Students should receive formal feedback on the presentations.
<u>4</u>	4 (90-120 mins)	• Sustainability • Power generation technologies • Unit conversion • Modelling energy usage and pollution.	• Team working • Group discussion • Independent learning • Critical thinking • Decision making – choosing which actions to model and making	The group will work with the spreadsheet model to evaluate whether their chosen approach from sessions 1-2 will be able to meet the nation's energy requirements and to determine the impact on the nation's carbon footprint. Groups will	<u>Before session:</u> Issue students with the following: - The 'session 4' summary which includes the ILOs. <u>In session:</u>. During the session ask groups to describe their approach to you and give some oral feedback on

			recommendations based on results • Written communication – preparing the report • IT skills –using a spreadsheet model	then compare their chosen approach with other power generation technologies. Students will write a short report summarising their findings.	this. <u>Before next session:</u> Students receive written formative feedback their report (before the next session if possible)
5	5 (90-120 mins)	• Sustainability • Power generation technologies • Unit conversion • Modelling energy usage and pollution. • Energy demands of heating and transport sectors	• Team working • Group discussion • Independent learning • Critical thinking – calculating values, making suitable approximations • Decision making – choosing which actions to model and making recommendations based on results • Written communication – preparing the report • IT skills –using a spreadsheet model	Part (a) Students will develop their model from the last session by determining the energy requirements for the transport and heating sectors. Students will determine how much extra generating capacity Northland requires to move a significant amount of the transport or built environment sectors to renewable energy. <u>Groups will submit an updated version of their report from last week which includes these figures.</u> Part (b) Groups will provide a report which details the mechanism of global warming and includes calculations of how much energy is emitted by the Earth at frequencies that are absorbed by CO_2	<u>Before session:</u> Issue students with the following: - The 'session 5' summary which includes the ILOs. - The two emails (parts a and b) <u>In session:</u>. During the session ask groups to describe their approach to you and give some oral feedback on this. <u>After the session</u> Students receive full written formative on their reports. These reports are marked summatively.

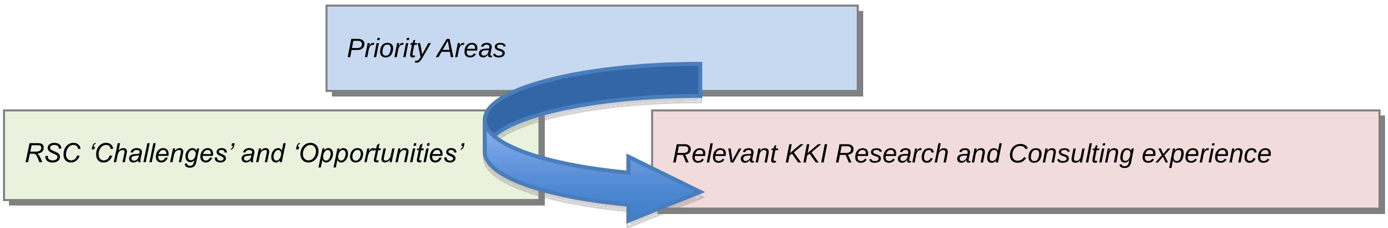
Comments from Dr Kevin Parker – KKI Associates

I was asked to contribute to the C/PBL project by adding context and 'realism' to the energy module. My background is that of a research chemist who worked for British Petroleum (BP) in a number of R&D, marketing, sales, and technology forecasting roles over a period of 12 years. In the latter role we carried out some of the earliest semi-quantitative technico-economic studies on solar power, biomass, and fuel cells.

I am also one of the UK's most experienced consultants in the area of science-based entrepreneurship, and business skills. I have been doing this for over 15 years, working on over 250 technico-economic consultancy projects, and training somewhere over 2500 workshop delegates. I use interactive and problem-based case study exercises to get across the complexity and apparently unstructured nature of typical commercialization projects.

Both at BP and as a consultant I have worked with senior government officials, trade bodies, national academies, and NGO's as well as researchers in energy technology and policy.

My reply to the original request to tender from the RSC included this analysis mapping my experience to their stated priorities from the 'Roadmap' themes.



The RSC roadmap document lists seven priority areas and picks out 41 challenges within those areas. In this schematic I have listed RSC priority areas in blue, some of the 'top 10' challenges in pale green and highlighted some of my relevant areas of expertise in the pale red boxes. Here are the results within the energy sector:

I therefore attempted to address the points listed in the RSC 'Priority areas' 'Challenges' and 'Opportunities' in developing this material. The module does include case studies on solar cells/energy, nuclear safety and exploitation, and power transmission (crucial in the storage/distribution of energy).

Creating and securing environmentally sustainable energy supplies, and improving efficiency of power generation, transmission and use

Solar energy - develop existing technologies … and …the next generation of solar cells …

Energy conversion and storage

Technico-economic studies for BP Solar
Carbon production and output model for London Accord consortium
Review of World Renewables for Aberdeen all energy conference publication
http://www.kkitech.com/YCF Renewable Energy.pdf

Paper on carbon-linked treasury bonds for World Bank conference

As well as dealing with specific areas of 'hard science' I wanted students to gain a feel for some of the scenarios they might meet and skills they might require in their ongoing careers, especially if they are interested in working in energy.

1. In the energy industry, virtually all work is carried out by multi-disciplinary teams, with a joint and several responsibility for the project. If someone, for example is unwell, the rest of the team will just have to work harder to meet their common deadline
2. The teams will be multi-disciplinary and a key requirement is the ability to communicate what you know (from your specialist knowledge) to others who need to able to understand and accept your reasoning. We had a telling quote from a senior manager responsible for graduate recruitment

'We interview hundreds of potential 'strategic recruits' each year. Most fail their technical interviews, not because they don't know their science but because they are not good at applying what they know to problems we might ask about '

3. Very often, technologists are required to give advice in situations with incomplete information. For example we don't completely know the feedback factors that linking increased carbon dioxide to temperature. We believe that increased CO2 will increase water vapour but we have to quantify this within quite large error bars. And we really aren't sure of the methane feedback/feedforward, although we do suspect at least one 'methane catastrophe' in paleoclimates. In our case, students are limited by what they can find in the time allotted, and there may well be other good information 'out there' they just haven't found. Meanwhile a different group of students may well find different information and reach a different conclusion
4. The other issue about energy, which confuses and frustrates those new to it, is the sheer amount of unit conversion. We can measure energy in Joules, MegaJoules/mol, kilowatt-hours, British Thermal Units, or Tera watt-hours. The size of an oil barrel varies between crude oil and oil products, while metric tonnes are different to UK tons which are different to US short tons, which are all different

from deadweight tons used in oil tankers (which are a measurement of volume not weight!). Because of this a chemist might often be asked to make or draw comparisons in layman's terms. In early 2011 I was asked (by a very serious client in the City of London) to compare the BP oil spill in the Gulf of Mexico with the amount of water in an Olympic Swimming pool1, and then with the amount of oil lost from US tankers in U-Boat attacks in 19422. The major issue in this analysis was getting, checking and re-checking the unit conversions. So we wanted students to be able to recognise and overcome this issue when working on energy problems

Why did we use the 'Northland' scenario? We wanted to show how energy policy in most countries is a series of compromises, where choices have to be made between several less than ideal resources. So while everyone agrees that 16GW of tidal power is worth accessing, not everyone wants the increased size of power transmission lines to get that power from the north of the country[3].

The e-mail exchanges in session 4 are meant to represent this. They illustrate fairly closely the kinds of comments that politicians and their advisors might be sending. It might be a useful exercise for a tutor to draw out a summary of the issues presented in the e-mails, once the students have read them. They show that

- Northland needs new power transmission lines to transmit the major tidal and wave power resources from the north to the industrial south of the country
- There are technical physical chemistry reasons why the power lines need to be very tall, which however makes them visually obtrusive
- There is much opposition in Northland to the new higher power lines, as exemplified by the e-mails from the Green party
- There are technical reasons why underground power transmission is currently expensive and impractical
- Fortunately the minister for Energy is going to Northland University to hear some new research proposals which relate directly to the issue of power transmission

The students then have the task of a) reading considering the features of the research projects that could make them relevant to this issue and b) supplementing and confirming their thoughts with some internet research. The exercise takes students from party politics, to the consideration of technical issues such as the electric skin effect and insulator 'treeing', and back again. This interplay of technical social and political issues is very common in the energy industry

By setting our problems with the context of a realistic country we can illustrate these compromises and choices. Many of the numbers here come from Scotland, which has the advantage of being smaller and easier for calculations than larger European countries. Scotland also has a balanced energy mix, with significant contributions from hydro, nuclear, gas, as well as oil and coal. The numbers/orders of magnitude in the Northland case would also be close to the real numbers in countries such as Finland, Switzerland, and the Czech Republic.

[1] There's really a lot of water in an Olympic swimming pool and the leak was twice that every day

[2] It turned out to be similar within an order of magnitude

[3] Look up 'Beauly Denny' line and you'll see what I mean

With this in mind the energy/emissions spreadsheet provides students with an opportunity to put numbers to the compromises inherent in energy policy. They should be able to see that unilaterally closing power stations, while it may reduce carbon emissions is also likely to lead to power shortages. They should also be able to see that widespread adoption of electric vehicles in Northland is likely to require very significant installation of new power generation capacity.

To me, the spreadsheet exercise is a crucial part in integrating the students' case study work into a real context. It should enable students to put their knowledge of the new technologies in the case studies (for example the sea water extraction of uranium) into proper quantitative context – how much uranium would we need to extract to make a real difference to Northland's energy requirements and carbon footprint? Working in technology assessment (both at BP and as a consultant) I have found that new energy technologies often fall down at this stage:

We've got a great way of making diesel fuel from tree waste!

Let me see, hmm yes, it does seem to work – how many trees do you need to get a kilo of fuel?

Here are the figures!

They're really good!

Yes but they seem to imply I'd need to reforest an area the size of Poland, to meet the fuel requirements of Andorra?!

I hope this discussion aids those contemplating doing this module at their Institutions. I am personally happy to be contacted by phone, e-mail, or Skype if further clarification is required and would consider requests for further involvement on a case by case basis.

Dr Kevin Parker MRSC CChem.

Comments from Dr Dylan P. Williams

The key objectives of the authors based at the University of Leicester were to develop and deliver a PBL case study (of 5 credit value) based on the priority area of energy which would engage students and allow them to enhance their core chemistry knowledge and develop their career and vocational skills in the context of an important issue to society. By participating in this project the authors also hoped that they could contribute to a programme which would encourage the adoption of innovative teaching methods in chemistry across the UK higher education sector.

Perhaps unsurprisingly, most university students studying chemistry, if asked to discuss the importance of chemistry in society tend to focus on medical and health issues. Hence, even amongst chemistry students their appreciation of the wider role of chemistry in modern society is somewhat lacking. In addition, the importance of some fundamental chemical principles e.g. kinetics and thermodynamics are often not appreciated by students, they see these as difficult topics that must be endured rather than subjects of prime importance in the application of chemistry. In this regard we felt that energy was an ideal topic to enthuse students in the importance of chemistry in their everyday lives and indeed the future of the planet. It was hoped that the use of PBL would also introduce students to the challenges faced by chemists while helping them develop communication, teamwork and organisational skills through the use of contextualised, open-ended group problems.

Dr Dylan P Williams MRSC

Student Outputs

'The Chemistry of Energy' is a group-based exercise. By the end of the module student groups should have produced the following outputs.

Part 1 - Power Generation

Students will study one of five renewable energy technologies, carry out some calculations in the potential usefulness of the technology and **produce a 15 minute presentation** about it. The presentation should be aimed at explaining the issues, advantages and issues around the technology in a non-technical fashion, as if the team were presenting at a press conference. They will have to answer questions on the topic from a group of 'journalists' in the audience.

As an extension of the work, students are asked to do a qualitative and semi-quantitative estimate of options for exploiting a 100 km south facing escarpment in Northland – the 'Northland fault line'. Potentially, this scarp face could be:

a) covered by photo-voltaic cells

b) planted with biomass crops

c) planted by carbon absorbing fast-growing trees

Which of these would be the best option? Groups may need to interact with each other to get the necessary information about the options for this part of the project. Each group will **produce a written report** that will be sent to the PM in response to his enquiry (suggested word limit 600 words).

Part 2 – Energy Conservation

Students will study and evaluate 5 research projects from 'Northland University' all of which have some bearing on the transmission of electric power through the national grid. Each team will **produce a (5 slide minimum) presentation** summarising the main advantages and issues facing each project, and recommend which ones should attract further Government funding.

Part 3 – Societal Issues

In the first part of this module students will use an Excel Model to develop new scenarios reflecting the impact of the technologies assessed in parts 1 and 2. The model quantifies both carbon emissions and electric power generation/consumption on a 'business as usual basis'. Students should use their scenarios to change/supplement the model. Can any of these new technologies both reduce carbon emissions and increase the generating capacity of Northland? **The output should be a clear, well-annotated spreadsheet model.**

In the second part students will use the model to estimate the total energy balance (not just electricity) in Northland. Is the amount used in Transport and Heating/Built Environment more or less than in electricity generation? What are the implications for power generation of electrifying the countries railways, or shifting from gasoline to electric vehicles? Again, the **output** should be a clear, well-annotated **spreadsheet model**.

Finally, the students are asked to provide a **short briefing note (600 words or less)** on the basic, unarguable, chemistry and physics behind Climate Change. This is a document that can be used by politicians and science communicators to increase the public understanding of the area and the best policy options arising from it.

Student Introduction

'The Chemistry of Energy' is a group case study which will guide you through some of the key chemical aspects of power generation, the distribution of energy and the relationship between science and policy. You will work in groups as a scientific advisory team to a number of ministries in the government of Northland. Please read the emails that you receive from government ministers and the accompanying attachments for more details on what you need to do.

Emails and News Stories

Throughout this problem you will be presented with a number of messages in the form of emails. These emails include important information on what you need to do for each part of the problem. Read them carefully and in your groups decide how best to respond.

You will also see a number of news stories relevant to the problem. These stories will provide some additional background information to the problem and will also contain some information that you will need to consider when preparing your solutions to the problem.

Learning Outcomes and Pre-session Preparation

The resource includes a list of relevant intended learning outcomes from each session. This acts as a check list for what you should be able to do after tackling the part of the problem covered in that session. The assessments for each part of the problem is aligned to these lists so please make sure you demonstrate the competencies listed in your assessed work.

The pre-session preparation should guide your research before each session. It is worth remembering that the information presented in the problem is meant to be a starting point, you will need to do further research to fully prepare for each session.

Assessment

This resource makes use of a range of different types of assessment based on the general theme of science communication in the workplace. Communicating your understanding to a range of different audience types in a number of different ways is a very important skill to have. This resource aims to give you the opportunity to develop a range of communication skills and to make key decisions based on your scientific understanding of various concepts combined with an understanding of related political and economic factors.

Facilitation

You will be guided through the problem solving process by a facilitator (or tutor). Although your facilitator can provide advice on problem solving strategies, the facilitator will not freely give information about the problem away (for example, they won't tell you which proposal they would back in the first part of the problem). Your facilitator will help you by encouraging discussion amongst the group and (if needed) focussing this discussion.

Dear Scientific advisory team,

I want to welcome you to your new role as scientific consultants to the Northland government. I am looking forward to working with you on the development of a plan to develop sustainable energy technologies which will ensure the long term security of our nation's energy supplies. I have given included some data about our current power generating facilities as well as some facts about transport habits and carbon footprint that you may need to refer to during this task.

Best wishes,

Robert Davies (Northland Science Minister)

Welcome to Northland

Northland is a small North-Western European nation with a population of around 5 million. Northland is a member state of the European Union and its economic and political structures are similar to those of other nations in the region.

Data on Northland (provided by the Northland office of statistics)

Location: North-Western Europe

Population: around 5 million (density about 60 per km2) – major population centres are in the south of the nation.

Political Unions: Member state of the European Union, NATO and UN member

Political/Economic Structure: Parliamentary democracy. Nation divided into constituencies with a political representative elected in each (similar to those of other EU member states in the region).

