Paper Battery
A paper battery is a flexible, ultra-thin energy storage and production device formed by combining carbon nanotube with a conventional sheet of cellulose-based paper. A paper battery acts as both a high-energy battery and super capacitor, combining two components that are separate in traditional electronics. This combination allows the battery to provide both long-term, steady power production and bursts of energy. Non-toxic, flexible paper batteries have the potential to power the next generation of electronics, medical devices and hybrid vehicles, allowing for radical new designs and medical technologies.

Paper batteries may be folded, cut or otherwise shaped for different applications without any loss of integrity or efficiency. Cutting one in half halves its energy production. Stacking them multiplies power output. Early prototypes of the device are able to produce 2.5 volt s of electricity from a sample the size of a postage stamp.

The devices are formed by combining cellulose with an infusion of aligned carbon nanotubes that are each approximately one millionth of a centimeter thick. The carbon is what gives the batteries their black color. These tiny filaments act like the electrodes found in a traditional battery, conducting electricity when the paper comes into contact with an ionic liquid solution. Ionic liquids contain no water, which means that there is nothing to freeze or evaporate in extreme environmental conditions. As a result, paper batteries can function between -75 and 150 degrees Celsius.

One method of manufacture, developed by scientists at Rensselaer Polytechnic Institute and MIT, begins with growing the nanotubes on a silicon substrate and then impregnating the gaps in the matrix with cellulose. Once the matrix has dried, the material can be peeled off of the substrate, exposing one end of the carbon nanotubes to act as an electrode. When two sheets are combined, with the cellulose sides facing inwards, a supercapacitor is formed that can be activated by the addition of the ionic liquid. This liquid acts as an electrolyte and may include salt-laden solutions like human blood, sweat or urine. The high cellulose content (over 90%) and lack of toxic chemicals in paper batteries makes the device both biocompatible and environmentally friendly, especially when compared to the traditional lithium ion battery used in many present-day electronic devices and laptops.

Widespread commercial deployment of paper batteries will rely on the development of more inexpensive manufacturing techniques for carbon nanotubes. As a result of the potentially transformative applications in electronics, aerospace, hybrid vehicles and medical science, however, numerous companies and organizations are pursuing the development of paper batteries. In addition to the developments announced in 2007 at RPI and MIT, researchers in Singapore announced that they had developed a paper battery powered by ionic solutions in 2005. NEC has also invested in R & D into paper batteries for potential applications in its electronic devices.
Specialized paper batteries could act as power sources for any number of devices implanted in humans and animals, including RFID tags, cosmetics, drug-delivery systems and pacemakers. A capacitor introduced into an organism could be implanted fully dry and then be gradually exposed to bodily fluids over time to generate voltage. Paper batteries are also biodegradable, a need only partially addressed by current e-cycling and other electronics disposal methods increasingly advocated for by the green computing movement.

**Paper battery offers future power**

**Flexible paper batteries could meet the energy demands of the next generation of gadgets, says a team of researchers.**

They have produced a sample slightly larger than a postage stamp that can store enough energy to illuminate a small light bulb.

But the ambition is to produce reams of paper that could one day power a car.

Professor Robert Linhardt, of the Rensselaer Polytechnic Institute, said the paper battery was a glimpse into the future of power storage.

The team behind the versatile paper, which stores energy like a conventional battery, says it can also double as a capacitor capable of releasing sudden energy bursts for high-power applications.

**Graphic: How a paper battery works**

While a conventional battery contains a number of separate components, the paper battery integrates all of the battery components in a single structure, making it more energy efficient.

**Integrated devices**

The research appears in the Proceedings of the National Academy of Sciences (PNAS).

"Think of all the disadvantages of an old TV set with tubes," said Professor Linhardt, from the New York-based institute, who co-authored a report into the technology.

"The warm up time, power loss, component malfunction; you don't get those problems with integrated devices. When you transfer power from one component to another you lose energy. But you lose less energy in an integrated device."

The battery contains carbon nanotubes, each about one millionth of a centimetre thick,
which act as an electrode. The nanotubes are embedded in a sheet of paper soaked in ionic liquid electrolytes, which conduct the electricity.

The flexible battery can function even if it is rolled up, folded or cut.

Although the power output is currently modest, Professor Linhardt said that increasing the output should be easy.

"If we stack 500 sheets together in a ream, that's 500 times the voltage. If we rip the paper in half we cut power by 50%. So we can control the power and voltage issue."

Because the battery consists mainly of paper and carbon, it could be used to power pacemakers within the body where conventional batteries pose a toxic threat.

"I wouldn't want the ionic liquid electrolytes in my body, but it works without them," said Professor Linhardt. "You can implant a piece of paper in the body and blood would serve as an electrolyte."

But Professor Daniel Sperling at University of California, Davis, an expert on alternative power sources for transport, is unconvinced.

