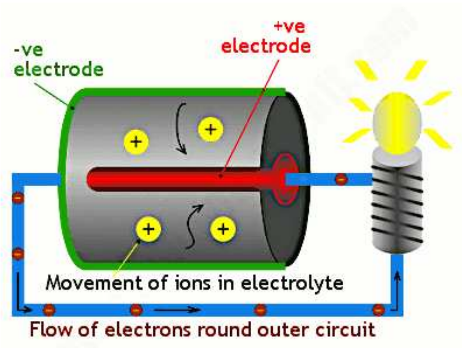
Nuclear batteries - the future?
Investigating advances in battery technology

The world needs more energy in a form that does not consume fossil fuels. 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 inside them. When exhausted, the cells are not re-chargeable and have to be replaced.
Secondary cells, in which a charging current causes chemical changes in the substances contained in the cells. The reaction is reversible, so the stored energy can be re-emitted as electricity. These are called re-chargeable batteries.

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.



How a battery works © *Explainthatstuff.*

Using different chemicals, materials and designs affects the properties of the battery, such as the voltage, 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 storage capacity, which relates to the mass of the battery, and the cost per unit of storage must also be considered.

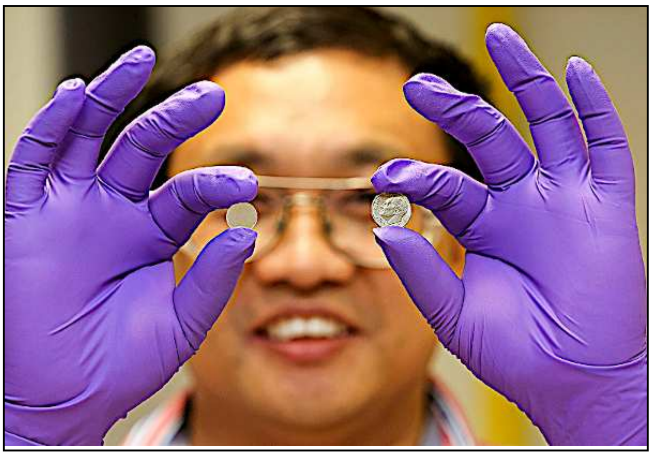
At the moment electrical energy is stored in a range of **re-chargeable batteries**:-
Nickel-metal-hydride cells are used for small, portable batteries. They use nickel oxide hydroxide at the positive electrode and an alloy which can absorb hydrogen for the negative electrode.

Lead-antimony-acid and **lead-calcium-acid** batteries are improved versions of the lead-acid rechargeable battery invented by Plante in 1859, They are used in vehicles as they are cheap and can supply high currents but have low energy density, i.e. energy stored per unit volume. They consist of two plates with a rigid separator in an electrolyte of sulphuric acid. When charged the positive plate consists of lead dioxide and the negative plate of lead metal. As the battery discharges, both plates become lead sulfate. The batteries have a life of typically five years.

Lithium-ion (Li-ion) batteries are used in portable electronic devices and now in electric vehicles. The prototype appeared in 1985. The positive pole is a complex lithium compound and the negative electrode is usually graphite. During charging lithium ions move from the positive pole to the negative pole and back again when discharging. Li-ion batteries have a high energy density but become less efficient as they grow older and are damaged by over-charging or over-discharging. There is also a safety hazard in incorrect charging as the electrolyte is flammable and may explode.

Vanadium redox batteries were first used successfully in the 1980s. They withstand many more charging cycles than other types, last longer and can be made to a large capacity. Against this, they have a poor energy/volume ratio and relatively poor charge/discharge cycle efficiency. Although they are not widely used, interest in vanadium batteries has recently revived.

New generation battery technologies
The following have 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.



All solid lithium-sulfur battery
© *Wikimedia/commons/thumb/a/a1/*

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, all batteries currently in use are based on serial, incremental improvements of ***two early prototypes:-***

The 'voltaic pile' (Alessandro Volta, 1799) which consists of a series of discs of different metals (e.g. copper and zinc) separated by cloth soaked in brine. Each pair produces a potential difference equal to the difference between the electrode potentials of the different metals. Hydrogen gas is liberated between each pair, so a current can only be maintained for a short time.

The Daniell cell (John Daniell, 1836) consisting of a copper pot filled with copper sulfate solution with a zinc rod in the solution. By eliminating the release of hydrogen, this cell can produce a steady current at about 1.1V. It is the model for subsequent anode-electrolyte-cathode designs.

There are some fundamental problems with the physics of our current batteries. In the UK, electricity is distributed to the consumer using 50Hz alternating current at 240 or 440 volts. Batteries are direct current (DC), low-voltage devices. To charge a battery, AC has to be rectified, which causes some losses. The charging voltage is always higher than the output voltage. When the battery provides power to an external circuit, the battery's 'internal resistance' makes up part of 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. Much research is currently being carried out to reduce these losses.

