Nuclear batteries - the future?
Investigating advances in battery technology

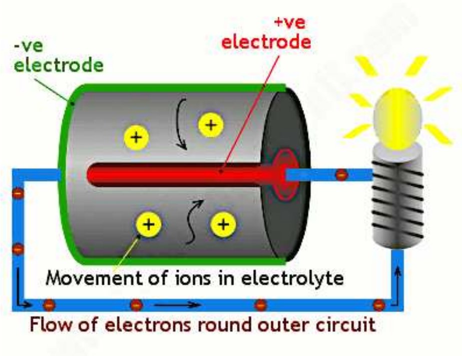
The world needs more power, preferably in a form that is renewable and does not emit greenhouse gases. That means more electricity, but electricity is not easily stored.

Batteries are of two fundamental types:
Primary cells which produce electricity by consuming chemicals packed into the cells. When exhausted, the cells are not re-chargeable and have to be replaced.
Secondary cells, in which a charging current causes energy changes in the chemicals contained in the cells. The reaction is reversible, so the stored energy can be re-emitted as electricity. These are called re-chargeable batteries.

At the moment electrical energy is stored in a range of re-chargeable batteries, such as nickel-metal-hydride for small, portable batteries, lead-antimony-acid and lead-calcium-acid batteries in vehicles, lithium-ion (Li-ion) batteries in portable computers and now electric vehicles. Li-ion batteries become less efficient as they grow older and are damaged by over-charging or over-discharging.

A battery is a pack of one or more cells, each of which has a positive electrode (the cathode), a negative electrode (the anode), a separator between the two with an electrolyte fluid surrounding them. Each cell produces typically 1.5 or 2 volts. Using different chemicals and materials for these affects the properties of the battery, i.e. how much energy it can store, how much power it can provide, that is, how fast the stored charge can be emitted, or the number of times it can be charged and discharged. Issues of the mass of the battery and the cost per unit of storage must also be considered.

There are some fundamental problems with the physics of our current batteries. Electricity is generated, transmitted and largely used as alternating current (AC) at high voltages. Batteries are direct current (DC), low-voltage devices. To charge a battery, AC has to be rectified which introduces losses. The charging voltage is always higher than the output voltage. When the battery provides power, the internal resistance of the cells is in series with the load, causing an internal efficiency loss. The higher the voltage of the battery, the more cells are in series and the higher the internal losses. If AC output is required, an inverter is introduced, with further losses. With existing technology, the charge/discharge cycle efficiency is around 60% so 40% is lost.



How a battery works.
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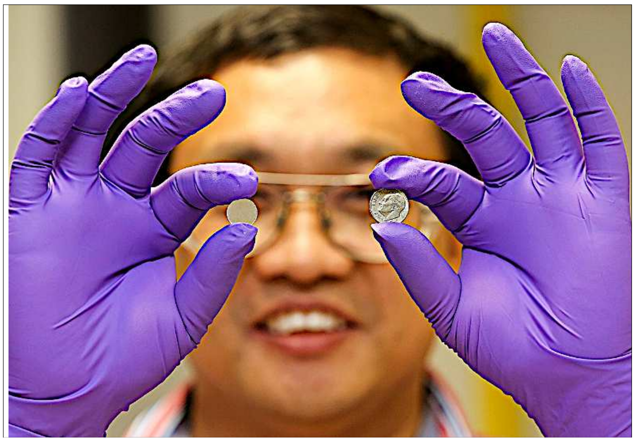
Much research is currently being carried out to reduce these losses; the following are new generation battery technologies with some potential:

Lithium-sulfur - when discharging, the lithium anode is consumed and sulfur transformed into a variety of chemical compounds. During charging, the reverse process takes place. These batteries are light in weight but currently have a short working life.

Solid state - the liquid electrolyte is replaced by a solid compound which nevertheless allows lithium ions to migrate within it. New families of solid electrolytes have been discovered with very high ionic conductivity, similar to liquid electrolyte. These batteries have low internal resistance (low internal loss) and are much safer in mobile use or in hot conditions and are potentially more compact.

Sodium-nickel-chloride - most of the problems of mass and use of rare-earths are removed, but the molten salt electrolyte has to be maintained at 300°C.

However, these and all batteries currently in use are based on serial, incremental improvements to the anode-electrolyte-cathode technology of the Daniell cell (1836).



All solid lithium-sulfur battery
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Into the future - a nuclear battery
The nuclear battery uses decaying isotopes to generate cheap and clean electricity continuously for decades with no combustion, fission, or noise. The technology works in much the same way as a solar panel except that the energy does not come from the sun; it comes from decaying isotopes. The idea is based on research into atomic batteries by Russian and American scientists in the 1950s.

A British-Australian start-up company with research operations in Cumbria, UK has found a way to harness gamma rays from the radioactive decay of cobalt-60. It is claimed that it could be the cheapest source of electricity on the planet. Sellafield in Cumbria has the world's largest stockpile of radioactive residue, seen today as a giant liability but with the potential to become an asset instead.

