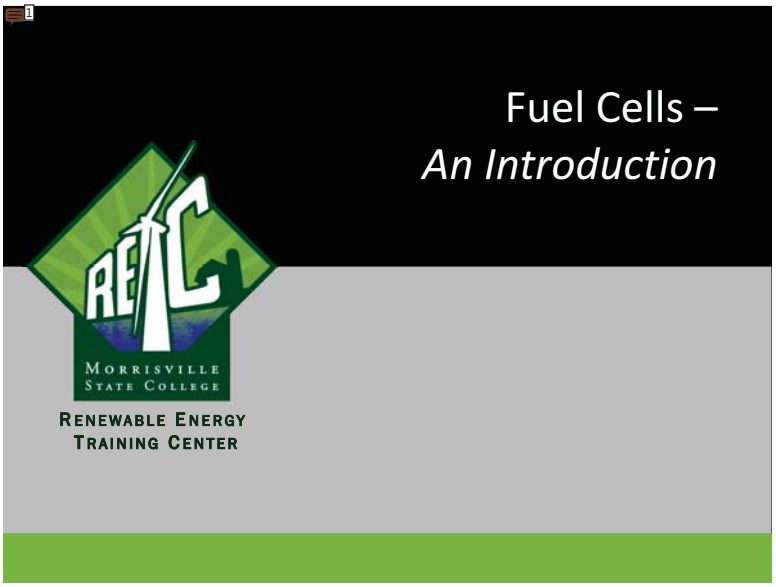

Summary of Comments on Fuel Cells – an Introduction

Page: 1

Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:07 AM

This presentation is designed to provide HS teachers with introductory teaching materials on fuel cells. We do not cover all types of fuel cells (except a general overview). We make use of a simple "reverse electrolysis" experiment to demonstrate the basic principle of the "fuel cells effect".

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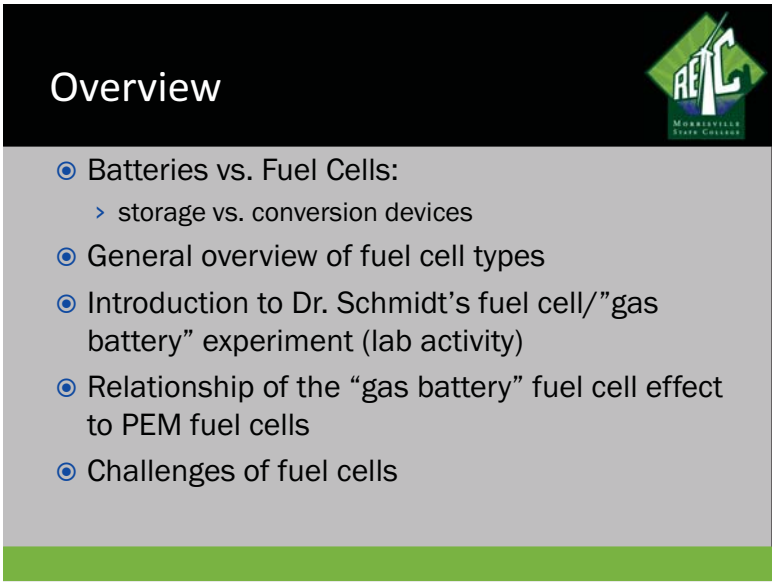

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:08 AM
An electrolyte (a.k.a. and ionic solution) is any substance containing free ions that behaves as an electrically conductive medium.

Batteries

- A battery (or electrochemical cell):
  - Two electrodes made of dissimilar metals, are immersed in a conducting liquid electrolyte.
- When you construct an electrochemical cell, you create a voltage between two electrodes.
- Current flows from the positive to negative electrode until chemical changes stop it.

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:08 AM
Copper-zinc cell: Insert sheets of copper and zinc into beaker of dilute sulphuric acid (or even a lemon.)
Voltage of about 1 volt appears between the two electrodes. (Copper is positive.)

Chemical energy is stored in a battery, until it is connected to an external load (e.g., a light bulb).

