Battery technologies

The advantages of electric flight are too obvious to repeat. The only real disadvantage is the battery. It is large and heavy and doesn't contain enough energy. The IC-heads rightly point out that when we leccies applaud our models managing a ten minute flight they can do that several times over. Each time I buy new batteries for my power models I add another 0.5 Ah to the capacity, so now I bung 500 gram bricks into even modest models. And still I only get maybe twelve minutes. And the ducted fan flyers only get three or four minutes compared with double that for gas turbines running on paraffin (kerosene).

The key criterion is energy density. This is the amount of energy the cell can store per litre. The energy is usually specified as watt-hours (Wh). Colloquially energy density may also be used for energy per kilogram, though the accurate term for this is specific energy. Secondary factors are cyclability (how many times it will recharge), charge time and safety. A comparison of specific energies shows that currently methanol has twenty times and petrol (gasoline) forty-five times the specific energy of a lipo. However in theory lithium-air could achieve parity or better with petrol.

I have left out the Lithium Polymer Lipo batteries that we currently (oh dear!) use. So, what is on the horizon for we leccies? I did a major read of publically available sources that are listed at the end. They range from published company information to university reports. Of course it's anyone's guess which will mature into a form suitable for flying. My notes are in [ ].

Why does this matter for glider flyers? After all we only use batteries during climbs and for powering the receiver and servos. Well, wouldn't it be nice (as the Beach Boys sang) to have a tiny battery that we could rely on for a whole day's flying and possibly charge in situ? That would make fuselage design a lot simpler and more elegant. No more easily removable canopies for one thing. Some indoor flyers use super-capacitors that can be charged in seconds.

The included links worked at the time of writing but I can't guarantee them for the future. This is, I hope, the complete list of technologies at the moment.

Lithium-ion
New generation lithium-ion
Zinc-air
Aluminium-ion
Aluminium-air
Lithium-sulphur
Solid state
Solid state lithium-ion
Sodium-ion batteries
Metal-air
Graphene
Sand
Gold nano-wire
Foam
Ryden dual carbon
ZapGo Carbon-ion battery

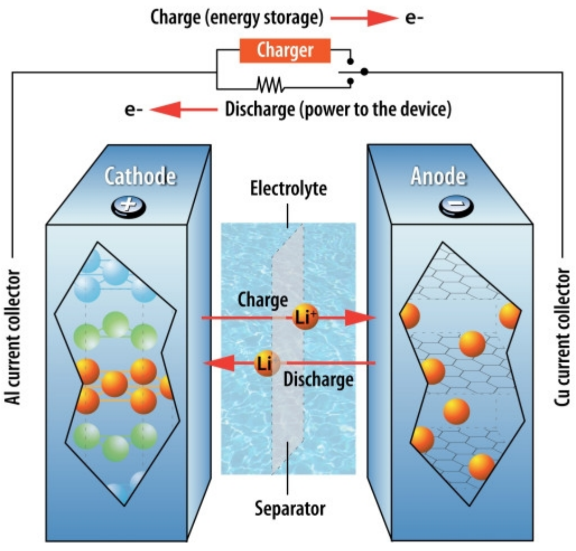
Laser-made micro supercapacitors
Iron-air batteries

At the moment lithium is the most-used material for batteries powering in electric motor. That is because it is highly reactive so each cell produces a high voltage and it is light. However there are three problems with it. It isn't in short supply but it is found in relatively few countries so making supply and price dependent on politics, greed and war. Its reactivity makes it dangerous under some conditions as I am sure we have all found. Perhaps most serious of all, refining it is highly polluting. Over two million litres of water are needed to produce a tonne of lithium and the methods used run the risk of ground water pollution in the event of leakage or accidents. It is also expensive. Other metals or materials will probably become dominant eventually, with iron, zinc or aluminium being likely candidates. These are all safer, much cheaper and their sources are worldwide.

Lithium-ion batteries

Lithium-ion batteries (LIBs) are currently used in the majority of electric vehicles, and it's likely that they will remain dominant into the next decade [presumably 20's] Manufacturers, including Tesla and Nissan, have invested heavily in this technology. In LIBs, positively charged lithium ions travel between the anode and the cathode in the electrolyte. LIBs have a high cyclability – the number of times the battery can be recharged while still maintaining its efficiency – but a low energy density – the amount of energy that can be stored in a unit volume. LIBs have garnered a bad reputation for overheating and catching on fire (e.g. Boeing jets, Tesla cars, laptops), so manufacturers have not only worked to make LIBs more stable, but they have also developed many safety mechanisms to prevent harm if a battery were to catch fire.