Cobalt-60 is relatively safe with a half-life of 5.2 years, though you would not want it in your kitchen. The small pencil-sized sticks are placed in tubes, protected by 30 cm steel in boxes. They are sealed in cement buildings when scaled up for more power. They do not require the fortress architecture that make nuclear fission plants so expensive. The batteries could be used in small power units or in warehouse-size power plants of 100 megawatts, or larger for industrial hubs. They are modular so more boxes can be added.

A nuclear mini-battery to generate light
© Infinite power

In the UK, it is thought that the cobalt-60 battery will help to solve the problem of how to switch from combustion engines to electric vehicles (EVs) without breaking the national electricity grid. The UK national grid is already under transition stress as it goes from being a 20th century fossil-based system to a 21st century flexible system of distributed green power. The raw material for cobalt-60 is cobalt-59 which comes from mines in Canada, Australia, Zambia and the Congo. The standard cobalt-59 is not scarce but nor is it cheap, as it is in needed for ordinary batteries. The larger issue is that cobalt-59 has to be converted in an industrial reactor by bombarding it with neutrons. There are 85 such reactors in Europe, some already producing isotopes for X-rays, scanners, smoke detectors, measuring devices, and so on. Others are scattered all over the world. The isotopes can be recycled again and again by putting them back in a reactor every ten years. By then they have partly decayed into nickel. There are almost no operating costs once the system is up and running.

The nuclear battery is a primary cell battery because it works by consuming cobalt-60 contained within it, though at the atomic level, It is re-chargeable in that the depleted cobalt can be re-energised.

Scientists are now working on tritium (hydrogen-3) and carbon-14 to make 'diamond batteries' from spent nuclear fuel. A group is currently working on an artificial diamond that harvests the energy from carbon-14 isotopes and promises to generate power on a 'near infinite basis'.

Ask the pupils, working in small groups, to make a list of the advantages and disadvantages of using nuclear batteries:

Possible answers:
Advantages:
- solve global energy needs;
- no carbon emissions;
- no pollution;
- can use radioactive waste material.

Disadvantages:
- must be sealed securely so no radioactivity can escape;
- cobalt-59 has to be converted into cobalt-60 in an industrial reactor by bombarding it with neutrons;
- cobalt-60 is expensive;
- at the present state of development a single nuclear battery has a capacity of about 15 joules per gm . A typical AA battery, nickel-metal-hydride, has a capacity of around 700 joules/gm.

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Back up

Title: Nuclear batteries - the future?

Subtitle: Investigating advances in battery technology.

Topic: Exploring the future of battery technology.

Age range of pupils: 16 years upwards

Time needed to complete activity: 30 minutes

Pupil learning outcomes: Pupils can:
- describe how a battery used today works;
- explain that batteries still use the anode-electrolyte -cathode technology of the Daniell cell of 1836;
- describe new generation batteries such as lithium-sulfur and solid state;
- describe how nuclear batteries will work;
- list the advantages and disadvantages of developing nuclear batteries.

Context:
It is believed that, in the future, nuclear battery technology could out-compete fossil-fuel plants for electricity supply. The batteries will be useable for anything from charging posts for electric vehicles to full-sized power plants for cities, generating cheap baseload electricity. This power could be used to balance national demand for electricity as intermittent wind and solar become the backbone of the system, but could also switch to the production of 'green hydrogen' from electrolysis at off peak-times. In 2019 the National Nuclear Laboratory in Europe launched an Americium battery on behalf of the European Space Agency that can generate power for hundreds of years in deep space, the first of its kind in the world.

It has been said that the radioisotope technology has lain dormant because the world was not ready. It has been compared to gasoline in the late 19th century before the combustion engine. The oil extracted then was deemed useless by early oil drillers and tipped into rivers in Pennsylvania. A single twist in technology turned waste into liquid gold. Using this technology, many countries may achieve net-zero much sooner than has been supposed.

Following up the activity:
Evaluate the possibilities for energy sources alternative to fossil fuels using the Earthlearningidea, 'What is/are the least bad option(s) for plugging the future global energy gap?' at https://www.earthlearningidea.com/PDF/343_Plugging_energy_gap.pdf for other ideas of what could be developed in your area.

Underlying principles:
- A battery works by transferring electrons from cathode to anode via an external circuit.
- The anode-electrolyte-cathode of the Daniell cell of 1836 is still the basic principle of any battery.
- There are two types of battery - primary cells (non-rechargeable) and secondary cells (rechargeable).
- New generation batteries have been developed.
- Nuclear batteries use decaying radioactive isotopes to generate electricity.

Thinking skill development:
A pattern develops in thinking about the mechanism of current battery power and developing the idea of nuclear batteries. Discussion of the advantages and disadvantages of this technology involves metacognition. Cognitive conflict occurs when balancing the advantages with the disadvantages and applying the new ideas to the real world is a bridging activity.

Resource list:
- normal school resources

Useful links:
Search 'net-zero' on the Earthlearningidea website to find other Earthlearningideas relating to climate change mitigation or adaptation. Use a search engine like Google to explore the internet for more information about likely global impacts of 'net-zero'.

Source: Martin and Elizabeth Devon of The Earthlearningidea Team