Chemical Energy Storage

- A battery is a store of chemical energy that can be converted into electrical energy.
- As electrode chemical reactions proceed, chemical energy is converted into electrical potential energy.
- Chemical energy is exhausted when reaction can proceed no furthe
  - (e.g. when a Zn electrode is dissolved in a sulfuric acid Cu and Zn cell.)

Fuel Cells (vs. Batteries)

- Fuel cells are devices that convert fuel (such as hydrogen, methane, propane, etc.) directly into DC electricity.
- The process is an electro-chemical reaction similar to a battery.
- Unlike a battery, fuel cells **do not store the energy** with chemicals internally.
- Instead, they use a continuous supply of fuel (chemical) from an external storage tank.

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DC – direct current

Fuel cells are like electrochemical cells (batteries), but energy is stored in a gaseous form, not as electrodes of dissimilar metals. Fuels are stored in separate containers and brought together in a reaction chamber (unlike a sealed electrochemical cell containing electrodes and electrolyte). The fuel cell is not a storage device, but rather a conversion device…

Fuel Cells

$$O_2 + 4e^- + 4H^+ \leftrightarrow 2H_2O$$

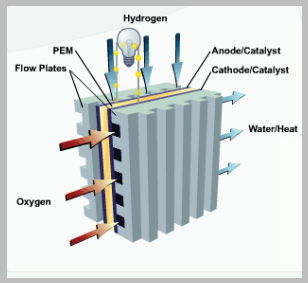

Image: http://en.wikipedia.org/wiki/File:Pem.fuelcell2.gif

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:09 AM

The beauty of a fuel cell (e.g., a PEM fuel cell) is that the input into the cell is oxygen, hydrogen (and electrons) and the end product is water!

Image from: http://en.wikipedia.org/wiki/File:Pem.fuelcell2.gif (accessed 6/18/09)

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What is a Fuel Cell?

- Fuel cells are usually classified by the type of electrolyte they use.
- Most fuel cells are powered by **hydrogen**, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels.

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:09 AM

This slide illustrates a Proton Exchange Membrane fuel cells or Polymer Electrolyte Membrane (PEM) fuel cell, which uses a hydrogen fuel source (the conducting ion) and a Pt catalyst

Image from: http://en.wikipedia.org/wiki/File:Fc_diagram_pem.gif (last accessed: 6/18/09)

The following description is an adaption from Dr. Azmin's introductory lecture on fuel cells (http://material.eng.usm.my/staffhome/mariatti/EBP412/Lect1.FuelCellGeneral.PPT ;last accessed 6/17/09; Dr. Azmin's personal website can be found at: http://aazmin.com/).

The anode: conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

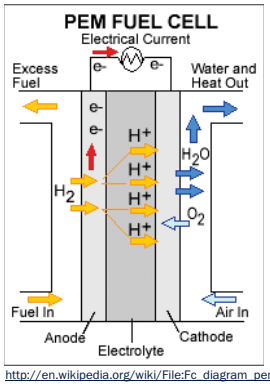
The cathode: the positive side of the fuel cell, has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.

The electrolyte: ion exchange membrane. The membrane blocks electrons. This specially treated material, looks similar to ordinary kitchen plastic wrap.

The catalyst: is a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum powder very thinly coated onto carbon paper or cloth. We will demonstrate the important role that the Pt catalyst plays in the laboratory activity included in this module (using Dr. Schmidt's experiment).

Chemistry of a Fuel Cell

- Anode side:
  $2H_2 \rightarrow 4H^+ + 4e^-$
- Cathode side:
  $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
- Net reaction:
  $2H_2 + O_2 \rightarrow 2H_2O$