A factor which connects all types of batteries is that ***they all depend on mined metals***. Some, like lead, are easily mined and inexpensive, Most are toxic. The increasing dependence on lithium is likely to become a significant problem.

Into the future - a nuclear battery

The nuclear battery uses decaying isotopes to generate cheap and clean electricity continuously, 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; but 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 energy from the radioactive beta-decay of the non-thermal isotope cobalt-60, a process producing highly-penetrating gamma photons. A new type of PV panel 'harvests' (collects) gamma photons rather than solar photons and withstands long-term gamma radiation. 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, as cobalt-60 can be extracted from ordinary nuclear waste reprocessing.

Cobalt-60 can also be made from cobalt-59 which comes from mines in Canada, Australia, Zambia and the Congo. Cobalt-59 is not scarce but nor is it cheap, as it is 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,

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 steel in boxes. They are sealed in concrete buildings when scaled up for more power, but do not require the fortress architecture that make most 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

Cobalt-60 batteries would have an expected life of 10 years or so before recharging. By then their cobalt-60 will have about 75% decayed into nickel-60, which is stable. There are almost no operating costs once the system is up and running.

In the UK, it is thought that the cobalt-60 battery could 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.

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 long-term basis. The mechanism in these cases is the harvesting of electrons from beta-decay. The working energy level is lower than the cobalt-60 method and PV panels more similar to the usual type may be used.

At the present state of development a single nuclear battery has a very low energy density of about 15 joules per gm. A typical AA battery, nickel-metal-hydride, has an energy density of around 700 joules/gm.

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;*
- *low capacity at present.*

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;
- explore the historical development of the anode-electrolyte-cathode technology from Volta;
- explain that batteries still use the anode-electrolyte -cathode technology of the 19th century work of Volta and Daniell;
- 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 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?'
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 construction of the Voltaic pile of 1799 and Daniell cell of 1836 is still the basic principle of all conventional batteries.
- There are two types of conventional batteries- primary cells (non-rechargeable) and secondary cells (rechargeable).
- New generation batteries have been developed.
- Nuclear batteries use emissions from decaying radioactive isotopes to generate electricity using photo-voltaic collectors (PV panels).

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. Applying the new ideas to the real world is a bridging activity.

Resource list:
- none

Useful links:
Search 'net-zero' on the Earthlearningidea website to find other Earthlearningideas relating to climate change mitigation or adaptation; the full list can be seen on the last page.
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 with thanks to John Perry, Keele University for technical advice.

This information was as accurate as possible in spring 2021,

The ‘How will the ‘net-zero’ target affect your local area?’ series of Earthlearningideas

Topic			**Earthlearningidea title**
Introduction			How will the ‘net-zero’ target affect your local area?
Possible mitigation measures	Use alternative energy sources	Solar	Harnessing the power of the Sun
		Wave	Harnessing the power of waves
		Wind	Farming the wind: through onshore and offshore windfarms
		Tidal	Tidal energy
		Nuclear	Nuclear power - harnessing the energy of the atom
		Nuclear waste	Nuclear waste disposal
		Biofuel	Liquid biofuels: keeping our wheels turning into the future
		‘Blue’ hydrogen	Blue hydrogen: the fuel of the future? *Also:* Hydrogen of many colours
		Geothermal – hot rocks	Deep geothermal power from ‘hot dry rocks’: an option in your area?
		Geothermal – flooded mines	A new use for old coal mines
		Hydro – small scale	Small-scale hydroelectric power schemes
		Heat pumps	Heat from the Earth
		Waste – incineration	Energy from burning waste
		Waste – methane	Energy from buried waste
	Stop fuels releasing greenhouse gases	Carbon capture	Capturing carbon?
	Store energy from sources that give irregular energy supplies	Batteries	Nuclear batteries: the future?
		‘Green’ hydrogen	Green hydrogen used to even out renewable energy supplies? *Also* Hydrogen of many colours
		Hydro – storage	Matching supply and demand using stored water
		Compressed gas	Storing gas underground: What can we store? How can we do it? How will it help?
	Provide raw materials for new technologies	Electric vehicles	Electric vehicles: the way to go?
		Insulation	How do I choose the best insulation?
	Remove carbon form the atmosphere	Enhanced weathering	Speeding up nature to trap carbon dioxide
		Tree planting	Let’s plant some trees
Possible adaptation measures		Coastal flooding	How will rising sea level affect our coastlines?
		Inland flooding	Inland flooding: a Sheffield case study
		Landslides	Landslide danger
		Agriculture	The future for global agriculture