# Fuel Cells

**Subject Area(s)** physical science, science and technology  
**Associated Unit** Clean Energy  
**Lesson Title** Fuel Cells  
**Grade Level** 11 (9-12)  
**Lesson #** 5 of 5  
**Lesson Dependency** Clean Energy, Energy, Power, and Electricity, Wind Power, Solar Power  
**Time Required** 240 minutes including associated activities

## Summary
Students learn the theory and engineering proton exchange membrane (PEM) behind fuel cells.

## Engineering Connection
Engineers have been working on ways to store and re-access energy for centuries. Proton exchange membrane fuel cells are a hot-topic of clean energy research because they allow us to store enormous amounts of energy using only hydrogen. Chemical and electrical engineers are the most active in this area of research that continues to burgeon as we look for clean ways to store energy and power our vehicles.

## Engineering Category
Engineering analysis or partial design

## Keywords
fuel cell, proton exchange membrane, clean energy, fuel, hydrogen, oxygen, water, electrolysis, electricity

## Educational Standards
**Colorado State Science:** Colorado, 2011, science, physical science, grades 9-12, 5b: Use appropriate measurements, equations and graphs to gather, analyze, and interpret data on the quantity of energy in a system or an object.
Colorado, 2011, science, physical science, grades 9-12, 5d: Identify different energy forms, and calculate their amounts by measuring their defining characteristics.

Colorado, 2011, science, physical science, grades 4, 1c: Describe the energy transformation that takes place in electrical circuits where light, heat, sound, and magnetic effects are produced.

Colorado State Math (from jesandco.net):
- NA

ITEEA: ITEEA, Standard 5, Grades 9-12, K. Humans devise technologies to reduce the negative consequences of other technologies.
ITEEA, Standard 2, Grades 9-12, Z. Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

Pre-Requisite Knowledge
Working knowledge of chemistry including the understanding that atoms contain protons and electrons, and that, under the right circumstances, those protons and electrons can dissociate. Functional knowledge of electricity (Energy, Power, and Electricity lesson will suffice). The understanding that molecules are made up of atoms, and that gasses can be made up of multiple atoms (e.g. O₂).

Learning Objectives
After this lesson, students should be able to:
- Describe the advantages and disadvantages of a proton exchange membrane (PEM) fuel cell over batteries or fossil fuels.
- Identify the two gasses needed to create electricity with a PEM fuel cell.
- Describe the function of a PEM fuel cell. Namely paths of proton transport and electron movement.
- Calculate the waste products of a PEM fuel cell.
- Identify the difference between electrolysis and recombination of hydrogen and oxygen to form water.

Introduction / Motivation
[Play Ballard Fuel Cell video]
There are many ways to generate clean energy, but what do we do with that energy? Wind and solar power are wonderful, but they can be are very unreliable and are not power-dense enough to directly power machines such as cars. We need a way to store unreliable clean power and then be able to re-access it when needed.

Engineers have been working on ways to store and re-access energy for centuries. Proton exchange membrane fuel cells are a hot-topic of clean energy research because they allow us to store enormous amounts of energy using only hydrogen. In a very controlled way, we can recombine this hydrogen with oxygen to make heat, water, and electricity!
Lesson Background & Concepts for Teachers

**Fuel Cells:** A fuel cell is a device that produces electricity by oxidizing a fuel source.

*The following is a summary with quoted text from "How Stuff Works.com"*

There are many different flavors of fuel cells currently being researched. However, all but the PEM are very expensive or require very high temperatures to operate:

- Solid oxide fuel cell (SOFC)
- Alkaline fuel cell (AFC)
- Molten-carbonate fuel cell (MCFC)
- Phosphoric-acid fuel cell (PAFC)
- Direct-methanol fuel cell (DMFC)
- Proton exchange membrane fuel cell (PEMFC or PEM): The Department of Energy (DOE) is focusing on the PEMFC as the most likely candidate for transportation applications. The PEMFC has a high power density and a relatively low operating temperature (ranging from 60 to 80 degrees Celsius, or 140 to 176 degrees Fahrenheit). The low operating temperature means that it doesn't take very long for the fuel cell to warm up and begin generating electricity.

A proton exchange membrane fuel cell has the following components and functions:

- **The anode**, the negative post of the fuel cell, conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit.
- **The cathode**, the positive post of the fuel cell, 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 proton exchange membrane** is a specially treated material, which looks something like ordinary kitchen plastic wrap, only conducts positively charged ions.
- **The catalyst** is a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the PEM.

**Efficiency:** no energy conversion process is 100% efficient. Hence, we seek to quantify how efficient our particular system is. As an engineer, it is important not only to optimize your system, but to understand how your optimized system holds up against the “ideal.” The comparison of your system’s performance to the “ideal” is called efficiency and is symbolized with the Greek letter eta: $\eta$

$$\eta = \frac{P_{\text{actual}}}{P_{\text{ideal}}}$$
Vocabulary / Definitions

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>Fuel cell</td>
<td>A device that produces electricity by the controlled (non-combustion) oxidization of fuel</td>
</tr>
<tr>
<td>Proton exchange membrane fuel cell (PEMFC)</td>
<td>A fuel cell that creates electricity by recombining hydrogen and oxygen into water</td>
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<tr>
<td>Proton exchange membrane</td>
<td>A thin film through which protons pass in a PEMFC fuel cell</td>
</tr>
<tr>
<td>Oxygen gas</td>
<td>A gas consisting of two oxygen atoms</td>
</tr>
<tr>
<td>Hydrogen gas</td>
<td>A gas consisting of two hydrogen atoms</td>
</tr>
<tr>
<td>Hydrogen proton</td>
<td>The remaining proton from a hydrogen atom when it has been stripped of its electron</td>
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</tbody>
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Associated Activities

Fuel Cell Activity

Lesson Closure

Clean energy sources are great ways to get clean power, but when we need to store that power for later use, fuel cells are a great way to go. Fuel cells have no net greenhouse gas emissions and are very energy dense. The primary challenge with fuel cells remains the ability to store large amounts of pressurized hydrogen safely. One of the great engineering challenges of your generation will be to determine how to safely and effectively store pressurized hydrogen for use in fuel cell powered cars, buses, trains, and other kinds of machines.

Assessment

Pre-Lesson Assessment:
Small Group Discussion: Ask students to discuss the following questions in small groups and present their answer on one question to the class:

- What is a fuel cell?
- What useful things can fuel cells do?
- Where did you first hear about fuel cells?

Post-Introduction Assessment: None Suggested

Lesson Summary Assessment:
What Can I Do With a Fuel Cell?: Students are to reflect on the power and applications of fuel cell technology by writing a paragraph on how a fuel cell could be used in their home or community to provide clean electricity.

Self Assessment: Students will fill out the “Fuel Cells” skeleton notes as well as construct, test, and optimize their own fuel cell car.

Homework: None suggested
Lesson Extension Activities
None

Additional Multimedia Support
None

References

Attachments
Fuel Cells Presentation(ppt)
Fuel Cells Presentation (pdf)
Fuel Cells Skeleton Notes and Worksheets (doc)
Fuel Cells Skeleton Notes and Worksheets (pdf)
Fuel Cells Image, Figure, and Table Citations (doc)
Fuel Cells Image, Figure, and Table Citations (pdf)
Fuel Cells Summary (doc)
Fuel Cells Summary (pdf)
Fuel Cell Car and Clean Energy Fueling Station Activity (doc)
Fuel Cell Car and Clean Energy Fueling Station Activity (pdf)

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