http://en.wikipedia.org/wiki/File:Fc_diagram_pem.gif

Characteristics and applications of common types of fuel cells

Fuel Cell Type:	Proton Exchange Membrane (PEM)	Phosphoric Acid Fuel Cell (PAFC)	Molten Carbonate Fuel Cell (MCFC)	Solid Oxide Fuel Cell (SOFC)
Operating Temperature:	80°C (200°F)	200°C (400°F)	650°C (1200°F)	600-1000°C (1100-1800°F)
Expected Early Market :	Available	1992 Reintroduction (2007)	Pre-commercial	Available (small systems)
System Electric Efficiency Ranges (HHV)*:	20-45%	35-40%	40-60%	30-70%
Size Range:	0.1 – 250 kW	200-400 kW	250 kW – 3 MW	1 kW – 1 MW
Cost (est.) Cost Target:	$1,500-4,000/kW $25-50/kW	$6,000/kW $1,800/kW	? $400/kW	? $400-$800 /kW (2010)
Applications:	Stationary/ Vehicles/Portable	Stationary/CHP	Stationary/CHP Marine	Stationary/CHP/ Portable

(Adapted from: Klein, 2006, University of Wisconsin-Madison)

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*System efficiency depends on fuel type, fuel processing method, and manufacturer's design

Notice that PEM fuel cells have several advantages: they are commercially available, have (relatively) lower cost, can operate at much lower temperatures, and have stationary, portable and vehicle applications.

Aside: Ballard Power (no relation) is a company leading the PEM fuel cells industry.

Slide adapted from: Klein, 2006, University of Wisconsin-Madison
http://ecow.engr.wisc.edu/cgi-bin/get/me/370/klein/lecture/fuelcelllecture.pdf (last accessed 6/12/09)

Fuel Cell Fundamentals – A Simple Experiment

Morrisville State College

Renewable Energy Training Center

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:10 AM

We looked at many different options for an instructive and affordable fuel cell kit or experiment. Most commercially available educational kits for fuel cells are expensive (hundreds of $), and they are not necessarily instructive (i.e., you can't actually see what is happening). The activity that we selected to share with you is a relatively inexpensive one. It's not one that we developed ourselves, but we have permission from the author to share it with you (and you can use it for your classes). The most expensive parts are the platinum electrodes (~$15 per foot). We found some platinum coated nickel wire that should do the trick. It's still not cheap, but you could get set up for an entire class for less than the cost of a single fuel cell model car kit.

Simple Fuel Cell Experiment

- **"Discovering the principle of the fuel cell at home or in school"**, by Dr. Martin Schmidt

http://www.geocities.com/fuelcellkit/pdf/FC1101e.pdf

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:15 AM

For detailed descriptions and instructions, please refer to the manual provided in you binder.

Link to the experiment manual: http://www.geocities.com/fuelcellkit/pdf/FC1101e.pdf

From: Dr. Martin Schmidt [mailto:fuelcellkit@yahoo.co.uk]
Sent: Wednesday, June 17, 2009 4:14 PM
To: Ballard, Benjamin
Subject: AW: request: fuel cell manual for educational use

Dear Professor Ballard,
I am very touched by your message. I gladly support your initiative to teach physical and chemical principles that lead to an understanding of fuel cells. Feel free to reproduce data and copies in whatever form that support your educational goals in New York State. It would be kind to mention my name and website.

Professor Schoenbein who published this experiment and its correct interpretation for the first time in 1839 was German (like me) who settled down in Switzerland (like me). About 150 years later I re-invented this experiment (and later re-discovered it) which is why I feel emotionally somehow attached to it. I feel privileged like Newton who stated, referring to Galilei, that he could see further because he stood on the shoulders of giants. It taught me that it can be good to go back to the roots to understand better.

With kind regards
Martin

Dr. Martin Schmidt
Physicist
fuelcellkit@yahoo.co.uk

See how to build your own fuel cell:
http://www.geocities.com/fuelcellkit/

--- Ballard, Benjamin <ballarbd@MORRISVILLE.EDU> schrieb am Mi, 17.6.2009:
Von: Ballard, Benjamin <ballarbd@MORRISVILLE.EDU>
Betreff: request: fuel cell manual for educational use
An: fuelcellkit@yahoo.co.uk
Datum: Mittwoch, 17. Juni 2009, 4:34

Dear Dr. Martin Schmidt,

We are working with a network of high school educators here in New York State on renewable energy and related topics. We are providing these teachers with educational modules that include simple experiments and demonstrations that they can incorporate into their classroom. We discovered your website and "gas battery" experiment. We too were discouraged by the high cost of fuel cell kits. Your experiment is a much more economical approach and provides an opportunity for students to actually see what is happening. Would it be acceptable to reproduce and share your manual for this purpose? We would like to provide printed copies to them, as well as access to the electronic file (if you prefer, we can direct them to your website for access to the electronic file).