Current energy resources:

- Declining offshore oil and gas
- 2 nuclear power stations that the government wishes to decommission
- 2 coal and 1 gas power plant where the government has expressed an interest in to install carbon capture and storage
- Around 1.5 GW of 1st generation hydro-electric schemes
- Considerable potential for wind, wave and tidal renewables in far north of country

Other relevant factors:

- New N-S power lines planned
- Renewables have peak output in summer
  - Long hours sunshine, steady winds
- High per capita fuel consumption for transport and winter heating

Carbon Footprint

- Current Carbon Footprint 55.4 million tonnes CO_2
  - Transport :14.4 MT
  - Built environment 22 MT
  - Power generation 16.6 MT, from total 10,600 MW installed capacity

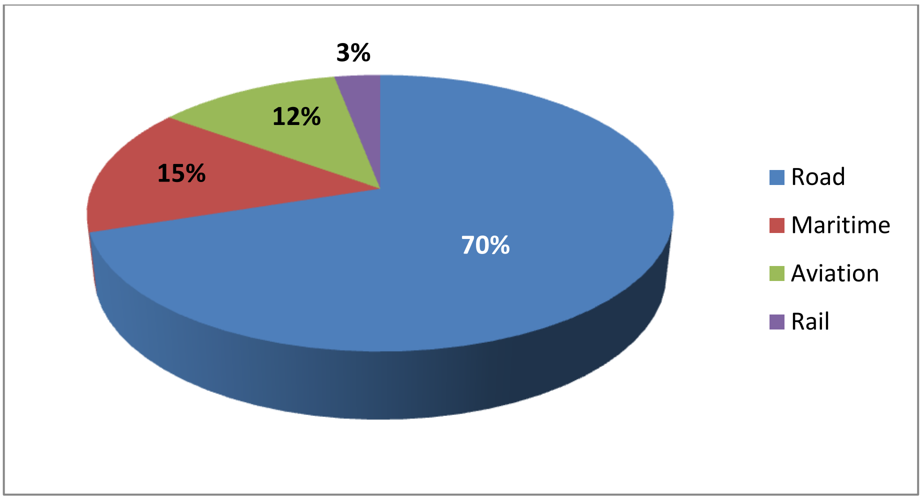
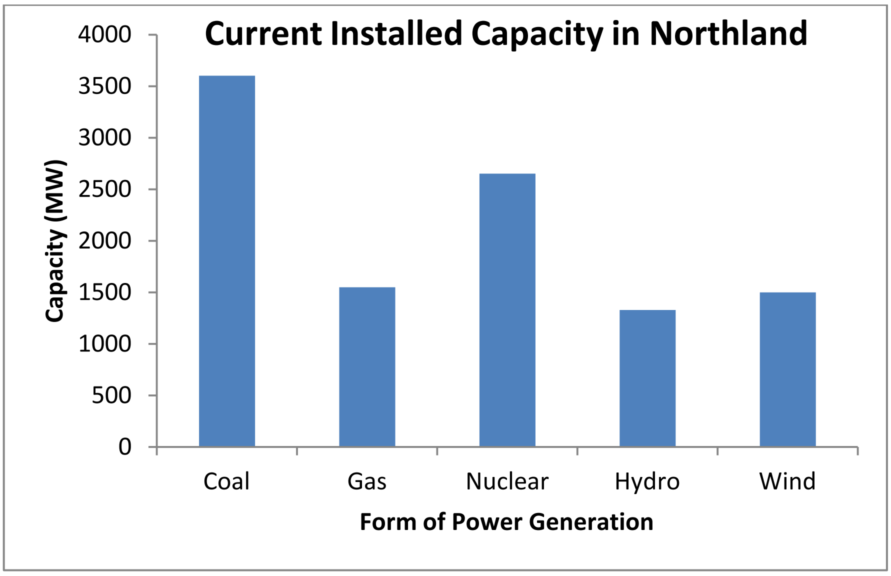


Figure 1 Contributions to carbon footprint from transport

- Other contributions to carbon footprint:
  - Built environment 22 MT
  - Power generation 16.6 MT, from total 10,600 MW installed capacity

Breakdown of installed capacity:

- 3600 MW Coal
- 1550 MW Gas
- 2652 MW Nuclear
- 1330 MW Hydro
- 1500 MW Wind



Information on Commuting in Northland:

- Average one way commute of 30 minutes.
- 25% of workforce have commutes of 45 minutes or more.
- 80% of urban workforce commute by car.
- 85% of rural workforce commute by car.

- The entire Northland rail network is run by a publically owned body (NorthRail). The government is in the advanced stages of planning the privatization of NorthRail which is hoped will provide an injection of cash to help modernize the nation’s aging rail network. The entire network is currently operated entirely by diesel trains.
- Under 5% of all car owners own electric cars

Part 1: Building for a Sustainable Northland (Power Generation)

Pre-session 1 Preparation (For the tutor)

You need to make the following resources available to students before the session:

- **The three page 'Student Introduction' section which includes the 'Data on Northland'.**
- **The outline page for session 1 (this includes the pre-session preparation and the intended learning outcomes).**
- **Give students access to part one of the problem (up to and including the executive summary for proposal 5) including the background information.**
- **Suggest to students that they should read chapters 4, 6, 23 and 24. The groups may want to divide this reading up and present a short summary to each other in the facilitation session.**

You need to make the following resources available to students during the session:

- **The relevant news article for the group's chosen technology. It is most effective to do this in the second half of the session.**
- **In the second half of the session give the students the email and the extra information about the press conference.**
- **Reinforce the nature of the task by discussing the problem with each group.**

You need to set a deadline for the report which allows you to return feedback ahead of the next session.

Session 1 (90-120 minutes)

Pre-Session Preparation

Students should be prepared to discuss the following topics in this session:

- All of the technologies and processes referred to in part one of the problem: photovoltaic cells, wind power, biorefineries, nuclear power, carbon capture technology and bastnäsite mining and processing.

Intended Learning Outcomes

Scientific:

By the end of this part of the problem students should be able to:

- Demonstrate an understanding of scientific principle of a number of sustainable power generation technologies
- Compare and contrast the relative merits of a number of different sustainable energy technologies.
- Evaluate the potential output of a number of new power generation technologies and decide which is most suitable for a small EU nation.
- Justify the chosen approach based on considerations of the future energy demands of the nation and the impact on the nation's carbon footprint.
- Consider the financial implications of the introduction of a number of power generation technologies.
- Calculate the anticipated power output from a number of different technologies by making reasonable approximations.

Transferable:

By the end of this part of the problem students should be able to:

- Work in a team on the peer-review of a number of funding applications.
- Plan and prepare detailed responses to possible questions that may be asked on a given scientific concept (i.e. one of these sustainable approaches to power generation in this case).
- Perform literature searches on active area of research in order to gain a greater understanding of fundamental scientific concepts are applied to current research
- Work in groups to produce written summaries of scientific research suitable for a range of different audiences
- Prepare for an interview (or in this case a press conference) based on the communication of a scientific concept to a specified audience type (the media in this case)

Resources and Arrangements

- This session will work best if students have access to computer facilities with internet access which will allow them to conduct research as they tackle the problem.

Make the following resources available to students **before** this facilitation session:

- Give students access to part one of the problems (up to and including the executive summary for proposal 5) including the background information.

- **You may decide to run this part of a problem in a different way by asking students to write a short report on all five proposals and then assigning a proposal to each group – this will help avoid several groups selecting the same option which creates difficulties for the press conference.**

Once students have chosen the proposal they want to back:

- **Give them access to the news articles which are relevant to their chosen proposal**

Assessment

The students should decide which proposal to support during the facilitation session. Students should work on the justification of this decision outside of timetabled hours but they may get on to planning how they will do this during the facilitation session. During the session you can ask students about their decision and give them some oral feedback (but try to avoid being overly directing. If you hear students get something wrong you might want to consider asking other group members whether they agree with the incorrect statement, this should encourage some level of reflection). The in-session feedback could include some comments on how well the group have worked together, discussed the problem and planned their problem solving strategy.

Students must hand in a one page summary of their chosen proposal which includes figures on the impact it will have on Northland's dependence on non-renewables and the nation's carbon footprint. Students are asked to write this report in the email from the science minister – <u>you will need to inform the students of the exact deadline yourself</u>.

The group should be asked to submit their summary in time to receive brief written feedback ahead of the next facilitation session – the exact timescale depends on how this is scheduled at your institution but we suggest having the second facilitation session one week after the first session (perhaps the summary deadline could be set two or three days after the first session allowing feedback to be given before the press conference). This is designed to be a group task.

You should provide written feedback on this submission. The feedback should focus on the quality of the scientific discussion, the scope of the group's research (have they gone beyond the proposal itself?). You can evaluate student performance on the questions here – if they have clearly got something wrong your feedback will give them a chance to review their understanding before the press conference.

<u>If students make mistakes in the calculation then their written report for session 1 should be marked down accordingly but the mistakes made by the group should be highlighted in the feedback. Guidance can be provided on how to calculate the correct values; this will allow students to correct their mistakes before going into the second session.</u>

To: scienceteam@northlandgreens.org.nld

From: sciencеminister@northland.gov.nld

Sent with high priority!

Subject: Review of grant proposals

Dear team,

I hope you had a chance to look through the data that I sent you. We recently put out a tender for a project to develop sustainable (i.e. using a fuel which is abundant enough to generate power for at least 1000 years) power generating facilities. Please take a look at the summaries of the most suitable proposals that we have received and write a one page summary of the proposal you feel is most worthy of investment which includes figures on the impact it will have on our dependence on non-renewables and our C footprint. The chosen approach must be clean, efficient, conform to our definition of sustainable (outlined above) and must be achievable with a realistic budget.

Please make sure you include the following points in your report:

- Describe the scientific basis of your chosen proposal
- A description of the potential this project has to meet the nation's energy demands (include any values you can calculate on how much energy this approach could produce) and the effect it will have on our dependence on non-renewables. Will it have an impact on our carbon footprint?
- The financial implications of this project – how much will it cost? What will get back in return?
- How does your chosen proposal compare to the other options?

Best wishes,

Robert Davies (Northland Science Minister)

Hint:

The discussion questions should help focus your discussion and the facilitation session. You may find it useful to consider the answers to these questions when planning your one page summary. Please note that the proposals and the discussion questions should act as a starting point – your research should go beyond these points.

The Proposals

Applicant 1 - Northland Maglev PLC

Title: Mining Bastnäsite in Northland

See Chapter 4 See Chapter D, MacKay, 2008 (and Chapter B for further information)

A recent geological survey has discovered potentially large quantities of the mineral bastnäsite (along with associated monazite) in the hills of Northland. We propose further analysis of this site followed by the establishment of a mining operation that would allow us to recover the mineral.

This development would be hugely significant for the renewable energy resources of Northland, the nation's dependence of Chinese sources of bastnäsite would be broken. By extracting bastnäsite on a large scale we could then press ahead with the second part of our project as detailed below:

- Wind power is constrained by environmental objections to the appearance of conventional wind turbines and suffers from intermittent output in variable wind conditions – including being unable to function when the wind is too strong!
- There is potential for a new design of wind turbine that addresses most of these problems – the Maglev device. We see this as the basis of a new wind power industry in Northland
- The MagLev wind turbine uses frictionless magnetic levitation: the vertically oriented blades of the wind turbine are magnetically suspended (using permanent Nd magnets) above its base
- Similar permanent magnets are used in the generator assembly as well as in the bearing
- The supply of sufficient quantities of these magnets will of course be crucial to the project, but we do not believe this will be a major problem

Discussion Questions

See Chapter 4 See Chapter D, MacKay, 2008 (and Chapter B for further information)

- What are bastnäsite and monazite?

  These are two minerals which are the main sources of rare earth elements (particularly lanthanum, cerium and yttrium).

- Why would a new source of bastnäsite and monazite be valuable to the economy of Northland?

  China dominates the world rare earth market. Given recent changes of policy by the Chinese government (i.e. export restrictions); it would be very valuable for any Western nation to secure its own supply of these minerals. This would allow local demand to be met and would potentially allow Northland to compete with China in the rare earth market.

- Why is the processing of these minerals considered to be difficult?

  Although rare earth elements are rather abundant, they tend to be difficult to extract which makes them expensive. Mineral deposits often contain a combination of (chemically similar) rare earth elements which makes separation more difficult.

- What is the connection between the mining operation and the potential application in the novel magnetic turbine? What physical property is being exploited here and what is its origin?

  Neodymium can be used in the powerful magnets present in wind turbines – Nd magnets (which are an alloy of Nd, Fe and B) are the most powerful permanent magnets available.

- What complications are caused by the presence of monazite as well in the minerals?

  Monazite contains some radioactive elements including thorium and uranium.

- How would technology helping the mine also potentially help the nuclear industry?

  Lanthanides also contaminate actinides as fission products, preventing the use of Thorium and other Actinides in nuclear power plants

  http://www.rsc.org/chemistryworld/News/2011/August/09081101.asp

- How does bastnäsite impact on the production of renewable and clean energy? Why does this process present a dilemma for environmental activists?

  Although the products of rare earth extraction are necessary for a number of 'green' applications (including the use of Nd in wind turbines as proposed here). lanthanide mining can be very polluting partly due to contamination by radioactive thorium – the Chinese operation has had many problems with contamination (See Daily Mail!): http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html

  www.bgs.ac.uk/downloads/start.cfm?id=1638

- How much power would be generated per m^2 for the onshore and offshore windfarms?

  There are different ways of thinking about this. The power generated depends on the wind speed, the diameter of the turbine, the efficiency and how closely packed they are. It's possible to find average data quoted and this is typically ~ 2 W m^{-2}. The equation used to calculate the power is

$$P = f \times \frac{1}{2} \sigma v^3 \times \frac{4}{\pi} d^2$$

  ***f* is the efficiency – typically 30 – 35 % - though could estimate to be 50 % using the new improved magnets. σ is the density of air which is ~ 1.3 kg m^{-3}. *v* is the wind speed – note that the power varies with the cube of the wind speed. *d* is the diameter of the rotor (these are typically 15 – 80 m).**

  So for a wind turbine with an efficiency of 50 % and a rotor diameter of 80 m the power when the wind speed is 11 mph (4.9 m s^{-1}) is

$$= 0.5 \times \frac{1}{2} \times 1.3 \times 4.9^3 \times \frac{4}{\pi} \times 80^2 = 312\ kW$$

Another question is how closely the turbines can be positioned. The minimum spacing is 5*d* as any closer and interference between turbines is created. So effectively you can have one wind turbine in an area of (5*d*)^2. So the power per unit area is

$$P = \frac{f \times \frac{1}{2}\sigma v^3 \times \frac{4}{\pi} d^2}{(5\,d)^2} = \frac{0.08}{\pi} f\ \sigma v^3$$

i.e. it is independent of the size of the rotors.

For the onshore windfarm, v = 11 mph or 4.9 m s^{-1} and power = 1.9 W m^{-2}.

For the offshore windfarm, v = 16 mph or 7.2 m s^{-1} and power = 6.2 W m^{-2}.

- How big would the offshore windfarm need to be to generate 10 % of Northland's total energy requirement?

Total energy = 10632 MW (from data supplied) so 10 % = 1063 MW or 1.063 x 10^9 W.

1 m^2 provides 6.2 W, so need 1.063 x 10^9 / 6.2 = 1.71 x 10^8 m^2 or 171 km^2.

Note – new windfarm in Thames estuary has estimated power output of 1 GW and occupies 245 km^2.

Tutor Notes for Northland MagLev PLC

The key point that students need to appreciate is that lanthanides (especially neodymium) are needed in wind farm magnets. Lanthanides are extracted from bastnäsite

Of all the rare earths, Neodymium is the one that might run out

http://setis.ec.europa.eu/newsroom/library/setis-presentations/jrc-report-on-critical-metals-in-strategic-energy-technologies

Lanthanides also contaminate actinides as fission products, preventing the use of Thorium and other Actinides in nuclear power plants http://www.rsc.org/chemistryworld/News/2011/August/09081101.asp

For a comprehensive view of the issues around lanthanide mining, see the British Geological Survey Publication – 'Rare Earth Elements' www.bgs.ac.uk/downloads/start.cfm?id=1638

Applicant 2: Northland Nuclear Limited

Title: New generation uranium fission reactors for Northland

Project Abstract:

See Chapter 24 See Chapter D, MacKay, 2008

In spite of a number of isolated safety incidents involving nuclear fission processes, nuclear remains the safest and most economically viable way to plan for a sustainable future for the nation. Nuclear power is an effective, sustainable power source and when compared to other nations in the area we underuse nuclear and rely too much on fossil fuels (see comparison of the energy mix in France and Northland below) Northland has relied on nuclear facilities to deliver over 2.5 GW of power since the mid twentieth century. As these first generation power stations are decommissioned we need to be ready to bring a new generation of once through nuclear fission facilities online in order to ensure that the energy demands of the nation are met.

