

# Ri Christmas Lectures 2012: The Modern Alchemist

## Teaching Resource - Climate Change and the Hydrogen Economy

### Overview:

This resource contains ideas and information based around the topics of Climate Change and the Hydrogen Economy. This is supported by relevant links to useful information, and video clips from the 2012 Christmas Lectures.

### Climate Change:

- Traditionally, climate change would refer to natural changes in weather and climate distribution across the globe, over time periods ranging from decades to millions of years.
- Climate change can be caused by various 'Forcing mechanisms' these are events or processes which cause a significant and lasting effect on the climate.
- Climate change can take the form of changes in weather patterns, overall warming or cooling of the planet, or combination of the two.

### Forcing Mechanisms (Causes of Climate Change):

- Oceans:
  - Oceans can effect the climate through currents - i.e. the transfer of warm or cold water from one part of the globe to another.
  - An example of a current affecting local climate is that of the Gulf Stream. This is a warm current which passes the west coast of the UK, resulting in higher than average temperatures in Cornwall and the south west.
  - A further example would be the El Niño effect, which causes changes in the climate of the tropical Pacific Ocean roughly every five years - strictly speaking this is not climate change, rather it is a cyclical effect; a climate pattern.
  - More information on El Niño can be found [here](#)<sup>1</sup>.
- Orbital Variation:
  - Variation in the orbit of the Earth can change how much sunlight is received by a specific area over the course of the seasons.

<sup>1</sup> NOAA, <http://www.elnino.noaa.gov/edu.html>

- The combined variations in the Earth's orbit produce cycles known as Milankovitch Cycles - which have been linked to the historic ice ages. More information is available [here](#)<sup>2</sup>.
- Solar Output:
  - The majority of the energy input to the Earth comes from the Sun. Therefore, changes in the energy output of the Sun can cause Climate changes here on Earth.
  - The energy output of the Sun varies in both the long term and short term. For example, early in its life, the Sun would only have emitted around 70 % of the energy that it does today; further to this, the output is likely to change dramatically in the future, as the Sun proceeds through its life cycle.
  - The Sun also varies its output and behaviour on a roughly 11-year cycle; moving through periods of both high and low activity.
  - Both long term, and short term variations in energy output are believed to cause climate change on Earth.
- Volcanoes:
  - The eruption of volcanoes can have a major effect upon the climate.
  - When a major eruption occurs, the dust and particulates which are released into the atmosphere can increase the amount of solar radiation that is reflected, preventing it reaching the Earth's surface.
  - This effect can have a cooling effect upon the Earth. For example, the eruption of Mount Pinatubo in 1991 caused global temperatures to fall by around 0.5 °C.
- Humans:
  - Human factors which could cause Climate Change are collectively known as 'anthropogenic' factors.
  - Primary among these activities are combustion of fossil fuels, release of aerosols, ozone depletion, and deforestation.

### **Climate Change Vs. Global Warming:**

- There is a subtle difference between Climate Change and Global Warming. Climate Change refers to changes caused by any source (see Forcing Mechanisms above); whereas, Global Warming generally refers to only changes believed to be caused by the activity of Humans.

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<sup>2</sup> NASA, Earth Observatory, <http://earthobservatory.nasa.gov/Features/Milankovitch/milankovitch.php>

## Potential Man-Made Causes of Climate Change:

- Fossil fuels: - The combustion of fossil fuels is believed to be the main contributor to man made climate change. This is believed to be due to the production of various 'greenhouse gases', which increase the amount of solar radiation trapped in the atmosphere, increasing worldwide average temperatures (more information below).
- Aerosols: - The effects of aerosols on the climate are difficult to predict and quantify, due to the many different types of particulate that re released into the atmosphere. Some (such as sulphates) may have a cooling effect, similar to the effect of a large volcanic eruption. While others may cause an overall increase in global temperatures (such as black carbon 'soot').
- Ozone depletion: - Ozone depletion refers to the loss of Ozone from the upper atmosphere. Predominantly, this is caused by the release of CFCs (chlorofluorocarbons) into the atmosphere. In the upper atmosphere, these CFCs break down *via* interaction with UV light, forming highly reactive 'free radical' species, which can destroy large amounts of Ozone (O<sub>3</sub>). This effects the climate, as Ozone adsorbs large amounts of harmful UV radiation, preventing it from reaching the Earth. Thus any loss of Ozone can cause UV levels at the surface to increase.
- Deforestation: - Destruction of forests can have a twofold effect upon climate. The first effect being that destruction of trees and plant life releases carbon dioxide (a greenhouse gas) into the atmosphere. The second being that forests act as natural 'carbon sinks', removing carbon dioxide from the atmosphere; obviously, with their destruction, the rate of removal of carbon dioxide from the atmosphere is reduced.