Thank you for your time and consideration. Sincerely, Ben Ballard...

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Supplies & Materials

- Small glass with water and ½ to 1 tsp. table salt
- Digital voltmeter
- One 6 volt battery (4.5 or 6 volt battery works well)
- Wire leads with alligator clips (4)
- 2 platinum wires as electrodes (most expensive part: $15+ per foot!)
- Optional:
  - Rubber bands (to secure wires on the glass)
  - Paper clips/pencil leads (alternate electrodes; control experiments)
  - Alternative energy source to "charge" the fuel cell

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Definitions

- **Ions** - charged particles that occur under the influence of the polar water molecules.
  - metals and hydrogen form positive ions (**anions**),
  - non-metals form negative ions (**cations**).
- Example: when dissolved in water NaCl (common salt) forms:
  - Na^+ (anion) and
  - Cl^- (cation)

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Understanding electrolysis

- To carry out electrolysis it is necessary to introduce two similar electrodes into a solution (e.g., the salt water solution).

Electrolysis reactions

Anodic reactions

Electron release (oxidation)	$Cl^- \rightarrow Cl + 1\ e^-$
Formation of chlorine (gas) molecule	$2\ Cl \rightarrow Cl_2$
Overall reaction	$2\ Cl^- \rightarrow 2\ e^- + Cl_2$

Cathode (-)

"RED CAT"

Anode (+)

"AN OX":

(Schmidt, 2000)

Cathodic reactions

Electron acceptance (reduction)	$Na^+ + 1\ e^- \rightarrow Na$
Secondary reaction: formation of caustic soda	$Na + H_2O \rightarrow NaOH + H$
Formation of hydrogen (gas) molecule	$2\ H \rightarrow H_2$
Overall reaction	$2\ Na^+ + 2\ e^- \rightarrow 2\ NaOH + H_2$

"LEO the lion says 'GER'"

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM

Slide content and notes developed (with permission for reproduction of content) from: FUELCELLKIT (Dr. M. Schmidt), which can be found at: http://www.geocities.com/fuelcellkit/ (last accessed: 6/18/09)

Notes:
Chemistry! □ □ you may want to come back to this again later (or not!).

"AN OX": Anode -- Oxidation
"RED CAT": Reduction – Cathode
"LEO the lion says GER": Lose Electron is Oxidation and Gain Electron is Reduction

Excerpt from FUELCELLKIT (Schmidt, 2000):
Cl- migrates to the positive electrode (anode), is discharged (give up an electron) and forms gas molecules (Cl2), which rise to the surface as small bubbles.

Na+ migrates to the negative electrode (cathode) and is discharged there (takes up an electron). Sodium, a highly reactive metal, is unstable in water and is immediately converted in a secondary reaction to sodium hydroxide (NaOH). For this to happen, an OH- ion must be torn from the water (H2O), leaving an H+. The H+ ions join to form hydrogen molecules (H2), which rise at the cathode as small bubbles.

The reaction products of the electrolysis of common salt solution are hence chlorine gas (Cl2) and hydrogen gas (H2).

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Initial setup – verify no voltage

(FUELCELLKIT/M. Schmidt, 2000)

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Understanding electrolysis

- To carry out electrolysis it is necessary to introduce two similar electrodes into a solution (e.g., the salt water solution).
- The electrodes are connected to the terminals of a source of direct current (e.g. a battery).