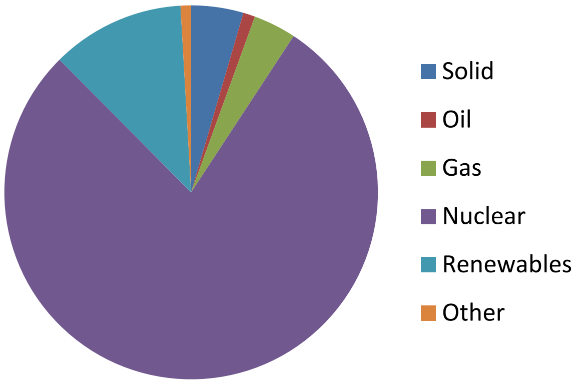
In order to make Northland self-sufficient in nuclear power, we plan to establish a facility which is capable of recovering uranium from the oceans. By opening the first industrial scale oceanic uranium recovery plant, the government of Northland will be sending a strong message out to the rest of the world that our nation is committed to the development of innovative solutions to the problem of ensuring a sustainable energy supply.

Northland currently relies entirely on imported Uranium for use in our nuclear facilities, by extracting uranium from our own coastal waters we would be able to reduce costs and possibly work towards becoming a net exporter of both uranium and the energy produced. Northland has coastal waters of 9000 cubic miles; initial findings have shown that these waters have a uranium concentration of 3.3 ppb by mass.

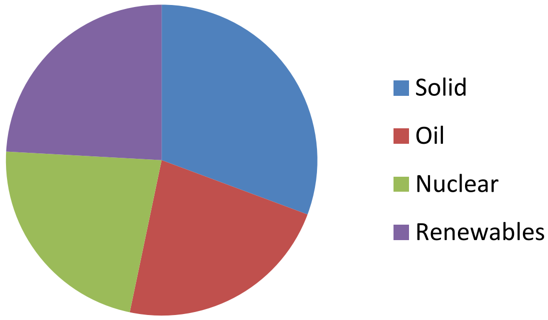
We plan on developing an approach based on that employed by the Takanobu Sugo group at the Japan Atomic Energy Research Institute (JAERI).The Japanese group has described an approach which uses an adsorbent which selectively soaks up uranium from sea water. This adsorbent is essentially a nonwoven fabric of polyethylene with amidoxime groups attached by graft polymerisation. It is the amidoxime groups which are responsible for recovery of uranium.[1]

The first stage of the project will see us take control of two existing nuclear sites and overseeing their decommissioning, the same land will be reused for the new generation sites.

We are confident this project will give Northland the energy security it needs in a time of global shortages of non-renewables.



2004 Domestic Production of Energy in France[2]

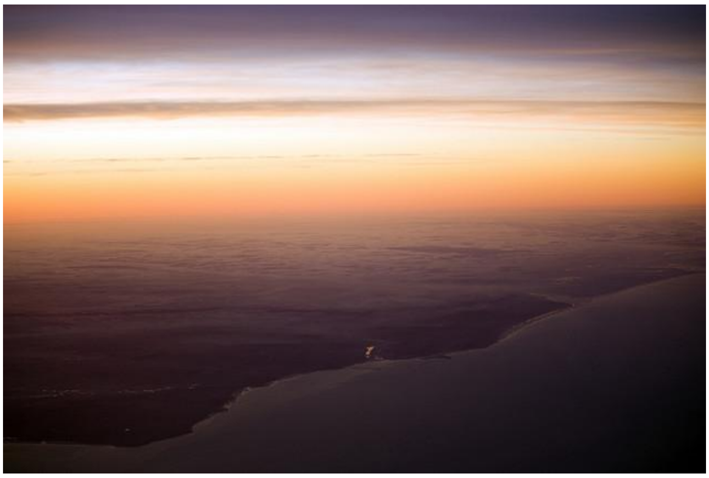


2010 Domestic Production of Energy in Northland

1 http://escholarship.org/uc/item/12h981cf.pdf
2 http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_fr_en.pdf

Executive Summary:

- The World's oceans contain around 4.5 billion tons of Uranium, new recovery technologies can be used to extract this Uranium and processing this material in new generation nuclear facilities provide an effectively sustainable supply of energy
- We propose the extraction of Uranium from the Western Sea. This will be used to run a new generation of fast breeder nuclear reactors
- In spite of the recent incident in Japan, nuclear remains amongst the safest power generation technology
- The Northland coastal waters contain a volume of approximately 9,000 cubic miles.
- We propose to develop new facilities on the sites the two existing nuclear facilities located on Northland's west coast.
- We will engage in public consultation on the decommissioning of the existing facilities



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Comment from Science Minister:

The PM is fascinated by the concept of using an adsorbent to extract Uranium. How does it work? Will this really work on a large scale?

Discussion Questions:

See Chapter 24 See Chapter D, MacKay, 2008

- Describe the process of nuclear fission.

  Nuclear fission is essentially the division of a heavy nucleus in to two medium mass nuclei. Thermal neutrons can be used to induce the fission of ^{235}U. The ^{235}U nucleus can fragment in a number of ways with the release of energy due to mass loss.

- Have there been any other projects comparable to this proposal?

  There is a number of relatively small scale, research based applications of the Uranium extraction technology, but it has never been applied on an industrial scale before.

- What issues are involved in the shutdown of a nuclear power station?
- Given his background in chemistry, the prime minister will be fascinated by the Uranium extraction process. Will the process described by the Japanese group work on a large scale? How does it work?

  See reference for 1 for a review of these approaches

- Based on the values quoted in the proposal, how energy per person, per day could be generated if this approach was sustainable?

There are two key limitations to the calculation below:

1 – the assumption that Northland's coastal waters behave as an isolated body of water is not really appropriate.

2 – the assumption that the population of the nation will remain static for 1000 years is also unlikely to be accurate.

Northland has 9000 cubic miles of coastal water which is equivalent to 3.75×10^{13} m^3 of water (3.75×10^{13} L). Given the concentration of Uranium given above (3.3 ppb by mass, T-L. Ku. K.G. Knauss. and G. C. Mathieu."Uranium in Open Ocean: Concentration and Isotopic Composition." *Deep-Sea Res.* 24, 1005-17 (1977): *Chem. Abstr.* 89, 11.766 (1978)), there are around 123 849 tons of Uranium dissolved in the offshore waters of Northland.

Assuming that 162 tons of U is equivalent to a GW-year (page 162, Sustainable Energy without the Hot Air, David MacKay, 2008 and www.world-nuclear.org/info/inf03.html), the total energy that can be generated is:

$$\frac{123849 \; tons \; U}{162 \; tons \; of \; U \; per \; GW - year} = 764.5 \; GW - years$$

Assuming 10% of this Uranium is extracted over a 1000 year period the rate of power generated is:

$$\frac{76.45 \; GW \; years}{1000 \; years} = 0.07645 \; GW$$

Given a population of 5 million:

$$\frac{0.07645 \; GW}{1000 \; years} = 15.29 \; W \; per \; person$$

Which is equivalent to 367 W hours per day per person for 1000 years.

Tutor Notes for Northland Nuclear Limited

- **Students need to include a discussion of nuclear clean-up**

Applicant 3: Northland Power

Title: Sustainable solid fuel for Northland

Project Abstract:

See Chapter 23 See Chapter D, MacKay, 2008

The current power generation strategy of Northland makes heavy use of coal-fired power stations (current installed capacity: 3600 MW). This is partly due to our nation's once abundant reserves of coal; of which approximately 1.4 Gt remain. We believe that coal will continue to play an important part in any future power generation strategy. Many renewable sources of power are very expensive to harness, the technologies aren't advanced enough to make a major impact or are simply incapable of generating sufficient energy to meet the growing needs of the population of Northland.

We need to change the way we think about coal power and use this resource much more efficiently and effectively. The energy equivalent value of one ton of coal is 8000 kWh (or

29.3 GJ); if we were to use our coal reserve responsibly, we could potentially meet a significant amount of the nation's energy requirements over a long enough period of time to consider this approach to be sustainable.

In order to address concerns about the environmental impact of continued fossil fuel combustion we propose the construction of new generation power stations which will use carbon capture and storage technology which will significantly reduce emissions of CO_2 minimising the impact of this approach on the nation's carbon footprint.

We argue that coal plays an important part in the power generation strategy of the nation alongside renewable approaches.

Executive Summary:

- Fossil fuels will continue to provide a vital contribution to the nation's energy mix for the foreseeable future – 'renewable' energy sources alone will not meet the nation's energy needs!
- Northland has coal reserves of around 1.4 Gt
- A new generation of coal based power stations utilising carbon capture and storage will be developed
- By working in parallel with other approaches to change Northland's energy usage profile, we can use our existing fossil fuel resources in a sustainable manner providing energy for the next 1000 years
- See: Carbonate chemistry for sequestering fossil carbon and Greenhouse Gas Mitigation Policy

Discussion Questions:

See Chapter 23 See Chapter D, MacKay, 2008

- How does this technology work? Will carbon emissions be completely eliminated?
  Carbon capture and storage technologies are based on extracting carbon dioxide emitted during fossil fuel combustion and providing a long term storage facility. There are a number of ways of doing this but this post combustion capture will be the most applicable to this implementation. Post combustion capture is based on the removal of flue gas followed by compression, transport and storage. Capture is typically achieved by passing the carbon dioxide through amine solvents (or 'adsorbents'). The Carbon capture process is very energy intensive so students should include this in their calculations (a 25-50 % penalty in the energy produced per person per day will suffice – 25% is stated on page 157 of Sustainable Energy without the Hot Air, David MacKay, 2008). This technology does not completely eliminate carbon dioxide emissions – it is thought the approaches can capture 80-90% of CO_2 emitted by power stations but this comes at a high energy cost.

  http://web.mit.edu/mitei/docs/reports/herzog-meldon-hatton.pdf

- How much energy does the carbon capture process use?

Cleaning up emissions in this way costs a lot of energy! The electricity delivered by this facility will be 25 % less than that delivered by combustion with no clean-up

- What is the energy equivalent value per person per day of this process?

  Example calculation (not a definitive answer – students may make other assumptions that may well be equally valid!):

  This assumes constant consumption (which isn't really correct – demand normally doubles every 20 years)

$$Energy\ equivalent\ of\ 1.4\ Gt\ of\ coal:\ (1.4\ \times 10^{9}\ t) \times 8000\ kWh = 1.12\ \times 10^{13}\ kWh$$

$$Energy\ equivalent\ per\ person\ per\ year = \frac{1.12\ \times 10^{13}\ kWh}{(6\ \times 10^{6}\ people) \times (1000\ years)}$$

$$= 1866.67\ kWh\ per\ person\ per\ year$$

$$Energy\ equivalent\ per\ person\ per\ day = \frac{1866.67\ kWh\ per\ person\ per\ year}{365\ days}$$

$$= 5.1\ kWh\ per\ person\ per\ day$$

$$Coal\ power\ stations\ have\ efficiencies\ of\ around\ 37\%:$$

$$(5.1\ kWh\ per\ person\ per\ day) \times 0.37 = 1.9\ kWh\ per\ person\ per\ day$$

$$Energy\ penalty\ for\ using\ carbon\ caputre\ allows\ us\ to\ produce:$$

$$(1.9\ kWh\ per\ person\ per\ day) \times 0.75 = 1.4\ kWh\ per\ person\ per\ day$$

Sources of Data

- **Energy equivalent value of coal – page 157 Sustainable Energy Without the Hot Air, David MacKay, 2008**
- **Efficiency of coal power stations - page 157 Sustainable Energy Without the Hot Air, David MacKay, 2008**
- **Energy penalty for using carbon capture – figures vary between about 25-50 %. The recommended text states 25% so that figure has been used here.**
- The coal fired power stations in Northland produce about 12.3 Mt of CO_2 each year. How much coal must they be burning to produce this? They produce about 14 TWh of electricity a year. Given the energy of combustion of coal, what does that say about the efficiency of these plants?

  Either get data such as 1 tonne of coal at 85% carbon will produce 3.12 tonnes of CO_2. Northland Power stations using 85% carbon anthracite are burning about 3.94 Mt (12.3 x 10^6/3.12) of coal. This amount of coal could produce 32.1 TWh of energy (enthalpy) of combustion (3.94 x 10^6 x 8140).

  OR: 12.3 Mt of CO_2 contains 12.3 x 10^{12}/44 = 2.80 x 10^{11} moles of CO_2.

  So 2.80 x 10^{11} moles of C must be burned to produce this. i.e. 2.80 x 10^{11} x 12 = 3.35 x 10^{12} g, or 3.35 Mt.

  If pure, then would need 3.35 Mt of coal. If only 85 % pure then 3.35 is equivalent to 85 % and 100 % corresponds to 3.95 Mt.

  To get the energy produced, EITHER calculate as above OR

the enthalpy of combustion of C to form CO_2 is -393.5 kJ mol^{-1} In 3.35 Mt we have 3.35 x 10^{12}/12 = 2.80 x 10^{11} moles of C if pure. 2.80 x 10^{11} moles of C will release 2.80 x 10^{11} x 393.5 x 10^{3} = 1.10 x 10^{17} J (or 3.06 x 10^{13} Wh, or 30.6 TWh).

Since only 14 TWh is produced the efficiency is 14/30.6 x 100 = 46 %

- How long would the current reserves of fossil fuel last at this rate of consumption?

  Currently have 1.4 Gt. If 3.94 Mt burned each year then have enough for only 355 years (1.4 x 10^{9} / 3.94 x 10^{6}). I.e. it is not sustainable.

Tutor notes for Northland Power

- **Sustainable has already been defined as 1000 years or more by the government (in the opening email). Students should use the figure of 1000 years in their calculations.**
- **This technology will not completely eliminate greenhouse gas emissions! Students must look in to how this technology works and come up with a realistic figure here.**
- **1 tonne of coal at 85% carbon will produce 3.12 tonnes of CO_2. Northland Power stations using 85% carbon anthracite are burning about 3.94 Mt of coal. This amount of coal could produce 31.5 TWh of energy (enthalpy) of combustion.**

Applicant 4: Photocell PLC

Title: The development of a sustainable solar farming sector in Northland

Project Abstract:

See Chapter 6, MacKay, 2008

This project will follow the example of ambitious schemes such as Bavaria Solarpark in Germany as well as smaller scale schemes such as the Rhosygilwen solar park in Wales. Northland can no longer afford to ignore the potential of solar cells as a solution to large scale power generation. If Northland persists with its dependence on non-renewable energy resources, it is likely that the nation will be entirely dependent on energy imported from other nations by the middle of the century. Given the constant concerns about security of supply and fluctuating energy prices, it makes sense for us to invest in our future now that we have the opportunity. Solar power is a totally clean energy source; we could eliminate a significant quantity of our CO_2 emissions if we were to invest in a large scale solar solution.

The sun provides 1000 W of power at midday on a clear day (see Figure 1 for the variation of average solar intensity throughout the year as recorded by Northland University). The key aspect of our proposal is the creation of a 50 hectare solar park which will make use of 15 % efficient photovoltaic cells fitted to solar trackers.

The project is based on the development of a large scale solar park for power generation but also includes two other vital sub-projects. We aim to make thermal panels commercially viable solutions to all households in Northland. With a government subsidy, it is likely that we could encourage mass take up of solar heating schemes amongst the population of

Northland. If we covered all south facing roofs with thermal panels we could significantly reduce the drain that these properties currently place on the national grid due to heating.

The third aspect of this project is based on the establishment of a research and development plant in collaboration with Northland University's Centre for Sustainable Energy. The aim is to develop a world leading site in the field of solar cell research. We aim to pursue research into the development of highly efficient, low cost solar cells based on both silicon semiconductor and dye sensitised technologies.

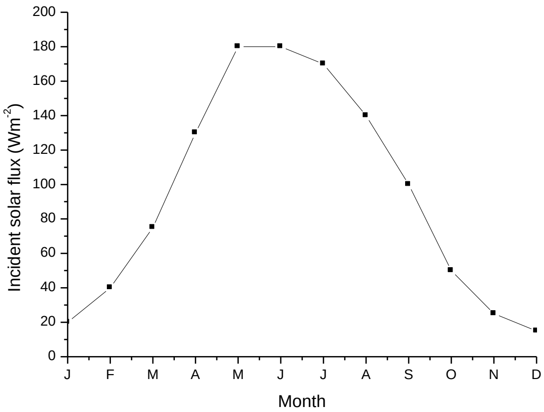

Figure 1. The variation of average solar intensity at Northland University throughout the year

Executive Summary

- We propose an ambitious plan to substantially reduce the dependence of Northland on non-renewable forms of energy.
- Our plan is based on three main components:
    - The installation of subsidised solar panels on south facing roofing of residential and business properties to provide hot water. This will be used to help reduce the drain on the national grid by individual properties.
    - Solar farming – we propose the development of a number of solar farms on suitable south facing land. This has the potential to produce a significant amount of power.

The final aspect of our plan involves the establishment of a large scale research and development plant which will investigate the development of photovoltaic cells with greater efficiency than currently possible.