The LIBs on the market today primarily use graphite or silicon anodes and a liquid electrolyte. A lithium anode has been the holy grail for a long time because it can store a lot of energy in a small space (i.e. it has a high energy density) and is very lightweight. Unfortunately, lithium heats up and expands during charging, causing leaked lithium ions to build up on a battery's surface. These growths short-circuit the battery and decrease its overall life. Researchers at Stanford recently made headway on these problems by forming a protective nanosphere layer on the lithium anode that moves with the lithium as it expands and contracts.



Movement of lithium ions and electrons in a lithium-ion battery during charging and use. Source: Argonne National Laboratory. Used under Creative Commons license.

New generation Lithium-ion

What is it?
In lithium-ion (Li-ion) batteries, energy storage and release is provided by the movement of lithium ions from the positive to the negative electrode back and forth via the electrolyte. In this technology, the positive electrode acts as the initial lithium source and the negative electrode as the host for lithium. Several chemistries are gathered under the name of Li-ion batteries, as the result of decades of selection and optimization close to perfection of positive and negative active materials. Lithiated metal oxides or phosphates are the most common material used as present positive materials. Graphite, but also graphite/silicon or lithiated titanium oxides are used as negative materials.

With actual materials and cell designs, Li-ion technology is expected to reach an energy limit in the next coming years. Nevertheless, very recent discoveries of new families of disruptive active materials should unlock present limits. These innovative compounds can store more lithium in positive and negative electrodes and will allow for the first time to combine energy and power. In addition, with these new compounds, the scarcity and criticality of raw materials are also taken into account.

What are its advantages?
Today, among all the state-of-the-art storage technologies, Li-ion battery technology allows the highest level of energy density. Performances such as fast charge or temperature operating window (-50°C up to 125°C) can be fine-tuned by the large choice of cell design and chemistries. Furthermore, Li-ion batteries display additional advantages such as very low self-discharge and very long lifetime and cycling performances, typically thousands of charging/discharging cycles.

When can we expect it?
New generation of advanced Li-ion batteries is expected to be deployed before the first generation of solid-state batteries. They'll be ideal for use in applications such as Energy Storage Systems for renewables and transportation (marine, railways, aviation and off road mobility) where high energy, high power and safety is mandatory.

Zinc-Air

Scientists at Sydney University believe they've come up with a way of manufacturing zinc-air batteries much cheaper than current methods. Zinc-air batteries can be considered superior to lithium-ion, because they don't catch fire. The only problem is they rely on expensive components to work. Sydney Uni has managed to create a zinc-air battery without the need for the expensive components, but rather some cheaper alternatives. Safer, cheaper batteries could be on their way!

Aluminum-ion batteries

Aluminum-ion batteries are similar to Lithium-Ion Batteries (LIBs) but have an aluminum anode. They promise increased safety at a decreased cost over LIBs, but research is still in its infancy. Scientists at Stanford recently solved one of the aluminum-ion battery's greatest drawbacks, its cyclability, by using an aluminum metal anode and a graphite cathode. This also offers significantly decreased charging time and the ability to bend. Researchers at Oak Ridge National Laboratory are also working on improving aluminum-ion battery technology. [Aluminium is a lot less reactive than lithium so presumably will produce a lower voltage per cell. Might need more cells in each pack.]

Aluminium-air battery

A car has managed to drive 1,100 miles on a single battery charge. The secret to this super range is a type of battery technology called aluminium-air that uses oxygen from the air to fill its cathode. This makes it far lighter than liquid filled lithium-ion batteries to give car a far greater range.

Lithium-sulphur

What is it?
In Li-ion batteries, the lithium ions are stored in active materials acting as stable host structures during charge and discharge. In lithium-sulphur (Li-S) batteries, there are no host structures. While discharging, the lithium anode is consumed and sulphur transformed into a variety of chemical compounds; during charging, the reverse process takes place.