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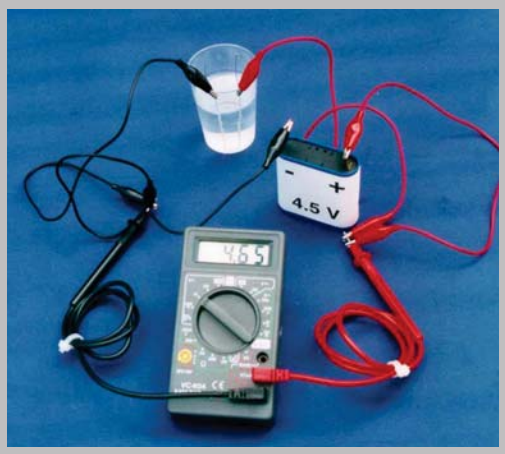
Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM
What happens when you apply the battery to the electrodes?
Can you smell the chlorine gas? The hydrogen gas has no odor, but you should clearly see the bubbles!

1

Electrolysis



(FUELCELLKIT/M. Schmidt, 2000)

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM
It is also called a "gas battery" or "reverse electrolysis"

From electrolysis to the gas battery

- If you remove the external voltage (battery) from the electrolysis experiment, the rising gas bubbles stop but many of them are left sticking to the electrodes.
- An electric voltage will still be measured on such a cell even after the external voltage is removed.
- The fact that **gas-covered electrodes** can supply electricity is the **fuel cell effect**.

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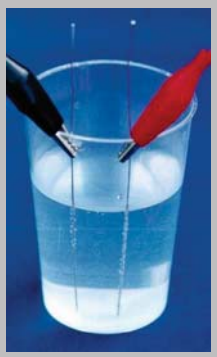
Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM
FUELCELLKIT/M. Schmidt, 2000: "But why does our gas battery work? We do not have different electrode materials and hence no voltage should appear! This objection would be perfectly correct, were there not to be gas bubbles on the electrodes as a result of the electrolysis. In our example of a salt solution, we in effect have a chlorine and a hydrogen electrode, i.e. different electrodes. here we see a further important point: the chemistry takes place not in the electrode but exclusively at its surface."

The platinum (Pt) acts as a catalyst (unlike zinc coated paper clips…try them to see). Pt is used as a catalyst in many fuel cell applications (e.g., Proton Exchange Membrane Fuel Cells).

Refer to the "manual" for a complete description of the fuel cell effect, galvanic elements, etc.

Observe: The "fuel cell effect"



(FUELCELLKIT/M. Schmidt, 2000)

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Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM
Solar cells? Wind turbine(s)? You may need to do some series (and parallel) circuits to get the voltage or amperage you require.

Control Experiment/Others

- Try paper clips as electrodes
- Try pencil leads as electrodes
- Do these function like the Platinum?
- Other power supplies? Are there renewable energy supplies that make sense? Can you build one from the supplies in your kit?

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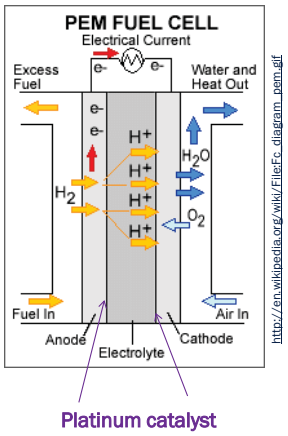
Number: 1 Author: Presenter Subject: Presentation Notes Date: 6/18/2009 11:33:16 AM
Now that you have completed the experiment(s), can you identify the role that Pt plays in this PEM fuel cell?

This slide illustrates a Proton Exchange Membrane fuel cells or Polymer Electrolyte Membrane (PEM) fuel cell, which uses a hydrogen fuel source (the conducting ion) and a Pt catalyst (on each electrode).

Image from: http://en.wikipedia.org/wiki/File:Fc_diagram_pem.gif (last accessed: 6/18/09)

Making the connection…

- Anode side:
  $2H_2 \rightarrow 4H^+ + 4e^-$
- Cathode side:
  $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
- Net reaction:
  $2H_2 + O_2 \rightarrow 2H_2O$



http://en.wikipedia.org/wiki/File:Fc_diagram_pem.gif

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Other resources for teaching:

- There are many online resources for additional fuel cell educational materials, research, etc.
- One website that we recommend looking at for resources for teachers and students is: http://www.fuelcells.org/ced/education.html

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Acknowledgements

- We thank Dr. Martin Schmidt for graciously sharing his instructional materials for the fuel cell experiment.