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Discussion Questions:

See Chapter 6, MacKay, 2008

- What is a reasonable value for the average value of the solar power per m^2 in Northland? You may assume that the intensity of sunlight in Northland is approximately the same as it is in Northern England.
The solar energy reaching the surface of the Earth (at midday on a cloudless day) is around 1kWm^{-2} (Sustainable Energy Technologies: Options and Prospects, K. Hanjalid, R. Van de Krol, A. Lekid, Springer, 2008, page 100 and Sustainable Energy without the Hot Air, D. MacKay, 2008, page 38). The actual power available from the sun per square metre is lower that his value because of the angle of incidence between the surface and the Sun and the fact that it is often cloudy. A more suitable value is 100 Wm^{-2} which takes these factors into account.
Students can work out an average value from the plot but they should be aware that the total raw power from the sun is significantly higher than this value and they should understand the factors that dictate why the actual average is lower.
- What is the potential total power output of this facility?
Example answer calculation
Assuming the average solar flux is about 100 Wm^{-2} (taking into account the fact that it's not always midday and cloud cover is variable).
Power per unit land area (15 % efficient cells – this is a typical value for affordable cells): $15\,\% \times 100\,Wm^{-2} = 15\,Wm^{-2}$
Total power generated by solar park (50 hectare plant, assume 25% coverage by cells): $15\,Wm^{-2} \times 125000\,m^2 = 1.875\,MW$
- What is the operating principle of silicon based photovoltaic cells? What is the typical efficiency these cells?
PV cells make use of amorphous, polycrystalline, monocrystalline amongst other materials. Solar radiation bombards the solar cells leading to absorption of solar photons by the semiconductor materials in the cells. This leads to the creation of an electron-hole pair, the electron and the hole are then separated with electrons flowing to a negative terminal and holes to a positive terminal. Depending on the level of students, you could use this to introduce band theory, conductivities of solids or p-n junctions.

- Why are researchers having difficulty creating photovoltaic cells with efficiencies higher than around 40%?

  Typical single junction solar cells have an upper efficiency limit of around 31 %. Most photovoltaic cells in current use have efficiencies significantly lower than this value. The 31% value is known as the Shockley-Queisser limit and depends on a number of factors including heat radiated by the cell as a blackbody emitter (which is more significant at higher temperatures) amd recombination losses. The 15% efficient cells mentioned in this application would actually be rather expensive.

Tutor Notes for Photocell PLC

Students should be alarmed by the inconsistency between the value quoted here and those in figure 1! Students need to think about the tilt between the sun and the land which reduces the midday intensity down to about 60% of the raw value and also because the figure quoted above is a maximum intensity, measured at midday! Cloud cover will also affect the value.

These are highly efficient so this would be very expensive!!!

Students need to discuss the factors limiting the efficiencies of solar cells and the fact there is practical limit on this value. Solar cells may become cheaper but the scope for enhanced efficiency is very limited.

Applicant 5: Northland Biomass

Title: Northland Biomass Refinery

Project Abstract:

See Chapter D, MacKay, 2008

This project will transform the global perception of Northland from a small nation dependent on environmentally unfriendly industrial activities powered by non-renewable energy supplies into a dynamic nation willing to embrace new technologies in order to guarantee a sustainable future.

This project will develop two biorefinery complexes which will process locally grown biomass such as rye-grass into a range of bio based products (such as chemical resources and materials such as plastics) and bioenergy (such as fuel, heat and power).

This processing method is will generate a number of high-value products (as described above). These refineries will generate electricity and process heat by making use of combined heat and power technology – this will generate enough power to run the refinery (thus reducing the refineries dependence on externally generated electricity) and may produce enough to contribute to Northland’s national grid system. The biofuel generated by this refinery has the potential to act as a petroleum substitute which could be used to relieve the dependence of the nation’s transport infrastructure on fossil fuels.

The biorefinery concept is well suited to Northland due to the abundant supply of feedstock which can be harvested without disruption to the land use pattern in the nation. This project will be highly valuable to the nation as it will aid in the economic and social regeneration of rural communities in Northland by producing a diversified farming industry.

We aim to harmonise our plans with those of the EU biorefinery project with the eventual aim of allowing our sites to become demonstration plants for the EU project. In order to apply for membership of the EU project we will require a commitment from the Northland government.

Executive Summary

- We proposal to develop two biorefinery complexes which will produce valuable chemical feedstocks and will generate electrical energy used to power the facility and to be distributed back in to the grid.
- We aim to get some financial and technical support from the EU biorefinery project with the eventual aim of opening our plants as demonstration sites for the biorefinery project.

Discussion Questions:

- What is the potential total power output of this facility? Assume that Northland has about 1.35 million hectares of woodland and plans to add another 0.65 million hectares. The incremental woodland will add around 1 million tonnes of wood biomass fuels per year as well as absorbing CO_2. How much energy might we get from this?
- Give details of some of the chemical processes that occur in similar biorefinery facilities.

Tutor Notes for Biomass

See Chapter D, MacKay, 2008

Data for wood fuel depends on the type of wood and how it is dried (see page 325 of D. MacKay, 2008). Go for air dried as doesn't require any extra energy! Soft wood – 4.4 kWh/kg, hardwood – 3.75 kWh/kg

- 1 Mt of softwood will produce $1 \times 10^6 \times 10^3 \times 4.4 = 4.4 \times 10^9$ kWh = 4.4 TWh = 1.54×10^{19} J.
- 1 Mt of hardwood will produce $1 \times 10^6 \times 10^3 \times 3.75 = 3.75 \times 10^9$ kWh = 3.75 TWh = 1.35×10^{19} J.
- OR – if get info direct – then 1 tonne of wood fuel produces around 13.5 GJ of energy when burnt. So a million tonnes could produce 13.5×10^{18} joules or 3.75 TWh.
- If used for heating that's about 5% of Northland's building heating. You could use it to generate electricity. However, ask the group working on coal power about the efficiency of thermal power stations – it's only around 45% for solid fuel so in practice you might get around 1.7 TWh.

For examples of chemical processes see: Green chemistry and the biorefinery: a partnership for a sustainable future by Clark et. al. in Green Chemistry (doi:10.1039/B604483M)

Tutor note

Distribute the relevant stories each group after they have chosen which technology to support (i.e. in the second half of the session).

News Stories from Northland Gazette

Nuclear

Public Favours Nuclear Decommissioning

Story from the Northland Gazette

A government survey has shown that the public wants the government of Northland to follow the lead of Germany by announcing a shut-down of the nation's nuclear programme. Over 60% of the public fear the risk of a repeat of the Japanese incident at one of our nuclear plants. The government has already announced the closure of two existing nuclear facilities which are approaching the end of their productive lifetimes. The government has yet to decide whether to invest in replacement nuclear facilities or to pull the plug on the nuclear programme.

China Considers Nuclear Future

Story from the Northland Gazette

The recent nuclear disaster in neighbouring Japan has prompted the Chinese government to consider its own nuclear options. The Chinese government has suspended the approval of all new reactors while the review process occurs. There are concerns that the increased costs of guaranteeing safety of nuclear plants and the issues related to China's lack of Uranium resources has led to some critics of nuclear power in the region claiming a change in strategy is needed – China currently plans to have 80 GW of installed capacity by 2020. Supporters of nuclear power have reminded critics that they need to consider the cost of nuclear decommissioning and importing of energy that Germany now faces following its recent decision to phase out nuclear power.

Lanthanides (Wind Power)

China Feels the Environmental Impact of Renewables

Story from the Northland Gazette

The extraction of rare earth elements (including Neodymium) in China is creating an environmental catastrophe. This process is necessary for the extraction of neodymium, a vital component in a magnetic alloy used in wind turbines across the world. The extraction process has transformed farmland into vast toxic and radioactive lakes which have made life difficult for some communities in Inner Mongolia. China dominates the world market for neodymium and as part of the drive for more environmentally 'friendly' power sources; demand for these materials from the west is high.

China Threatens West with Rare Earth Trade Restrictions
Story from the Northland Gazette

The Chinese government has announced that it is considering restricting the availability of rare earth elements for the international market. China dominates the world market (they supply over 90% of all rare earths used globally) for rare earth elements due to natural wealth of these elements. The Chinese government is hoping to reduce the environmental impact of extracting these materials by limiting the amount extracted to quantities needed to meet the demands of the domestic market.

Biomass

Fears That Biomass Will Push Food Prices Up
Story from the Northland Gazette

An international committee has today expressed concern that the intense growth of crops intended for use in energy production may have a significant impact on the cost of food in a number of vulnerable areas. The growth of crops as biomass can divert agricultural resources (such as land, machinery and labour) away from the harvesting of food crops. Given the current vulnerability of international markets and the high levels of global poverty, the committee recommended that proposed biomass developments are approved by inter-government agencies before projects get the green light.

Solar

Government Confirms Commitment to Solar Power

The Northland government has confirmed that the programme of subsidies for the installation of domestic solar panels following recent announcements from governments of neighbouring nations outlining plans to withdraw similar subsidies due to difficult financial circumstances. A statement for the minister for energy confirmed that the subsidy would be continued for the foreseeable future and also outlined the government's support for larger scale solar power generation schemes: 'We are interested in reviewing plans from private sector industries about the efficient generation of solar power. These projects would have to prove that they offer value for money and can make a significant contribution to the energy demands of the nation in the throughout the 21st century.

Biomass

Northland Company Aims to Become EU Biomass Leader

A Northland company plans to establish two new biorefinery plants which will process biomass for the production of a range of chemical products as well as energy. Northland Biomass aims to become part of the EU biomass refinery project with the intention of making these two sites the most advanced Biorefineries in Western Europe. Northland Biomass has yet to reveal just how much power could be generated by this process but the company has announced that these figures will be made public when a formal bid for funding is submitted in the near future.

To: scienceteam@northland.gov.nld

From: scienceminister@northland.gov.nld

Sent with high priority

Subject: Press conference

Dear team,

Thanks for agreeing to take a look through these proposals. We need you to do one more thing related to this. It is very important that we make a positive impact when we announce these plans to the press so I would like to invite you along to the press conference as subject experts. Please make sure you know the background of your chosen project so you can deal with any tricky questions!

Please note that journalists are often very keen on asking questions based on the following points:

- The cost of the project and the potential return.
- Environmental impact – Particularly pollution and Carbon footprint.
- What is the scientific basis of the project?
- Journalists may also ask how this is linked to other hot topics in the news. Please take a look through the latest news in the Northland Gazette.

Best wishes,

Robert Davies (Northland Science Minister)

The Press Conference

A brief description of the press conference format is given below. You may find it useful to spend 10-15 minutes at the end of this session discussing this format with all groups and asking them to think about what they already know about this format what seems to and work and what doesn't. In the trials it was useful to compile some of the better student comments on press conferences on a whiteboard.

A press conference is another way of communicating scientific ideas; the one page summary that you have prepared will form the basis of this conference. A typical press conference will start with a short address from the presenters (usually up to 5 minutes long) which summarises the message that they hope to get across. This is followed by a longer period of questioning from the audience (members of the press).

It is important to remember these points:

- This is not a standard oral presentation, the majority of the time you will be answering questions. Although you will be given a few minutes (usually no more than 5 minutes) at the start of your press conference to outline your decision, you do not need to prepare a PowerPoint presentation.
- Communicate your responses at an appropriate level, the audience (members of the press) won't be experts on these technologies so it won't be much use to simply quote findings direct from a research paper!

- The fact that you don't know how the press conference will unfold beforehand makes this a more challenging scenario than a normal oral presentation. You could possibly ask some friends to help you practice by reading through your summary and asking some general questions.
- The discussion questions should be used as a starting for preparing for the press conference.
- Critically evaluate your decision (and one-page summary) and compile a list of possible questions. Put yourselves in the shoes of the press. Some of the things that you may want to think (depending on your decision) about include:
- What are the key advantages of your chosen proposal? What does it offer that the other proposals lacked?
- What is the impact on the economy and environment of Northland? Is your chosen proposal sustainable?
- Can you support your decision with numbers which demonstrate why your chosen proposal is the most suitable option.

Hint:

Once again you may find it useful to look back at the discussion questions when planning for the press conference.

Assessment

- Your group must hand in a one page report on one of the proposals.
- You must thoroughly research your chosen proposal and be prepared to be questioned on it at a press conference in the next session.
- When you are not presenting, you will be a member of the press in the audience. Make sure you have questions prepared for the other groups – **questioning will be student led!**

Suggested Questions for the Press Conference

Given the range of options available to the students, it is difficult to come up with a comprehensive list of potential questions. This list consists of a number of general questions which will apply to any of the applications. The questions can be modified for the specific group recommendation as needed. Please note that you may want to add some questions of your own, you may also replace this entire list with some questions of your own.

The tutor is not expected to be an expert in these areas of research. The audience take the role of the gathered press so are not expected to be experts in these areas.

- **What will be the impact on the environment of this approach (e.g. the visual impact on the landscape of wind turbines)?**
- **Can you explain the science behind this approach?**
- **How do we know this approach will be safe (particularly relevant for nuclear, solid fuel combustion and, based on the risks associated with mining bastnasite, wind power)?**
- **How long will it take to implement this approach?**
- **How much will this cost the taxpayer?**
- **Just how much power can this set-up generate?**

- **Will enough power be generated to compensate for the closure of older power stations?**
- **What will be the impact on Northland's carbon footprint?**
- **You may also wish to question the groups on how the recent news stories (given out in the first session) relate to their chosen technology. e.g. for those choosing nuclear you may wish to ask 'If Germany has decided to end its nuclear programme, why are we investing in a new generation of nuclear reactors?'**

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Review your progress in this session and think about what remains to be done. Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Ask the students to briefly summarise their progress during the session and to present a plan of what they intend to do before the next session.

Pre-session 2 Preparation (For the tutor)

You need to make the following resources available to students before the session:

- **Feedback on the summary report from session 1.**
- **Remind the students that they must be prepared to answer questions on their chosen approach during this session.**
- **Remind students to read the guidance on the press conference format issued in session 1.**

During the session you should be making notes based on the quality of the press conference given by each group.

You should give the groups full feedback on their presentations. Please consult the guidelines in the tutor notes for this session and the marking criteria at the end of this document for more guidance.

Session 2 (90-120 minutes)

This session will be used for the press conference. You may want to call groups in one at a time in order to avoid groups who talk later in the session having an unfair advantage from hearing the questions asked earlier in the session. You may want to consider asking students at the same level who do not study this module to form an audience and possibly peer assess the groups and contribute to the questioning.

Alternatively if it is not practical to run one presentation at a time, you may prepare a number of additional questions which will allow enough variation in questioning between groups to avoid making the process easier for groups who go later in the session.

The questioning should be student led but you may need to seed each session with one or two questions. During the trials (year two chemistry) students engaged well with this scenario and asked a number of good questions. The audience take the role of the gathered press so are not expected to be experts in these areas.

Pre-Session Preparation

Students should be prepared to discuss the following topics in this session:

- Your chosen proposal (from session 1) so that you can answer a range of questions on this subject (you will need to thoroughly research the background of this proposal).

Intended Learning Outcomes

Transferable:

By the end of this part of the problem students should be able to:

- Verbally communicate scientific ideas with an audience of peers and to respond to a range of questions on the ideas presented
- Act as ambassadors of science in the community by helping the public gain a deeper understanding of scientific concepts which are often miscommunicated by the media

Scientific

By the end of this part of the problem students should be able to:

- Describe the relative advantages and disadvantages of a number of different approaches to power generation based on scientific considerations.

Resources and Arrangements

- Give students the 'Press Conference' email from the Science Minister after the hand in of their reports from the previous session.
- This session will take the form of a press conference. You should give each group a time slot to answer questions (they should at the front facing the rest of the audience while this happens). You may need to ask the first question (to give the students an example of what to ask) but you should allow the students to lead the questioning.

- You may want to consider asking the students to peer-review each other's attempts. A possible mark scheme for this has been included in the appendix.
- You need to make sure this room has a suitable capacity and has any audio-visual (and/or IT) support that students may need when answering questions.

Feedback

During the trials, peer and academic feedback was returned to groups within a week of the session. Feedback from the tutor should focus on the quality of the delivery of the answers as well as the level of research that the group had done before the session. You may find it useful to base your feedback on the marking criteria given at the end of this document.

Optional: Integrative Exercise - Whose Fault is it?

This exercise is an optional follow up to the press conference. This activity is based on a more detailed comparison of two different technologies: photovoltaics and biomass. As the press conference may take up an entire session, you may want to run this as an additional session. The task builds on the research that the groups have already done on these two technologies but now requires them to compare the two approaches in a given situation. The student report must include:

- A quantitative comparison of the output from these two technologies
- An investigation of how much CO_2 planting woodland along the fault line would absorb and how much energy could be generated from woodland biomass using this option.
- Clear explanations of all of the units used in the calculations.