What are its advantages?
A Li-S battery uses very light active materials: sulphur in the positive electrode and metallic lithium as the negative electrode. This is why its theoretical energy density is extraordinarily high: four times greater than that of Li-ion. That makes it a good fit for the aviation and space industries.

Saft has selected and favoured the most promising Li-S technology based on solid state electrolyte. This technical path brings very high energy density, long life and overcomes the main drawbacks of the liquid based Li-S (limited life, high selfdischarge). Furthermore, this technology is supplementary to solid state Li-ion thanks to its superior gravimetric energy density (+30% at stake in Wh/kg).

Lithium-sulphur batteries (Li/S) typically have a lithium anode and a sulphur-carbon cathode. They offer a higher theoretical energy density and a lower cost than LIBs. Their low cyclability, caused by expansion and harmful reactions with the electrolyte, is the major drawback. However, the cyclability of Li/S batteries has recently been improved. Li/S batteries, combined with solar panels, powered the famous 3-day flight of the Zephyr-6 unmanned aerial vehicle. NASA has invested in solid-state Li/S batteries to power space exploration, and Oxis Energy is also working to commercialize Li/S batteries. [The higher energy density of this cell looks promising for models.]

Solid state

What is it?

Solid-state batteries represent a paradigm shift in terms of technology. In modern Li-ion batteries, ions move from one electrode to another across the liquid electrolyte (also called ionic conductivity). In all-solid-state batteries, the liquid electrolyte is replaced by a solid compound which nevertheless allows lithium ions to migrate within it. This concept is far from new, but over the past 10 years – thanks to intensive worldwide research – new families of solid electrolytes have been discovered with very high ionic conductivity, similar to liquid electrolyte, allowing this particular technological barrier to be overcome.

What are its advantages?
The first huge advantage is a marked improvement in safety at cell and battery levels: solid electrolytes are non-flammable when heated, unlike their liquid counterparts. Secondly, it permits the use of innovative, high-voltage high-capacity materials, enabling denser, lighter batteries with better shelf-life as a result of reduced self-discharge. Moreover, at system level, it will bring additional advantages such as simplified mechanics as well as thermal and safety management.

As the batteries can exhibit a high power-to-weight ratio, they may be ideal for use in electric vehicles. [...and model aircraft probably.]

When can we expect it?
Several kinds of all-solid-state batteries are likely to come to market as technological progress continues. The first will be solid-state batteries with graphite-based anodes, bringing improved energy performance and safety. In time, lighter solid-state battery technologies using a metallic lithium anode should become commercially available.

Solid state lithium-ion

Solid state batteries traditionally offer stability but at the cost of electrolyte transmissions. A paper published by Toyota scientists writes about their tests of a solid state battery which uses sulphide superionic conductors.

The result is a battery that can operate at super capacitor levels to completely charge or discharge in just seven minutes - making it ideal for cars. Since it's solid state that also means it's far more stable and safer than current batteries. The solid-state unit should also be able to work in as low as minus 30 degrees Celsius and up to one hundred.
The electrolyte materials still pose challenges so don't expect to see these in cars soon, but it's a step in the right direction towards safer, faster-charging batteries.

Sodium-ion batteries

Scientists in Japan are working on new types of batteries that don't need lithium. These new batteries will use sodium, one of the most common materials on the planet rather than rare lithium – and they'll be up to seven times more efficient than conventional batteries.

Research into sodium-ion batteries has been going on since the eighties in an attempt to find a cheaper alternative to lithium. By using salt, the sixth most common element on the planet, batteries can be made much cheaper. Commercialising the batteries is expected to begin for smartphones, cars and more in the next five to 10 years.

In the face of such a challenge perhaps it's no surprise that some are trying to work out how to reduce our reliance on lithium.

One start-up to watch is UK Sheffield-based Faradion, one of the world leaders in an exciting new battery technology: sodium ion. Sodium is, like lithium, light and reactive. Like lithium it works well in a cathode - the business end of a battery. But unlike lithium, sodium is plentiful. You can even extract it from table salt (sodium chloride).

There are other advantages: sodium ion batteries are significantly safer than lithium ion ones, less prone to catching on fire if something goes wrong.

There is a catch too: they hold less charge than their lithium counterparts. Still: given the concerns about getting enough lithium out of the ground, perhaps new batteries like this might hold promise for the future.