## Global Warming and the Greenhouse Effect:

The 'Greenhouse effect' is a very important physical effect, by which a portion of the energy from the Sun which reaches the Earth is trapped within the atmosphere. This effect allows global temperatures to be maintained within the levels required to support life; without the Greenhouse effect, the temperature of the Earth's surface would be an average of -18 °C.

The Greenhouse effect is caused by certain gases in the atmosphere which absorb a percentage of the heat energy reflected from the Earths surface, thus preventing it from exiting the Earths atmosphere. The captured energy is then re-emitted into the lower atmosphere and towards the Earth's surface, raising the overall temperature of the Earth.

There are several major Greenhouse gases. These are summarised in the table below, along with their calculated contribution to the Greenhouse effect.

Greenhouse Gas	Global Warming Potential	Calculated Contribution to the Greenhouse Effect (%)	Average lifetime in the atmosphere
Water Vapour	NA	33 - 66 %	9 days
Carbon Dioxide	1	9 - 26 %	30 - 95 years
Methane	25	4 - 9 %	12 years
Ozone	2000	3 - 7 %	1 - 2 days

The global warming potential of a gas relates to how effective it is at absorbing IR radiation to the lifetime in the atmosphere; these are quoted as relative to carbon dioxide. Therefore, a molecule with a higher GWP than carbon dioxide is capable of being a more potent greenhouse gas.

Although water vapour appears on initial consideration to be a much greater issue than carbon dioxide, the lifetime of water in the atmosphere is much lower than that of carbon dioxide. This means levels of water vapour are not accumulating, and therefore do not steadily increase. Whereas, carbon dioxide is much more persistent in the atmosphere, leading to a steady build up and a growing contribution to the overall greenhouse effect.

Levels of carbon dioxide and methane in the atmosphere have been steadily increasing in recent times. Scientific consensus is that this increase in methane and carbon dioxide has been caused by human activities, and that it is the increase in these levels that are causing global climate change.

	Pre-Industrial Levels	Modern Levels	Percentage Change
Carbon Dioxide	280 ppm	370 ppm	32 % increase
Methane	0.8 ppm	1.8 ppm	123 % increase

### Climate Change Mitigation:

Despite controversy, the majority of scientists are in agreement that human activities have increased the amount of carbon dioxide in the atmosphere, and this is having a significant effect on global climate. Therefore, several strategies to reduce the effect humans are having on the environment have been formulated. In general, these take the form of burning less fossil fuels, or carbon capture.

- Carbon Capture:
  - Carbon capture and storage is one strategy which has been developed to reduce the amount of carbon dioxide released into the atmosphere from the burning of fossil fuels.
  - Typically it involves reacting the carbon dioxide at source, tying it up as a chemical compound (for example, calcium carbonate), or capturing the carbon dioxide, and piping it to a storage facility. Some carbon capture programs use this CO<sub>2</sub> as part of oil or gas extraction, pumping it into the empty space left behind after the fossil fuel has been extracted.

- Further information on carbon capture can be found [here](#)<sup>3</sup>.
- Reducing the Burning of Fossil Fuels:

Fossil fuels have a multitude of uses, but foremost among these are electricity generation, and transportation - i.e. cars, aircraft, ships etc.

- Therefore, is it possible to reduce our emissions by burning something other than fossil fuels to meet transportation needs?
- One (slightly surprising) answer may be contained in water - hydrogen.
- Hydrogen is the most abundant element in the universe, and when burnt, only produces water vapour and energy.
- The catch is that energy must be supplied to split water into hydrogen and oxygen in order to provide enough hydrogen for us to use (See below).

### Reducing Emissions - Video clip - Energy from Water?

In this clip from the 2012 Christmas Lectures, Dr Peter Wothers demonstrates that energy is required to split water into its component gases, and also demonstrates that energy is most definitely released on recombining them to form water.

#### [The Hydrogen Economy - Energy from Water?](#)

Running Time - 5 min 04 secs

- The hydrogen and oxygen generated in the clip were made by *electrolysis*. This is a process by which compounds (such as water) can be split into their constituents using electricity (See the [RSC Learn Chemistry](#) website<sup>4</sup>).
- There are other ways in which water could be split into hydrogen and oxygen, and the majority of these use a *catalyst*. Catalysts allow chemical reactions to take place with less energy; therefore, using a catalyst to split water reduces the amount of energy we need to generate hydrogen and oxygen.
- Producing a catalyst which can split water into hydrogen and oxygen efficiently is a major goal of the scientific community worldwide. One such example of a prototype catalyst is shown in the video clip below.