You may want to help students identify these as the key points if they are having difficulty with the problem.

Intended Learning Outcomes

Scientific:

By the end of this part of the problem students should be able to:

- Compare two approaches to sustainable power generation and decide what the most suitable option is by calculating the energy output of each in a given situation.
- Explain what a kilowatt hour is and show how it can be converted into other energy units.
- Make realistic approximations when calculating the energy output of various technologies (e.g. how does cloud cover affect photovoltaic cells?).
- Explain the concepts which give rise to the efficiency limits of photovoltaic cells.

Transferable:

By the end of this part of the problem students should be able to:

- Work in a group to evaluate two scientific options.
- Work in groups to produce a short written report based on the evaluation of two approaches to sustainable power generation.

To: scienceteam@northland.gov.nld

From: scienceminister@northland.gov.nld

Sent with high priority

Subject: Northland fault line

Dear team,

The PM needs us to do a feasibility study to make sure his feasibility study is going to find the right answers. OK, where to start? How efficient are PV cells these days? Could we produce a 100% efficient cell? Do we get enough sun, I know we have long summer hours of daylight but does that compensate for our dark winters? And how much energy do they produce –

what on earth are kilowatt hours? Can you compare the PV option (i.e. dedicating the Northland Fault Line to solar farms) with the energy we could generate from planting a biomass crop like wood fuel or oil seed rape along the fault line? Please send a short report (around 500 words) addressing the following points and anything else raised in the forwarded email below:

Best wishes,
Robert Davies (Northland Science Minister)

To: scienceminister@northland.gov.nld

From: pm@northland.gov.nld

I've just had a meeting with a Californian state government advisor on renewable energy policy. They've done some amazing things over there; the latest photo-voltaic devices that they are using are really efficient. If we could adapt their idea to meet our needs we could cover all or more of Northland's energy if we just had a large enough area of south-facing slope. One of my advisors has suggested that we would look into using the Northland Fault Line as it's a south-facing ridge about 100 miles long and roughly 200 metres high right across the width of central Northland. I want to announce a major feasibility study into the Northland Fault Photo-voltaic Scheme at the Party Conference next month. It's just the kind of imaginative plan that will enthuse the Party and the Voters. But I want to check it out before I announce the study – I don't want it to come back with the wrong results. So can you check out the idea over the next week or so? What might such a scheme cost, and how much energy could we generate? Could we store the energy we make in the summer for use in our long dark winters? And can you come up with a response to any likely problems – just make sure we can actually get enough PV cells and that sort of thing? Of course the Greens will just want to plant trees on the ridge and absorb CO_2 but that's not really high-tech is it? Mind you, we could harvest them for biomass! I'm sure I saw an article about a new process in Chemistry World recently, can you check that out as well?

Information for Team

Insolation data for Northland Fault

	Average Incident W/m^2 Daily Flux	Average daylight Hours
Jan	20	7
Feb	40	9
Mar	75	11
Apr	130	14
May	180	16
Jun	175	17
Jul	170	17

Aug	140	15
Sep	90	13
Oct	50	10.5
Nov	20	8
Dec	15	7

Oil Seed Rape Planting Northland

Current Planting 35,000 hectares, which produces 124 kilotonnes Oil

Estimated yield biodiesel from Rape Oil 94%

Energy Yield from Biodiesel 37.2 MJ/kg

Forestry Biomass Planting: Northland has about 1.35 million hectares of woodland and plans to add another 0.65 million hectares. The incremental woodland will add around 1 million tonnes of wood biomass fuels per year as well as absorbing CO_2. Fuel wood has around 42% of the calorific value of coal (which is around 32.15 MJ/kg).

Forestry CO_2 uptake. Currently 3.316154 million acres of Forest in Northland. Absorbs around 10 million tonnes CO_2 pa.

Tutor Notes

Here are some spreadsheet screenshots looking at some of the energy numbers. There are a lot of potential conversions in this exercise!

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Review your progress in this session and think about what remains to be done. Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Ask the students to briefly summarise their progress during the session and to present a plan of what they intend to do before the next session.

PV calculations					
	Incident Flux	Hours daylight	Energy/day KJ	Energy/month	
Jan	20	7	504	15,624	kiloJoules
Feb	40	9	1296	36,288	
Mar	75	11	2970	92,070	
Apr	130	14	6552	196,560	
May	180	16	10368	321,408	
Jun	175	17	10710	321,300	
Jul	170	17	10404	322,524	
Aug	140	15	7560	234,360	
Sep	90	13	4212	126,360	
Oct	50	10.5	1890	58,590	
Nov	20	8	576	17,280	
Dec	15	7	378	11,718	
	1105			1,754,082	
Mean	92.08				
			KWh/sq metre	200.24	
			ave per day	0.549	
We have 2000 hectares =		20,000,000	sq meter		
Incoming solar energy		10,971,927	KWh/day		
at efficiency	15%	1,645,789	KWh/day electricity		
		600,713,014	KWh/year		
AC conversion	30%	420,499,110			
and other losses		0.42	TWh/year		
Annualised Energy	914.13	kWh/yr/KW			

Oil Seed Rape biomass			
Oil seed rape	35000	hectares in Northland	
Produces	124,000	tonnes oil	
	3.543	tonnes/hectare	pa
Northland Fault	7085.71	tonnes	pa
Yield of biodiesel	94%	ref below	
See http://www.angus.gov.uk/ac/documents/sacreport.pdf			
Amount Biodiesel	6687.321		pa
energy yield biodies	37.2	MJ/kg	
Energy	248,768,330	MJ	pa
1MJ equals	0.27777778	KWh	
So we make	69,102,315	KWh	pa
	69	GWh	
	0.069	TWh	pa
Total Energy road fu	37.8	TWh	
	0.18%	Northland's Transport Fuel Use	

Woodland CO2			
Conifer	1,045,000		
Broad	297,000		
Northland Total	1,342,000	hectares	
Absorbs	10,000,000	tonnes CO2	
Ratio	7.452	tonnes/hectare	
Northland Fault	2000	hectares	
Fault trees	14903.1	tonnes CO2	
Northland Vehicles	14,400,000	tonnes CO2	
	0.103%	of Northland Vehicle CO2	
Equivalent of	0.039	TWh of clean energy	
Woodland Biomass Fuel			
	650,000	incremental hectares	
	1,000,000	wood biomass	
Yield Biomass fuel	1.5385	tonnes/hectare	
So we make	3077	tonnes timber biomass	
1 tonne fuel wood	13.503	GJ	
Energy	41,548	GJ	
	11,541,026	KWh	
	0.0115	TWh	

At first sight the PV option looks to generate an order of magnitude more energy than either of the biomass options. However the students might be able to think of reasons why it would quite work out that way

The above calculation assumes 100% area coverage
The installation will need a lot of cables – see the next module!
What about bad weather, wind/snow etc?

Some useful sources

Biomass action plan for Scotland 2007 Crown Copyright ISBN 978 0 7559 6506 9 (also on web)

Handy guide to wood energy http://www.unece.org/forests/mis/energy/guide.html

Just how big is a 2 kW photovoltaic system?
http://www.homeenergy.org/graphics/HomeEnergy_20-1_feature.pdf

Part 2: Lost in Transmission (Energy Conservation)

Pre-session 3 Preparation (For the tutor)

You need to make the following resources available to students before the session:

- **The 'Government Stalls on Interconnector' news story and the accompanying email.**
- **The outline page for session 3 (this includes the pre-session preparation and the intended learning outcomes).**
- **The trail of emails.**
- **The research funding applications.**

Session 3 (90-120 minutes)

Pre-Session Preparation

Students should be prepared to discuss the following topics in this session:

- The five research funding applications based on new conductor wire technology produced by academics at northland University
- Energy losses during transmission and skin effect
- The physical properties (including electrical conductivities) of a range of different materials

Intended Learning Outcomes

<u>Scientific:</u>

By the end of this part of the problem students should be able to:

- Explain the electrical properties of a range of different types of materials based in terms of the structure of the material and an appropriate description of bonding (e.g. band theory)
- Explain how electrical power is transmitted by Grid type systems
- Decide on the suitability of a range of materials for a specific purpose (the transmission of power over long distances) based on an evaluation of a range of physical properties
- Make a decision on which material to use for a new generation of conductor wires based on a range of factors (including efficiency, safety and security) and compare the chosen approach to the other options.
- Evaluate the potential losses during transmission of power during transmission
- Explain the ‘skin effect’ phenomenon and minimise the impact of this phenomenon in conductor wires (or cables) through choice of an appropriate material

<u>Transferrable:</u>

By the end of this part of the problem students should be able to:

- Work within a group to critically evaluate a number of different scientific funding applications
- Create a short presentation which justifies a decision to back a scientific proposal.

Resources and Arrangements

- You may want to devote around 15 minutes at the start of this session to a plenary discussing this part of the problem. You can do this by asking students what the key aspects of the problem (i.e. the construction of an ‘interconnector’ which will link a major new tidal power facility with the major population centres which are over 200 miles away). You may want to ask students what some of the key issues and what some of the qualities they should be looking for in their choice of conductor.
- Give students access to the sequence of emails which introduces the problem

- Students need to have access to the five proposals ahead of this session. They should be advised to so some extra reading based on these proposals and come to the session prepared to discuss the key scientific issues with their group
- Again, students will benefit from access to computer facilities with an internet connection so they can research any issues raised when discussing the proposals and to start to put the deliverable together

This news story sets the scene for this part of the problem.

Government Stalls on Interconnector

Story from the Northland Gazette

The Northland government has come under increased pressure to underline its plans for the North-South interconnector which will allow power to be transferred from a new tidal power station due to be commissioned in 2013. The new power station will provide 10 GW of installed capacity. The interconnector is an integral part of the government vision to use the plant to power the heavily populated regions in the central region of Northland.

The controversial plan to build the interconnector through hundreds of miles of National Park has polarised opinion within the coalition government as some members of the Democratic party keen to see the plans pushed through whereas members of the Liberal party are keen to find an efficient alternative that won't blight the landscape of the nation.

Dear team,

Please read through the following research funding applications that were presented to the minister for industry and energy by academics at Northland University. For more background information, please read through the forwarded emails below.

We need a solution that both links our large reserves of renewable energy to the main electric grid system 300 miles away and reduces the financial and environmental costs of imported copper cables and the increasing problem of cable theft?

Our coalition partners (the greens) are unlikely to back our original plans to use pylons which are double the normal height. They have already asked us to look into burying power cables or using new technology which would allow smaller pylons and/or wires.

Prepare a short presentation (around 3 slides) for the industry and energy minister which details the potential of one or more of the projects in this area.

Best wishes,

Robert

Northland Science Minister

Tutor Notes:

The e-mail exchange is meant to reinforce the fact that energy policy in most countries is a series of compromises, where choices have to be made between several less than ideal resources. They illustrate fairly closely the kinds of comments that politicians and their advisors might be sending. It might be a useful exercise for a tutor to draw out a summary of the issues presented in the e-mails, once the students have read them. They show that:

- Northland needs new power transmission lines to transmit the major tidal and wave power resources from the north to the industrial south of the country
- There are technical physical chemistry reasons why the power lines need to be very tall, which however makes them visually obtrusive
- There is much opposition in Northland to the new higher power lines, as exemplified by the e-mails from the Green party
- There are technical reasons why underground power transmission is currently expensive and impractical
- Fortunately the minister for Energy is going to Northland University to hear about some new research funding applications which relate directly to the issue of power transmission

To ministerindustryenergy@northland.gov.nld:

From: pm@northland.gov.nld

How are we doing with the North-South interconnector project? Are we ready to move to detailed planning approval yet? I know that you're in discussions with the Greens, but they are our coalition partners so they'll have to fall into line eventually. Don't let them mess you around and delay the project unduly. I have every faith in your energetic (ho ho) approach on this one!

To ministerindustryenergy@northland.gov.nld:

From ministerenviron@northlandgreens.org.nld

Jo,

My party are finding it very difficult to support this interconnector project. The existing lines are bad enough but you want to double the height of this power line cutting across over 250 miles of some of the most beautiful scenery in Northland. We understand that we need to transmit the power from the new tidal scheme but why on earth do the pylons need to be so big? Can't you bury power cables? Isn't there any new technology out there to make the wires and/or the pylons smaller? Frankly, you'd better come up with a story about this if you want to have any chance at all of convincing my party

To: ministerenviron@northlandgreens.org.nld

From: ministerindustryenergy@northland.gov.nld

Jan,

Thanks for your helpful e-mail outlining the concerns of your party. We always try to work closely with our coalition partners and to that end I have asked some of my top people to produce an outline report explaining the key issues by the end of the week after next. I hope you find this useful in both explaining things to and persuading your colleagues

To: ministerindustryenergy@northland.gov.nld:

From: ceo@northlandpowertrans.co.nld

Dear Minister,

I know we have spoken about this before, but I really must repeat that the Northland N-S interconnector is crucial for our industry's and your government's plans regarding renewables. The fact is that our largest source of renewables is 250 miles away up on the north coast and we have to get the power down here. We might have 16 GW of capacity up there and we'll have to transmit it at 750KV or we'll waste huge amounts just heating the conductor wire! We'll need multiple lines to carry that AC current (Google skin effect if you want the technical stuff) and at that voltage we've got to keep it high off the ground. Sorry, but there is no alternative to our interconnector project.

To: ceo@northlandpowertrans.co.nld

From: ministerindustryenergy@northland.gov.nld:

Remind me again why we can't bury the cables?

To: ministerindustryenergy@northland.gov.nld:

From: ceo@northlandpowertrans.co.nld

Well basically the cost is so much greater. It's not just that you have to dig a trench; it's also that the cable (by the way we call them wires when they are above the ground, but cables when they are buried) itself is so much more expensive. Most underground power cables have a triple or quadruple insulated structure, with some bits being at high potential, some at earth (the outer insulator) but often you need to put ionic salts at low potential in between those layers to reduce the chance of water getting into micropores in the insulator. And of course metal is so expensive these days – hence all the thefts of copper cable that are causing such problems on the railways. Ideally we need something really cheap to carry current underground. Sadly, the cheapest electrical conductor is actually metallic sodium! Try burying that in our damp soil…'

To: ministerindustryenergy@northland.gov.nld:

From: chiefstaff.industryenergy@northland.gov.nld:

Time to go over to Northland University; you are looking at some research funding applications this afternoon.

To: chiefstaff.industryenergy@northland.gov.nld:

From: ministerindustryenergy@northland.gov.nld:

OK, on my way. Do you suppose there's any chance that this group will come up with anything useful or relevant?

To: ministerindustryenergy@northland.gov.nld:

From: chiefstaff.industryenergy@northland.gov.nld:

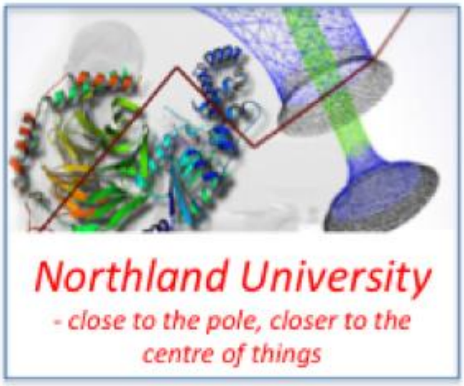
Could be. You were at the School of Architecture before, but this lot are physical scientists, and their research has been rated as 'world-leading'. Don't let them bog you down in technicalities, though – just ask the odd 'so what' question every now and then until you've got it clear what they can actually do.

The Task:

- Look through the research funding applications from 'Northland University'
- Consider the problem and discuss the grid approach to power transmission.
- Compare the relative strengths and weaknesses of each of the described approaches.
- Do any of the approaches described in these funding applications look like they might be relevant to the problems facing the Minister of Energy in Northland as it struggles to link its large reserves of renewable energy to the main electric grid system 300 miles away?
- Could any of these approaches potentially reduce the financial and environmental costs of imported copper cables and the increasing problem of cable theft?
- What is the skin effect? Is it relevant to any of these approaches?
- Create a short (around 3 slides) presentation for the minister detailing the potential of one or more of the projects in this area (<u>use the above bullet points as a guide to what should be included</u>). Include a description of what is shown in the slides in the 'Notes' section beneath the slides.

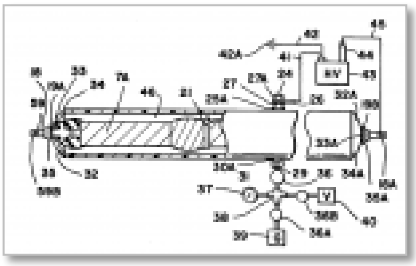
Note for tutors:

Depending on your student numbers you may choose to get groups to deliver their presentations or you could just ask them to hand the slides in and mark them (as described above). During the trials one institution showed students how to convert PowerPoint presentations into screencapture clips and asked groups to submit short screencaptures of their presentations. This meant that students still had to give the presentation but removed problems associated with scheduling these presentations.