'More difficult'

"Batteries and capacitors are being steadily improved, but electricity storage is much more difficult and expensive than liquid fuels and probably will be so forever," he said.

"The world is not going to change as a result of this new invention any time soon."

Professor Linhardt admitted that the new battery is still some way from the commercial market.

"The devices we're making are only a few inches across. We would have to scale up to sheets of newspaper size to make it commercially viable," he said. But at that scale, the voltage could be large enough to power a car, he said.

However, carbon nanotubes are very expensive, and batteries large enough to power a car are unlikely to be cost effective.

"I'm a strong enthusiast of electric vehicles, but it is going to take time to bring the costs down," said Professor Sperling.

But Professor Linhardt said integrated devices, like the paper battery, were the direction the world was moving.

"They are ultimately easier to manufacture, more environmentally friendly and usable in a wide range of devices," he said.
The ambition is to produce the paper battery using a newspaper-type roller printer.

Electricity is the flow of electrical power or electrons

1. Batteries produce electrons through a chemical reaction between electrolyte and metal in the traditional battery.
2. Chemical reaction in the paper battery is between electrolyte and carbon nanotubes.
3. Electrons collect on the negative terminal of the battery and flow along a connected wire to the positive terminal.
4. Electrons must flow from the negative to the positive terminal for the chemical reaction to continue.

Development

The creation of this unique nanocomposite paper drew from a diverse pool of disciplines, requiring expertise in materials science, energy storage, and chemistry. In August 2007, a research team at Rensselaer Polytechnic Institute (led by Drs. Robert Linhardt, the Ann and John H. Broadbent Senior Constellation Professor of Biocatalysis and Metabolic Engineering at Rensselaer; Pulickel M. Ajayan, professor of materials science and engineering; and Omkaram Nalamasu, professor of chemistry with a joint appointment in materials science and engineering) developed the paper battery. Senior research specialist Victor Pushparaj, along with postdoctoral research associates Shaijumon M. Manikoth, Ashavani Kumar, and Saravanababu Murugesan, were co-authors and lead researchers of the project. Other co-authors include research associate Lijie Ci and Rensselaer Nanotechnology Center Laboratory Manager Robert Vajtai.

The researchers used ionic liquid, essentially a liquid salt, as the battery’s electrolyte. The use of ionic liquid, which contains no water, means there’s nothing in the batteries to freeze or evaporate. “This lack of water allows the paper energy storage devices to withstand extreme temperatures,” Kumar said. It gives the battery the ability to function in temperatures up to 300 degrees Fahrenheit and down to 100
Paper Battery

below zero. The use of ionic liquid also makes the battery extremely biocompatible; the team printed paper batteries without adding any electrolytes, and demonstrated that naturally occurring electrolytes in human sweat, blood, and urine can be used to activate the battery device. According to Pushparaj “It’s a way to power a small device such as a pacemaker without introducing any harsh chemicals – such as the kind that are typically found in batteries — into the body.”

Durability

The use of carbon nanotubes gives the paper battery extreme flexibility; the sheets can be rolled, twisted, folded, or cut into numerous shapes with no loss of integrity or efficiency, or stacked, like printer paper (or a Voltaic pile), to boost total output. As well, they can be made in a variety of sizes, from postage stamp to broadsheet. “It’s essentially a regular piece of paper, but it’s made in a very intelligent way,” said Linhardt, “We’re not putting pieces together — it’s a single, integrated device,” he said. “The components are molecularly attached to each other: the carbon nanotube print is embedded in the paper, and the electrolyte is soaked into the paper. The end result is a device that looks, feels, and weighs the same as paper.”
Uses

The paper-like quality of the battery combined with the structure of the nanotubes embedded within gives them their light weight and low cost, making them attractive for portable electronics, aircraft, automobiles, and toys (such as model aircraft), while their ability to use electrolytes in blood make them potentially useful for medical devices such as pacemakers. The medical uses are particularly attractive because they do not contain any toxic materials and can be biodegradable; a major drawback of chemical cells

However, Professor Sperling cautions that commercial applications may be a long way away, because nanotubes are still relatively expensive to fabricate. Currently they are making devices a few inches in size. In order to be commercially viable, they would like to be able to make them newspaper size; a size which, taken all together would be powerful enough to power a car.
Paper Battery

Conclusion

A paper battery is a battery engineered to use a paper-thin sheet of cellulose (which is the major constituent of regular paper, among other things) infused with aligned carbon nanotubes.[1] The nanotubes act as electrodes; allowing the storage devices to conduct electricity. The battery, which functions as both a lithium-ion battery and a supercapacitor, can provide a long, steady power output comparable to a conventional battery, as well as a supercapacitor’s quick burst of high energy -- and while a conventional battery contains a number of separate components, the paper battery integrates all of the battery components in a single structure, making it more energy efficient.