Metal-air batteries

Metal-air batteries have a pure-metal anode and an ambient air cathode. As the cathode typically makes up most of the weight in a battery, having one made of air is a major advantage. There are many possibilities for the metal, but lithium, aluminum, zinc, sodium remain the forerunners. Most experimental work uses oxygen as the cathode to prevent the metal from reacting with CO2 in the air, because capturing enough oxygen in the ambient air is a major challenge. Furthermore, most metal-air or metal-oxygen prototypes have problems with cyclability and lifetime.

Graphene

[Note that graphene batteries are available for flying now but they are just a variant of standard lipo-style batteries]

Samsung's graphene battery

Samsung has managed to develop "graphene balls" that are capable of boosting the capacity of its current lithium-ion batteries by 45 per cent, and and recharging five times faster than current batteries. To put that into context, Samsung says its new graphene-based battery can be recharged fully in 12 minutes, compared to roughly an hour for the current unit.

Samsung also says it has uses beyond smartphones, saying it could be used for electric vehicles as it can withstand temperatures up to 60 degrees Celsius.

Grabat graphene batteries

Graphene batteries have the potential to be one of the most superior available. Grabat has developed graphene batteries that could offer electric cars a driving range of up to 500 miles on a charge.

Graphenano, the company behind the development, says the batteries can be charged to full in just a few minutes and can charge and discharge 33 times faster than lithium ion. Discharge is also crucial for things like cars that want vast amounts of power in order to pull away quickly. There's no word on if Grabat batteries are currently being used in any products, but the company has batteries available for cars, drones, bikes and even the home.

Sand battery

This alternative type of lithium-ion battery uses silicon to achieve three times better performance than current graphite li-ion batteries. The battery is still lithium-ion like the one found in your smartphone, but it uses silicon instead of graphite in the anodes.

Scientists at the University of California Riverside have been focused on nano silicon for a while, but it's been degrading too quickly and is tough to produce in large quantities. By using sand it can be purified, powdered then ground with salt and magnesium before being heated to remove oxygen resulting in pure silicon. This is porous and three-dimensional which helps in performance and, potentially, the life-span of the batteries. We originally picked up on this research in 2014 and now it's coming to fruition.

Silanano is a battery tech startup that's bringing this technique to market and has seen big investment from companies like Daimler and BMW. The company say that its solution can be dropped into existing lithium-ion battery manufacturing, so it's set for scalable deployment, promising 20 per cent battery performance boost now, or 40 per cent in the near future.

Gold nanowire batteries

Great minds over at the University of California Irvine have cracked nanowire batteries that can withstand plenty of recharging. The result could be future batteries that don't die.

Nanowires, a thousand times thinner than a human hair, pose a great possibility for future batteries. But they've always broken down when recharging. This discovery uses gold nanowires in a gel electrolyte to avoid that. In fact, these batteries were tested recharging over 200,000 times in three months and showed no degradation at all. [I think these were the ones NASA was keen on, but are currently very expensive.]

Foam batteries

Prieto believes the future of batteries is 3D. The company has managed to crack this with its battery that uses a copper foam substrate. This means these batteries will not only be safer, thanks to having no flammable electrolyte, but they will also offer longer life, faster charging, five times higher density, be cheaper to make and be smaller than current offerings.

Prieto aims to place its batteries into small items first, like wearables. But it says the batteries can be upscaled so we could see them in phones and maybe even cars in the future.

Ryden dual carbon

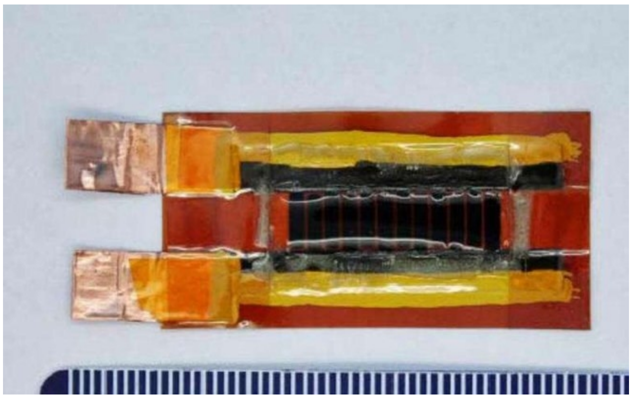
Power Japan Plus has already announced this new battery technology called Ryden dual carbon. Not only will it last longer and charge faster than lithium but it can be made using the same factories where lithium batteries are built. The batteries use carbon materials which mean they are more sustainable and environmentally friendly than current alternatives. It also means the batteries will charge twenty times faster than lithium ion. They will also be more durable, with the ability to last up to 3,000 charge cycles, plus they are safer with lower chance of fire or explosion.