Research Funding Application

Gas Pressurised cable and conduit system



The chemical engineering department at Northland works on cable and electrical system safety in offshore oil platforms. Typical problems are in power transformers, and situations where there is a danger of chemical or fire hazards near electrical equipment.

We have used our own hazard extreme electrical testing unit plant (HEETUP) for many years. We wish to upgrade this plant by installing much more robust electric cabling conduits. We have developed a way of pressurising sulphur hexafluoride to form an insulating layer around metal conductors. Sulphur hexafluoride is both chemically inert and a high dielectric insulator. We have designed a system for producing gas pressurised SF_6 cables, which comprises taping machines for surrounding the conductor with a continuous insulating spacer and uses through taping machines for applying a conducting shielding material which partially covers the spacer. The insulated and shielded cable is continued on in the same production line into conduit, which is laid out horizontal in long lengths or is extruded loose-fit over the cable. The cable is then subjected to vacuum while in the conduit.

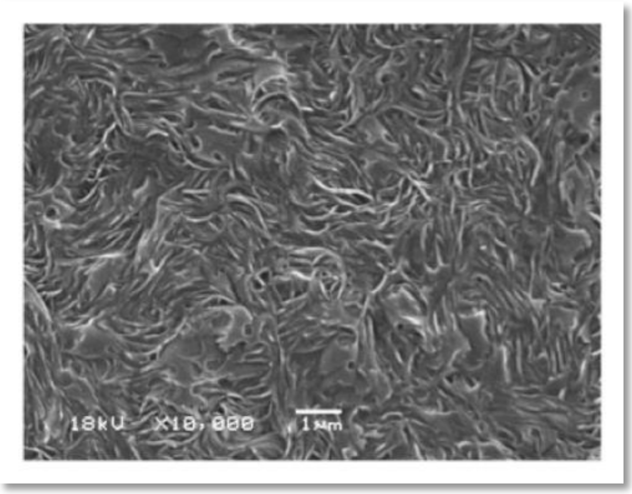
Experimental sections of cable using this technology have shown extreme resistance to fire, electrical breakdown and chemical hazard. At temperatures up to 1000C and under severe reactive conditions (oxidants, acids, alkalis) the central current carrying core is still protected by the insulating layer.

While we would like initial funding to upgrade our HEETUP system we would like to apply for ‘follow-up’ funding to investigate other applications. We feel that there could be potential for extending this cable technology to other applications, in the oil refining, chemical, and electrical industries.

Northland University
- close to the pole, closer to the centre of things

Research Funding Application

New polyethylene blend materials



We have produced a novel polyethylene material by blending linear and branched polyethylene (LPE / BPE) as potential replacement materials for chemically crosslinked polyethylene (XLPE).

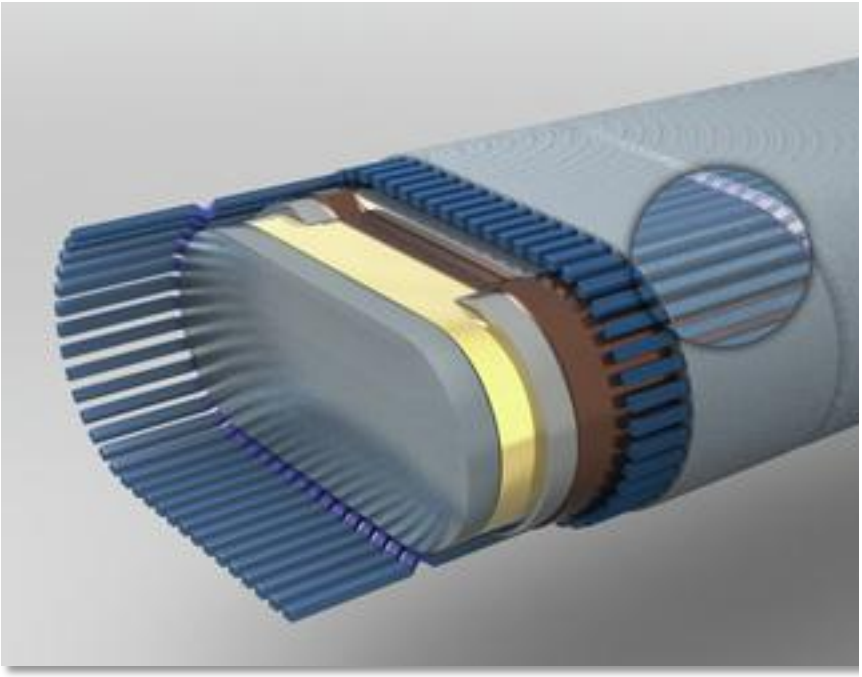
XLPE is a form of crosslinked polyethylene It is formed into tubing, and is used predominantly in hydronic radiant heating systems, domestic water piping and insulating applications.

Our blends contain BPE in virgin and crosslinked states and also blended with 20wt% LPE. We have analysed the thin film AC ramp breakdown behaviour of blends as a function of temperature up to 97 C. In addition we have carried out dynamic mechanical analysis. In concert, these data show that with appropriate control the blended thermoplastic material outperforms XLPE under conventional operating conditions and may even be suitable for higher temperature operation than XLPE.

Our lamellar crystal distribution and uniform distribution of impurities means that electrical tree growth can be greatly retarded. Developing this material does require more funding. We plan to carry out extensive mechanical creep testing and model cable trials. The effects on mechanical and electrical properties of longer term annealing, possible ageing at higher temperatures and of recrystallization following high temperature short circuit transients would require more research.

Research Funding Application

Lightweight electrical cabling



We are working on a new form of electrical cabling with world leading weight for weight conductivity. The key feature of the technology is the light-weight core which exploits metals with extremely mobile isolated 2s or 3s electrons. We believe this cable could be a third of the price of copper cabling which it could replace in many applications.

In many applications, it is not the resistance of the cable per se that is important, but rather its impulse tolerance (how much electricity you can briefly put through it without damage). Our cable is capable of surviving electrical impulses 700% more intense than the tolerance of an equivalent copper wire. Uniquely the core metal can still conduct electricity even if an overload causes it to melt, and defects are effectively self-healing. The cable is made using a single microfluidic continuous casting ("MCC") process and can be produced in a wide range of lengths and diameters. It incorporates unique safety bulkheads, which are the subject of a national patent.

Copper prices, although historically high, do not reflect the true cost of primary copper production, which includes billions of dollars annually in environmental damage, health costs and human suffering. Each ton of copper extracted produces five tons of CO_2, one ton of SO_2, global warming, acid rain, NO_x, arsenic, antimony, lead, mercury, zinc and other forms of air and water pollution.

We would like to apply for funding to support extensive field trials of this unique material.

Northland University
- close to the pole, closer to the centre of things

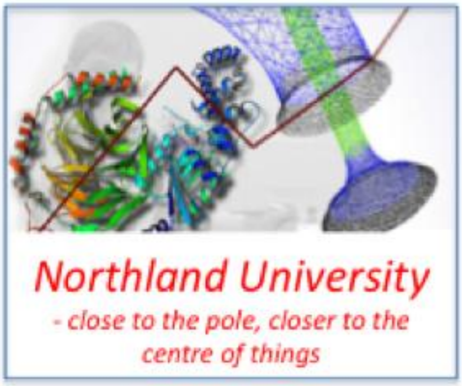
Research Funding Application

Aluminum Core Power Line

Most power transmission lines are based on steel cores that support the aluminum conductors. Many of the existing transmission lines were designed and installed years ago and are now thermally constrained, which affects the amount of power that can be transmitted before performance is impacted. Due to a phenomenon called skin effect, the current capacity of a cable is not proportional to cross section, for the larger sizes. Some installations bundle multiple wires together to increase capacity, however this can be a problem in areas with strong prevailing winds.

We have developed a power line with aluminum rather than steel cores. Each core includes aluminum oxide fibers, which impart very high strength to weight ratio. The resulting cable weighs half as much and is able to continuously handle 210 degrees Celsius (and in an emergency 240 degrees Celsius), with considerably less sag than traditional conductors. This means that the power transmission capacity of a line can be greatly increased. Technically, the ceramic fibers are continuously oriented in the direction of the wire and are fully embedded within high-purity aluminum.

We would like to apply for funding to trial this power line in some field trials in Northland.



Very high conductivity of layered lead zirconate titanates

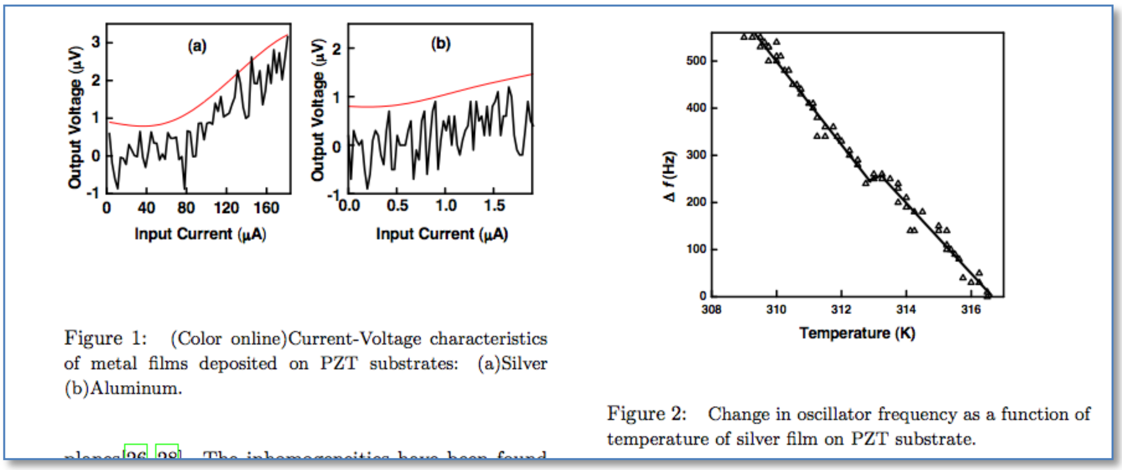


Figure 1: (Color online)Current-Voltage characteristics of metal films deposited on PZT substrates: (a)Silver (b)Aluminum.

Figure 2: Change in oscillator frequency as a function of temperature of silver film on PZT substrate.

We report extremely high conductivity in composite layers of either aluminum or sliver deposited on a substrate of lead titanate zirconate (LTZ). The samples used for current-voltage measurements were (i) thin strips 2 cm × 2 mm cut off from commercial LTZ discs 0.3 mm thick and with an average grain size 1 μm which were supplied in the poled state and with 0.1 mm silver coating on both faces and (ii) the same type of strips with the original silver coating removed and 4000A aluminum deposited by vacuum evaporation. The Curie temperature of the material was 360^0C as specified in the manufacturer's data sheet.

Measurements were carried out at room temperature using a four-probe arrangement with the sample placed inside a double permalloy magnetic shield, the residual magnetic field inside the enclosure being less than 10^{-5} tesla. The output voltage, which was of the order of microvolts, was measured using a home-built instrumentation amplifier based on an Analog Devices AD620 chip. Data were recorded in an Agilent 54622A digital storage oscilloscope by using a sawtooth current excitation at a frequency of 20 Hz from a function generator. It was found that scanning near this rate yielded the most consistent and reproducible data, least affected by fluctuations and noise.

The experimental results reported here strongly suggest the presence of very high conductivity near room temperature in the interface between a metal film and a LTZ substrate. We interpret the data in terms of the experimentally-observed inhomogeneous charge patterns in high-temperature superconductors.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Review your progress in this session and think about what remains to be done. Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Ask the students to briefly summarise their progress during the session and to present a plan of what they intend to do before the next session.

Tutor's Notes

General Points Students should bring out

1. **Having good connections to the national grid is crucial for renewable energy schemes that are located in peripheral locations (eg offshore wind, tidal in the Pentland Firth)**

2. **I^2R means that it is efficient to transmit power at high voltages rather than at high currents. Even at 400 kV or more there are still serious losses in powerlines (up to 10% of total production)**

3. **High voltage lines mean that electricity pylons need to be high – power lines in pylons are generally not insulated (except by air). There are controversies about the building of new pylons (or raising existing lines) to accommodate new electric generation capacity**

4. **Most high voltage lines are made from aluminum, not copper as the latter is heavy and expensive. Much existing low voltage cabling for domestic and industrial use is copper, and this has been subject to a lot of theft in recent years as the price of copper increases**

5. **AC current tends to flow through increasingly shallow surface layers of the conductor as the frequency increases – the skin effect. This means that you can't just add thicker cables to get more capacity**

6. **The lifetime of underground cables, (which obviously need to be insulated) is limited by the phenomenon of 'treeing' (see next page)**

7. **There are clearly opportunities for chemists to contribute to the development of better power transmission technologies, by working on cable metallurgy, better insulation materials, and perhaps superconductors**

Specific Comments about each technology

Gas Pressurised cable and conduit system

This is a real project deriving from two US patents filed in 1979 and 1982 and 1

http://www.freepatentsonline.com/4581478.html

http://www.wikipatents.com/US-Patent-4343665/method-for-manufacturing-sfsub6-pressurized-gas-continuous-spacer

The key things for students to find out here are

1. **that SF6 is indeed a very good insulator and that you could in principle make good high current underground cables using this technology**

but that

2. **it is a horribly long-lasting greenhouse gas (22,000 times worse than CO_2) and is therefore banned for use in everything except switchgear where it can be reliably sealed and recovered after use.**

Now, if someone could invent a way of polymerizing it into a sulphur analogue of Teflon that really would be a great insulator!

New polyethylene blend materials

This is recent work by the University of Southampton.

http://eprints.ecs.soton.ac.uk/22717/

Thanks to Professor Alun S Vaughan for permission to use the idea and picture, and Dr Martin Given of the University of Strathclyde for alerting me to the paper.

Students should be able to identify the problem of 'treeing' in cable insulation – a mechanism by which insulation materials degrade underground especially in contact with water. There is a good general presentation they might find at

http://www.docstoc.com/docs/22067455/ELECTRICAL-PROPERTIES-OF-CABLE-INSULATION-MATERIALS

and http://www.ims.uconn.edu/~eprcable/ref01.pdf

The Southampton technology is apparently a promising step forward in the technology of 'undergrounding' cables.

Lightweight electrical cabling

You really can make cables from sodium metal! Union Carbide pioneered the idea back in the late 1960's and they were tested in the UK a few years later.

http://www.y12.doe.gov/library/pdf/about/history/y12bulletins/V20N16_19660420.pdf

and this discussion (near the bottom)

https://groups.google.com/group/alt.engineering.electrical/tree/browse_frm/month/2000-02/2017c2d28b16a460?rnum=71&_done=/group/alt.engineering.electrical/browse_frm/month/2000-02?&hl=en

So give a little credit to students who realize that these 'metals with extremely mobile isolated 2s or3s electrons' are lithium and sodium, but more credit to those who don't just dismiss the idea out of hand. The cables apparently worked well but concerns over how long the insulation would last stopped the project (see 'treeing' above). The technology has recently been revived, as light weight cables for the aerospace industry:

http://www.sodiumwire.com/index.html

Thanks to John Rye, (retired) test engineer at the Electrical Council Research Centre for the story of sodium cables.

Thanks to Dr David Levine, Sodium Wire LLC, inventor of the modern sodium wire product, for permission to use his graphics and adapt his promotional text.

Aluminum Core Power Line

This is actually a (new) commercial product of 3M corporation

See http://www.realwire.com/releases/3m-accr-can-help-overcome-land-permission-problems-for-connecting-offshore-wind-farms-to-the-onshore

and

http://solutions.3m.com/wps/portal/3M/en_US/EMD_ACCR/ACCR_Home/Proven_Tech/TransmissionGrid_Support/

The key point is that doubling the current capacity of existing wires means that you might not have to build large new pylons. Its interesting to work out the current flowing in cables taking 500MW+ power even at 400 kilovolts!

Very high conductivity of layered lead zirconate titanates

This is a recently published arxiv article apparently reporting superconductivity at near room temperature (313K).

http://arxiv.org/pdf/1007.2736v1

For many years room temperature superconductivity has been the holy grail of power transmission. However the current capacity of these wires is nowhere near that needed for serious power transmission purposes. In addition, the better students should be able to spot that superconductivity suffers significant power loss and limitations dealing with AC currents – which most grids in most countries use. For an overview of power distribution issues (in a country not a million miles from 'Northland') see this video:

http://vimeo.com/8668292

Further thanks to Martin Queen, R&D Project Manager (Future Networks and Policy) at Scottish and Southern Energy for his helpful advice, discussion and corrections.