<sup>3</sup> CCSa, <http://www.ccsassociation.org/faqs/ccs-general/>

<sup>4</sup> Learn Chemistry, <http://www.rsc.org/learn-chemistry/resource/listing?searchtext=electrolysis>

### **Video clip - Splitting Water with a Catalyst**

In this clip from the 2012 Christmas Lectures, Dr Peter Wothers demonstrates a new catalyst developed at the Tokyo University of Science. This catalyst is capable of splitting water into hydrogen and oxygen using only light.

[The Hydrogen Economy - Splitting Water with a Catalyst](#)

Running time - 2 min 39 secs

In the future it is hoped that catalysts capable of splitting water using visible light will be available - as plants manage to do in nature during photosynthesis.

### **The Hydrogen Economy**

- Despite desires to reduce the amount of fossil fuels burnt, is it really plausible to base our energy use on a 'hydrogen economy'? Will the technology ever exist to make this a reality?

### **Video Clip - Hydrogen Fuel Cell Motorbike**

In this clip from the 2012 Christmas Lectures, Dr Peter Wothers has a visit from Nathan Chang of Valeswood Fuel Cells Ltd, who demonstrates the use of a hydrogen fuel cell to power a possible vehicle of the future.

[The Hydrogen Economy - Hydrogen Fuel Cell Motorbike](#)

Running Time - 2 min 39 secs

- The motorbike in the clip runs on hydrogen stored in a 'Fuel Cell'. Fuel cell technology involves turning chemical energy into electrical energy in a controlled reaction; at a basic level, it is the reverse of an electrolysis process.
- The first hydrogen/oxygen fuel cell was developed by William Grove, and a diagram of the original fuel cell (sent in a letter to Michael Faraday of the Royal Institution) is available on the RSC Learn Chemistry website, and a diagram of a basic modern fuel cell is shown below:

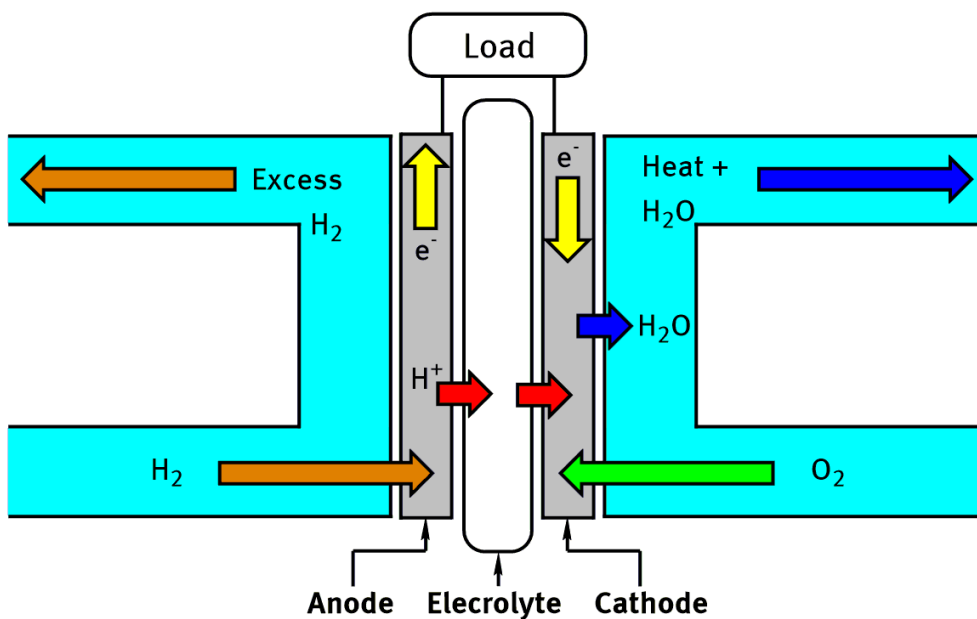


Diagram representing the set-up of a modern hydrogen oxygen fuel cell

View the full 2012 Ri Christmas Lectures - *The Modern Alchemist*, along with behind the scenes footage, and related content, at the [Ri Channel](http://www.richannel.org)<sup>5</sup>.

<sup>5</sup> The Ri Channel, [www.richannel.org](http://www.richannel.org)