ZapGo Carbon-ion battery

Oxford-based company ZapGo has developed and produced the first carbon-ion battery that's ready for consumer use now. A carbon-ion battery combines the superfast charging capabilities of a supercapacitor, with the performance of a Lithium-ion battery, all while being completely recyclable. The company has a powerbank charger that be fully charged in five minutes, and will then charge a smartphone up to full in two hours.

Laser-made micro supercapacitors

Scientists at Rice University have made a breakthrough in micro-supercapacitors. Currently, they are expensive to make but using lasers that could soon change.



By using lasers to burn electrode patterns into sheets of plastic, manufacturing costs and effort drop massively. The result is a battery that can charge 50 times faster than current batteries and discharge even slower than current supercapacitors. They're even tough, able to work after being bent over 10,000 times in testing.

Iron-air batteries

Iron-air batteries promise a considerably higher energy density than present-day lithium-ion batteries. In addition, their main constituent – iron – is an abundant and therefore cheap material. Scientists from Forschungszentrum Jülich are among the driving forces in the renewed research into this concept, which was discovered in the 1970s. Together with American Oak Ridge National Laboratory (ORNL), they successfully observed with nanometre precision how deposits form at the iron electrode during operation. A deeper understanding of the charging and discharging reactions is viewed as the key for the further development of this type of rechargeable battery to market maturity. The results were published in the renowned journal Nano Energy.

For reasons including insurmountable technical difficulties, research into metal-air batteries was abandoned in the 1980s for a long time. The past few years, however, have seen a rapid increase in research interest. Iron-air batteries draw their energy from a reaction of iron with oxygen. In this process, the iron oxidizes almost exactly as it would during the rusting process. The oxygen required for the reaction can be drawn from the surrounding air so that it does not need to be stored in the battery. These material savings are the reason for the high energy densities achieved by metal-air batteries.

“We consciously concentrate on research into battery types made of materials that are abundant in the Earth’s crust and produced in large quantities,” explains institute head Prof. Rüdiger-A. Eichel. “Supply shortages are thus not to be expected. The concept is also associated with a cost advantage, which can be directly applied to the battery, particularly for large-scale applications such as stationary devices for the stabilization of the electricity grid or electromobility.”

There is, however, still a long way to go until market maturity. Although isolated electrodes made of iron can be operated without major power losses for several thousand cycles in laboratory experiments, complete iron-air batteries, which use an air electrode as the opposite pole, have only lasted 20 to 30 cycles so far.

Energy and power densities

Blanks show not yet known. Wh means watt-hours.

Type	Specific energy	Energy density	Specific power	Cycles

	Wh/kg	Wh/litre	W/kg	
Lead acid	33 - 42	60 - 110	180	500 - 800
Nickel-cadmium	40 - 60	50 - 150	150	2000
Nickel metal-hydride	60 - 120	140 - 300	250 - 1000	500 - 2000
Lithium-ion	100 - 350	250 - 620	250 - 340	400 - 1200
Lithium-polymer	100 - 265	250 - 730		
Lithium sulphur	500	350		
Lithium-air	11 140	6000		
Iron-air	1200	9700		

The Cycles column shows how many charge cycles should be achieved. In practice I think this is lower as the numbers rely on perfect treatment of the cells.

For comparison of specific energies:
Methanol 22.7 MJ/kg
Petrol 45 MJ/kg
Lipo 0.95 MJ/kg
Lithium-air 40 MJ/kg
Of course liquid fuels are not 100% methanol or petrol so the true numbers will be lower.

Calculations:
1 Wh = 3600 Ws = 3600 J
The best **current** technology for flyers is Lipo which stores 265 Wh/kg
This gives 265 x 3600 = 954000 J/kg
This is 20 to 40 times less good than liquid fuels.
If lithium-air matures this becomes:
11140 x 3600 = 40MJ/kg

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Peter Scott 2021
Last edit 9 February 2022