Part 3: Environmental Impact & Societal Issues

Pre-session 4 Preparation (For the tutor)

You need to make the following resources available to students <u>before</u> the session:

- **The email from the science minister.**
- **The spreadsheet model.**
- **The outline page for session 4 (this includes the pre-session preparation and the intended learning outcomes).**

During the session you should ensure that students have access to a computer which ahs Microsoft Excel installed on it.

You need to set a deadline for this part of the report which allows you to return feedback ahead of the next session.

Session 4 (90-120 minutes)

Pre-Session Preparation

Students should be prepared to discuss the following topics in this session:

- The emission of carbon dioxide due to the existing means of power generation (outlined in the 'Welcome to Northland' information) and the new approaches referred to in part 1 of the problem (i.e. Biofuel, Photovoltaic cells, Nuclear, Wind power and Fossil fuel combustion with carbon capture)
- Other sources of carbon dioxide emission associated with power generation by the means listed above. This includes emissions due to transport of fuel and emissions due to other associated processes (e.g. Fuel processing)
- The impact of carbon dioxide emissions in the context of the greenhouse effect

Intended Learning Outcomes

<u>Scientific:</u>

By the end of this part of the problem students should be able to:

- Use a spreadsheet to model the energy needs of a nation over a 12 year period and determine the carbon footprint of the nation over the same period
- Use the a spreadsheet model to compare the environmental impact and energy output of different approaches to power generation
- Write a set of meaningful conclusions based on the output from a spreadsheet model.

<u>Transferable:</u>

By the end of this part of the problem students should be able to:

- Work effectively in a group on a data processing task.
- Use a spreadsheet model in Microsoft Excel.
- Write a short report based on the outcomes calculated by a spreadsheet model.

Resources and Arrangements

- You need to give students access to the template spreadsheet provided
- Students must have access to computer facilities with Microsoft Excel installed in order to access and edit the spreadsheet model (alternative programmes such as Numbers and Open Office may be able to support the spreadsheet **but this has not been tested**)
- You may want to give a plenary introduction to this part of the problem. You may want to talk students through the 'Business as Usual' scheme which has been prepared as example of how to use the model on the basis that the means of power generation will not change over the next ten years. You may want to remind students that there is no model answer to this problem and that there will be a number of suitable solutions
- You may find it useful to spend around 20-30 minutes at the end of the session getting each group to briefly feedback their solutions to the entire class. This should be done using a whiteboard or flip chart (a PowerPoint presentation will take too long to prepare if this is done in a single session).
- You should ask the students to submit their spreadsheets along with their reports.

To: scienceteam@northland.gov.nld

From: scienceminister@northland.gov.nld

Sent with high priority

Subject: 12-year projection

Dear Team,

Thank you for selecting a suitable sustainable solution for our nation's future energy needs. It is now important for us to predict the short term impact of this project in terms of the nation's total energy output and our carbon footprint. We need to be able to back up our decision with some numbers!

Please find a spreadsheet model attached to this email. You should be able to use this model to calculate the nation's estimated carbon emissions and energy output for the 2011-2022 period. Please use your selected form of power generation (as presented to the press recently) as a starting point, work out how much power it will deliver, how much CO_2 it will produce and what the impact of phasing some existing forms of power generation (e.g. the existing nuclear power facilities) will be on these numbers.

It is important that we take action that will allow us to reduce the carbon footprint of the nation while still producing enough energy to meet the nation's needs. Summarise your findings in a one to two page report which includes figures (include the spreadsheet as an appendix).

Provide a comparison of the impact of your chosen approach with the other proposals that were made (i.e. the other four proposals that were discussed in session 1). It would be useful these figures backed up our decision to invest in your chosen technology.

Best wishes,

Robert Davies (Northland Science Minister)

Tutor notes

The energy/emissions spreadsheet is an important part of the problem as it allows to students to calculate some numbers based on the more qualitative decisions made in earlier sessions (particularly the decision made in sessions 1 & 2).

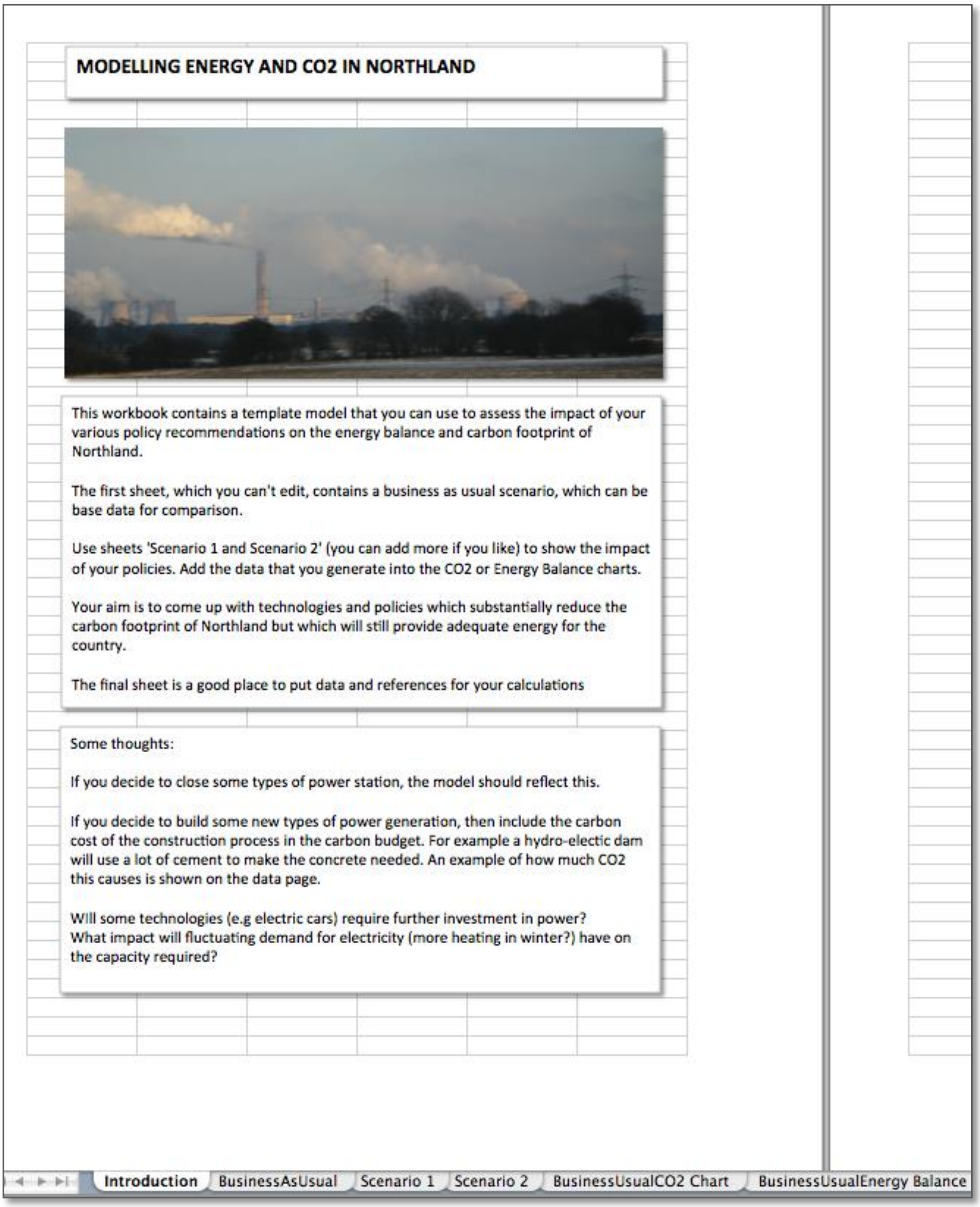
The energy/emissions spreadsheet provides students with an opportunity to put numbers to the compromises inherent in energy policy. They should be able to see that unilaterally closing power stations, while it may reduce carbon emissions is also likely to lead to power shortages. They should also be able to see that widespread adoption of electric vehicles in Northland is likely to require very significant installation of new power generation capacity.

To me (Dr Kevin Parker), the spreadsheet exercise is a crucial part in integrating the students' case study work into a real context. It should enable students to put their knowledge of the new technologies in the case studies (for example the sea water extraction of uranium) into proper quantitative context – how much uranium would we need to extract to make a real difference to Northland's energy requirements and carbon footprint? Working in technology assessment (both at BP and as a consultant) I have found that new energy technologies often fall down at this stage.

Tutor Notes - Excel Template

MODELLING ENERGY AND CO_2 IN NORTHLAND

The spreadsheet model should be made available to groups working on this project. On the following pages are some screenshots and explanations. For more detailed questions refer to Dr Kevin Parker (KKI Associated Ltd). **<u>It is well worth spending some time familiarising yourself with this spreadsheet before the students start working on it.</u>**



MODELLING ENERGY AND CO2 IN NORTHLAND

This workbook contains a template model that you can use to assess the impact of your various policy recommendations on the energy balance and carbon footprint of Northland.

The first sheet, which you can't edit, contains a business as usual scenario, which can be base data for comparison.

Use sheets 'Scenario 1 and Scenario 2' (you can add more if you like) to show the impact of your policies. Add the data that you generate into the CO2 or Energy Balance charts.

Your aim is to come up with technologies and policies which substantially reduce the carbon footprint of Northland but which will still provide adequate energy for the country.

The final sheet is a good place to put data and references for your calculations

Some thoughts:

If you decide to close some types of power station, the model should reflect this.

If you decide to build some new types of power generation, then include the carbon cost of the construction process in the carbon budget. For example a hydro-electic dam will use a lot of cement to make the concrete needed. An example of how much CO2 this causes is shown on the data page.

Will some technologies (e.g electric cars) require further investment in power? What impact will fluctuating demand for electricity (more heating in winter?) have on the capacity required?

Introduction | BusinessAsUsual | Scenario 1 | Scenario 2 | BusinessUsualCO2 Chart | BusinessUsualEnergy Balance

It is suggested that if computer resources allow, all students take a look at the model in order to work out how to use it (i.e. using separate computers). After this has been done (perhaps 20 minutes or so into the session), students should get back together to discuss what they plan on doing and nominate one or two students to manipulate the model and enter data while the other group members observe and offer guidance.

This first page sets out the problem, how to use the spreadsheet, and shows the main worksheets available in the work book – there is one other page called 'data' where students can put references other data sources and frequently used calculations.

This is part of the spreadsheet model showing the main CO_2 sources in Northland – this is the 'Business as Usual' sheet which models the impact of the power generation approaches currently used in Northland (i.e. assuming that the existing power stations all remain open and are not supplemented by any new facilities).

Outline Carbon and Energy Budget for Northland

Carbon Production - Million tonnes of CO_2 per year

Time	2011	2012	2013	2014	2015	2016	2017	2018
Agriculture and Land Use								
Tree planting	-10	-10	-10	-10	-10	-10	-10	-10
Agriculture	13	13	13	13	13	13	13	13
Subtotal	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Built Environment Assets								
Domestic Heating etc	7.3	7.5	7.7	8.0	8.2	8.5	8.7	9.0
Industrial Heating etc	11.4	11.7	12.1	12.5	12.8	13.2	13.6	14.0
Manufacturing	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Existing power lines	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
New Power Lines								
Subtotal	21.13	21.69	22.27	22.86	23.48	24.11	24.76	25.43
Time	2011	2012	2013	2014	2015	2016	2017	2018
Transport								
Road Transport								
Private Motoring	6.50	6.7	6.9	7.1	7.3	7.5	7.8	8.0
Light transport	1.18	1.2	1.3	1.3	1.3	1.4	1.4	1.5
HGV	1.94	2.0	2.1	2.1	2.2	2.2	2.3	2.4
Other								
Trains	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Maritime	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
Aviation	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73
Agricultural Machinery	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Subtotal	14.44	14.73	15.02	15.33	15.65	15.97	16.31	16.65
Time	2011	2012	2013	2014	2015	2016	2017	2018
Power Generation								
CoalStation 1	8.00	8.2	8.5	8.7	9.0	9.3	9.6	9.8
Coal Station 2	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.3
Gas	4.30	4.4	4.6	4.7	4.8	5.0	5.1	5.3
Nuclear								
Hydro								
Wind								
Wave								
Solar								
Subtotal	16.60	17.10	17.61	18.14	18.68	19.24	19.82	20.42
Carbon Total (MT)	55.47	56.82	58.20	59.63	61.11	62.62	64.19	65.79
Cumulative Carbon tota	55	112	170	230	291	354	418	484

Students can decide whether the model is correct in assigning zero emissions to nuclear, hydro, wind, wave and solar power generation.

Lower down the same sheet is the calculation of energy produced in Northland. If students decide to close certain power stations in order to reduce CO_2 they should reflect this reduction in available power capacity in their scenario. The power capacity figures are quoted in Megawatts, and the energy production figures are in TeraWatt Hours – students should understand the difference between these values.

Time		2011	2012	2013	20				2018	2019
Electric Energy Supplies - Units in TeraWatt hours										
	Capacity	Energy(TWh)								
CoalStation 1	2400	16	16	16	16	16	16	16	16	16
Coal Station 2	1,200	8	8	8	8	8	8	8	8	8
% of rated cap	*75%*									
Gas	1550	12	12	12	12	12	12	12	12	12
% of rated cap	*85%*									
Nuclear	2652	16	16	16	16	16	16	16	16	16
% of rated cap	*71%*									
Hydro	1330	5	5	5	5	5	5	5	5	5
% of rated cap	*45%*									
Wind	1500	3	3	3	3	3	3	3	3	3
% of rated cap	*20%*									
Wave		0	0							
% of rated cap	*40%*									
Solar		0								
% of rated cap	*15%*									
Total Capacity	10.63	GW								
Total Potential Productio		59.56	59.56	59.56	59.56	59.56	59.56	59.56	59.56	59.56
Total Annual Demand		30.00	30.90	31.83	32.78	33.77	34.78	35.82	36.90	38.00
Annualised peak demar		50.00	51.50	53.05	54.64	56.28	57.96	59.70	61.49	63.34

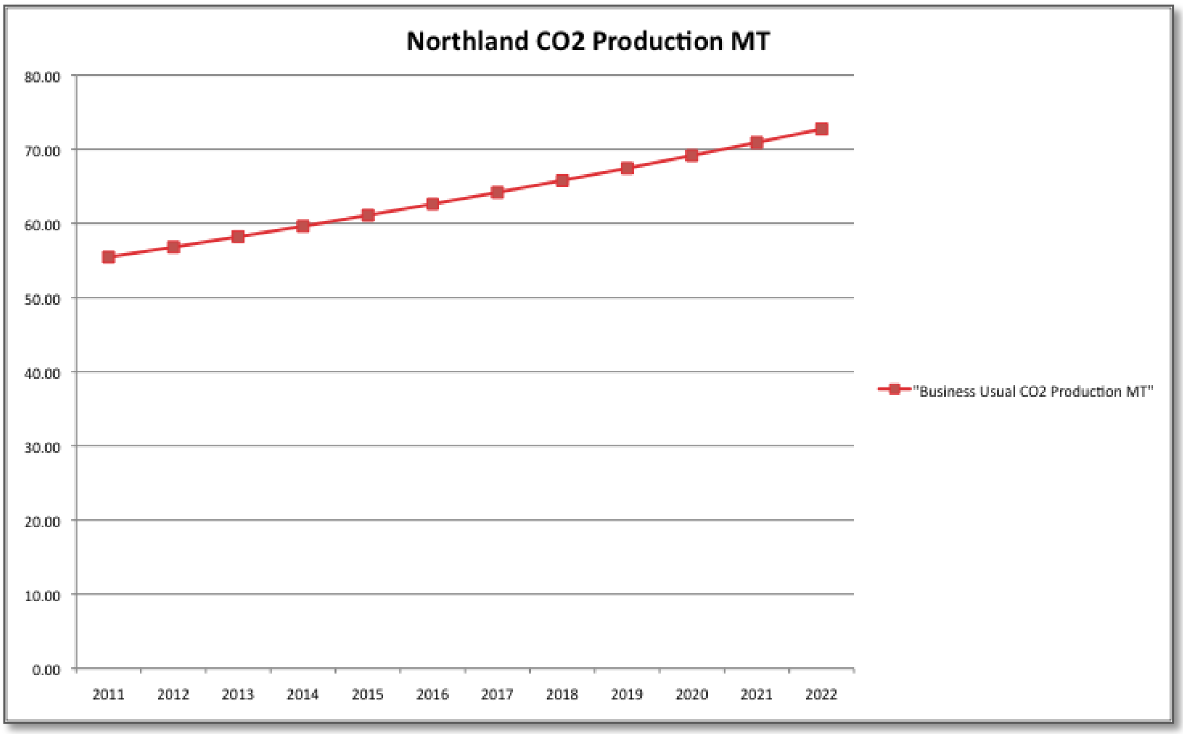
One way of reducing CO_2 in transport would be to electrify rail transport and to increase the number of electric cars on the road. Ultimately the power for this comes from electricity generation and so students should be encouraged to calculate the extra electric capacity required to do this.

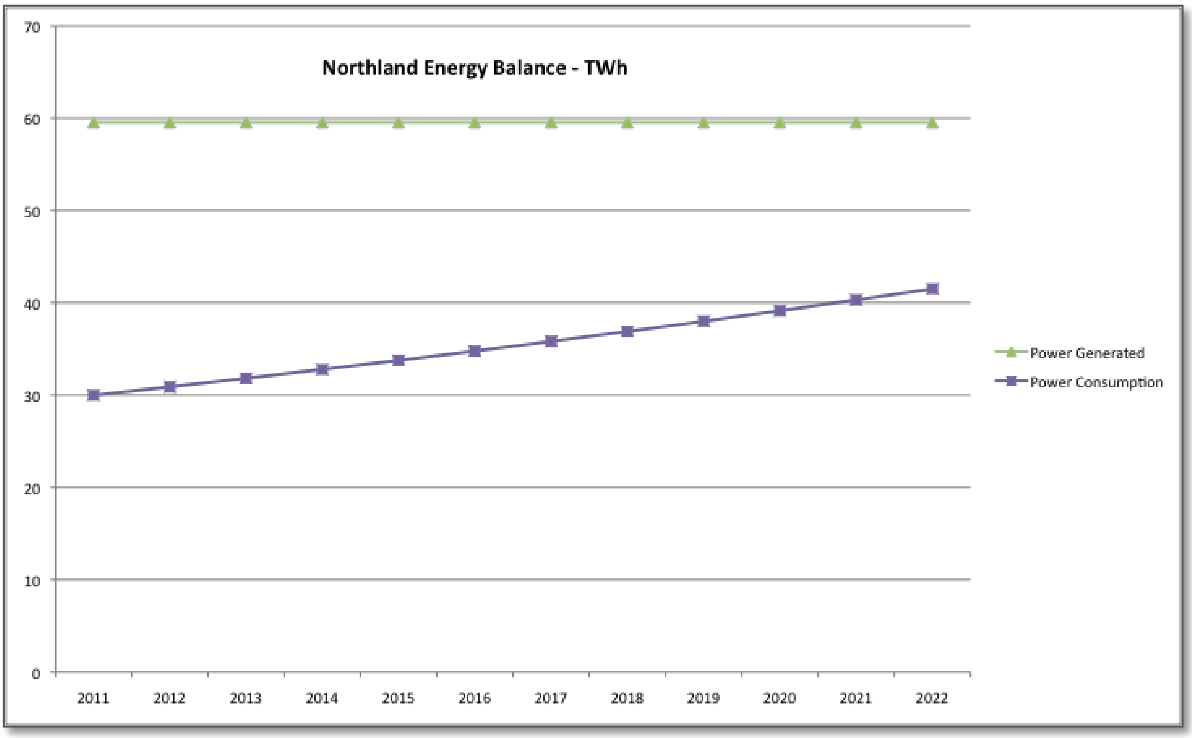
NB Tutor notes: The extra energy required, if it is all to come from extra electric generation, is very large! Here is one potential calculation – you'd almost need to double the present power consumption if all the cars in Northland were electric (not counting diesel vans, HGV's etc).

Car Energy Consumption		
Assume 30 mpg		
Energy Content of Gasoline		
1 litre	**35**	**MJ/litre**
1 gallon is	**4.55**	**litres**
Fuel Energy is	**159.11**	**MJ/gallon**
Energy/distance	**5.30 MJ/mile**	**3.31 MJ/km**

Distance driven by cars in Northland	**34650**	**million km**
Energy consumed by cars in Northland	**1.1486E+11**	**MJ**
	31.91	**TWh**

These two charts are already in the workbook, showing the CO_2 production and electrical power generation/consumption lines for the 'business as usual' scenario. Students should add to these graphs by incorporating numbers from their chosen scenario(s).





Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Review your progress in this session and think about what remains to be done. Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Ask the students to briefly summarise their progress during the session and to present a plan of what they intend to do before the next session.

Pre-session 5 Preparation (For the tutor)

You need to make the following resources available to students before the session:

- **The outline page for session 5 (this includes the pre-session preparation and the intended learning outcomes).**
- **The emails for both parts i and ii**
- **The spreadsheet model from the previous session.**
- **Each group should receive feedback on their report from the previous session before this session.**

You need to set a deadline for this part of the report and return full summative feedback on both reports.

Session 5 (90-120 minutes)

Pre-Session Preparation

Students should be prepared to discuss the following topics in this session:

- The mechanism of global warming including both the physical basis of the phenomenon and the actual impact on average global surface temperature
- The impact of transport and heating to the carbon footprint of nation

Intended Learning Outcomes

Scientific:

By the end of this part of the problem students should be able to:

- Calculate the energy consumed by transport and heating sectors and compare these values with the electricity sector
- Decide how much installed capacity is required to match the energy demands of various sectors
- Determine how the required amount of installed capacity would have to vary if a programme of rail electrification and/or introduction of electric vehicles was pursued.
- Use the a spreadsheet model to evaluate a number of potential solutions to a nation's future energy needs
- Describe the absorption of infrared radiation by greenhouse gases and explain why this phenomenon leads to a global average surface temperature higher than that predicted by a simple black-body model of the atmosphere.
- Describe measures that can be taken to minimise global warming.

Transferable:

By the end of this part of the problem students should be able to:

- Work effectively in a group on a data processing task.
- Use a spreadsheet model in Microsoft Excel.
- Write a short report based on the outcomes calculated by a spreadsheet model.
- Research an area of scientific interest for the general public (i.e. global warming) and write a report in a way that is accessible for a defined audience type (i.e. a chemistry graduate)

Resources and Arrangements

- The students will again need access to the spreadsheet model from the last session in order to perform the calculation. The figures specified in the problem statement can be found in the 'Data' tab of the spreadsheet
- Students need access to computer facilities with internet access for this session
- These two parts of the problem have written deliverables which should be be submitted by a deadline after the session.

Part (i)

Government Announces Ambitious Transport Plans

Story from the Northland Gazette

The Government last night unveiled its ambitious plans to end the nation's dependence on diesel transport. The government plans to make a major investment which will allow recharging points for electric vehicles to be fitted across the nation. The government has also announced the electrification of two mainline rail routes. It is hoped that this will keep the government on target for its goal of producing 80% of the nation's energy needs from renewable sources.

To: scienceteam@northland.gov.nld

From: sciencеminister@northland.gov.nld

Sent with high priority

Subject: Northland Energy Balance

Dear team,

There has been some confusion in the press about our policy of trying to achieve 80% of our energy from renewables. Some commentators are accusing us of only including electricity in that figure and ignoring transport and Built environment (heating). Before we put out a statement clarifying things can you do a quick estimate for us?

I'm sure that electricity is in fact much the largest sector, but can you quickly calculate the energy requirements of the heating and transport sectors? As chemists, you should be able to work back from the carbon dioxide emissions of each sector to get the energy consumption. Can you compare these sectors with the electricity sector so we can see what the implications might be if, for example, we moved much of our transport to electric vehicles or trains?

Use these figures:

Current Carbon Footprint 55.4 million tonnes CO_2

- *Transport :14.4 MT*
- *Built environment 22 MT*
- *Power generation 16.6 MT, from total 10,600 MW installed capacity*

to calculate the energy consumed in the transport and built environment sectors of Northland

The 'Northland Carbon template' spreadsheet has some data which should enable to go from tonnes of CO_2 emitted to tonnes of diesel fuel, gasoline or natural gas used. You should be able to use heats of combustion to calculate the energy consumption of these sectors

Convert the energy figure from Joules to Terawatt-hours so you can make a direct comparison with the electricity figures. How much extra generating capacity would Northland require to move a significant amount of transport or built environment to zero-carbon renewables?

Please submit an updated version of your report from last week which includes these figures.

Best wishes,

Robert Davies (Northland Science Minister)

Part (ii)

To: scienceteam@northland.gov.nld

From: scienceminister@northland.gov.nld

Sent with high priority

Subject: Warming mechanism

Dear Team,

The Prime Minister has requested a report on the mechanism of global warming. Recent statements from members of the opposition have demonstrated increasing scepticism about the science behind global warming and a general lack of enthusiasm in investment in renewables. The PM feels that we have to do something to inform both the public and the politicians.

As a trained chemist, the PM understands that CO_2 absorbs photons of energy and stops them from radiating out into space. The PM feels that climatologists have confused the public with their computer models and attempts to measure baseline temperature changes.

The PM believes that these models are trying to calculate how quickly we had to reduce carbon production and not whether it was important to do so! The PM said that 'the thermodynamics is settled, the models are just trying to establish the kinetics', but I'm not entirely sure what he meant by this!

Is it possible to calculate how much energy is emitted by the Earth at frequencies that are absorbed by CO_2. If we could determine this (and the amount of CO_2 in the atmosphere) we should be able to determine how much radiation has been absorbed by the CO_2 shouldn't we?

Please prepare a short report (no more than 600 words) on this process and include any relevant calculations. There are a few other points that you should include in your report: Is it possible to measure the infrared spectrum of the atmosphere somehow and see this absorption? And what happened to the energy? Did it go down to the ground or stay in the atmosphere? What can we do to minimise this warming effect?

Best wishes,

Robert Davies (Northland Science Minister)

Tutor notes: The calculated average surface temperature of the Earth (from Wien's law, using an albedo of 0.31) is -19 ˚C – the actual value is almost 40 ˚C higher. This assumes the Earth behaves as a perfect black body which given the composition of the atmosphere isn't a fair assumption to make.

The Earth's surface absorbs high energy UV and Visible radiation which penetrates the atmosphere; it then re-emits radiation at a lower frequency – infrared radiation. This form of EM radiation can excite molecules into higher vibrational energy states.

These molecules then relax back down to the vibrational ground state either by re-emitting photons of infrared radiation in all directions (which can subsequently be re-absorbed by other molecules) or through collisions with other molecules.

CO_2 is one of the most important anthropogenically produced greenhouse gases. H_2O and CH_4 are also very effective greenhouse gases. All of these gases also have natural sources. CFC's, nitrous oxide and ozone are also greenhouse gases.

Infrared spectra showing the absorption of infrared radiation by all of these gases can be obtained and the spectrum for the absorption by CO_2 should be included in the report.

There is direct data (from Satellites) of the infra-red emissions from earth to space showing a large dip around the CO_2 vibration band of 15.3 microns. The implication is that the atmosphere is absorbing infra-red at that frequency.

There is direct measurement of the heat reaching the earth at 15.3 microns (and other CO_2/CH_4 bands) and this heat transfer is increasing.

See graphs from papers quoted on this page

http://www.skepticalscience.com/empirical-evidence-for-global-warming.htm

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Review your progress in this session and think about what remains to be done. Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Ask the students to briefly summarise their progress during the session and to present a plan of what they intend to do before the final deadline.

Outline Marking Criteria – we suggest each assignment is marked separately

Press Conference

- Did the students summarise their decision in a concise and informative manner in the press conference?
- Did the group demonstrate a clear understanding of the scientific basis of their chosen proposal? Was it clear that the students had considered the points in the discussion questions from the first session?
- Did the students respond well to questioning? Had all of the discussion questions been addressed? Could students provide a realistic estimate of how much energy their chosen proposal could produce?
- Were the students able to discuss the impact of their chosen approach on the nation's dependence on non-renewable forms of energy? Could the students describe the potential impact on the nation's carbon footprint?
- Did students consider the advantages of their chosen proposal relative to the other proposals?

Mark out of 10:

8 (or more) -The oral presentation was very well structured and clear. The group responded very well to all questions asked – responses were scientifically correct and delivered in a clear, confident manner. All of the points listed above were covered very well.

7 - The oral presentation was sufficiently clear to allow the listener to understand the key points made by the group. The group responded well to most questions – responses were scientifically correct and were delivered generally well. Most of the points listed above were covered well by the group's responses.

5 - The standard of the presentation was adequate. The group managed to cover some of the points listed above – The group struggled to respond to some of the questions and appeared to be 'against the ropes' at times .There may have been some scientific errors.

3 - The standard of presentation was very poor. The group struggled with most of the questions and failed to address many (or all) of the points listed above. The group struggled with most (or all) of the questions asked.

Part 1a - Building for a Sustainable Northland (Power Generation)

- Does the written summary demonstrate an understanding of the scientific principle being applied in the selected proposal?
- Does the summary include a justification of why this proposal was chosen in terms of impact it will have on the future energy demands of Northland as well as the impact on the nation's carbon footprint?
- Has the potential financial value of the proposal been taken into account in the written report?
- Have the relative advantages and disadvantages of this approach compared to the other options been considered?
- Has the anticipated power output from the group's chosen technology been (correctly) calculated (as requested in the discussion questions)?
-

Part 1b – Whose Fault is it?

- Did the report include calculations to show how much energy could be produced by dedicating this land to photovoltaics and to biomass?
- Did the report include an explanation of the kilowatt hour?
- Did the report take the various factors affecting solar intensity into account (such as variation of intensity with time and the effect of cloud cover).
- Did students discuss (and explain) the efficiency limits of photovoltaic cells?

Part 2 – Lost in Transmission (Energy Conservation)

- Does the presentation provide a background to the problem which includes a brief explanation of the use of a grid system to transmit power?
- Does the presentation summarise and justify the decision for which technology to support?
- Have the students discussed the relative strengths and weaknesses of their chosen technology compared to the other available options?
- Have the students taken the original concerns into account (i.e. will the technology be efficient, safe and secure?)
- Does the presentation consider the background scientific issues (such as the electrical properties of the technologies described, potential losses during transmission, skin effect – see the tutor notes for other relevant factors)

Part 3a: Environmental Impact & Societal Issues

- Have the students used the Excel template to evaluate both the potential energy output and the carbon emissions from their chosen approach from part 1.
- Have the students gone on to model a number of different scenarios using the template.
- Have the students provided any comments and conclusions with their models? Have students commented on how their chosen approach compares with those of other groups?

Part 3b: Environmental Impact & Societal Issues

- Have students used the mode from the previous part of the problem to estimate the total energy balance (not just electricity) in Northland?
- Have the students provided conclusions on whether the amount used in Transport and Heating/Built Environment is more or less than in electricity generation?

- Does the solution consider the implications for power generation of electrifying the countries railways, or shifting from gasoline to electric vehicles?

Part 3c: Atmospheric Warming

- Does the report summarise the mechanisms of atmospheric warming by the absorption of infrared radiation by greenhouse gases.
- Is the level of information suitable (i.e. the audience is someone with a degree in chemistry but the conclusions should be sufficiently clear that non-experts could understand them)?
- Does the report discuss the widespread misconception of this concept?
- Does the report make any recommendations as the how government policy can be changed to minimise the impact of this effect?

Written content:

- **A (1st) - Excellent** The answer contains all the things listed in the criteria and one or two extra related things. All numerical values have been correctly calculated and are presented with units and discussion.
- **B (2.1) - Very Good** The answer has almost all the things listed in the criteria (only minor things missing) – any calculated values are close to the recommended values.
- **C (2.2) - Good** Most of the things listed in the criteria appear in the answer, some missing content and/or some error in written content and/or calculations.
- **D (3rd) - Modest** The answer has significant content missing. There are a number of errors throughout the answer.
- **E (Fail) - Poor** The answer contains only a few of the important points from the list. There are significant errors and missing sections of content.

Presentation of written solutions

- **A (1st) - Excellent** The solution is very well structured and produced. It is easy to find the different sections and there is similar presentation on different pages. Each section is virtually free from errors in grammar, spelling and punctuation and makes good use of **referenced & labelled** diagrams.
- **B (2.1) - Very good** The solution is well structured and produced. It is clearly written apart from relatively minor aspects which would not seriously affect the understanding of the reader. The solution makes good use of referenced and labelled diagrams to clarify key points in the answer.
- **C (2.2) - Good** Though reasonably well structured and produced, the solution contains significant errors in grammar and spelling. Diagrams were provide, these were not always referenced and/or there was little attempt made to relate these to the answer.
- **D (3rd) - Modest** The solution was disorganised and disjointed and so badly produced that it would inevitably misguide the reader. There were lots of errors – spelling, grammar, lots of different fonts and little or no evidence of teamwork. There was little or no effort to provide diagrams or examples to illustrate points in the answer.