Research into batteries will give electric cars the same range as petrol cars

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Li-air batteries are a promising opportunity for electric cars. "If we succeed in developing this technology, we are facing the ultimate breakthrough for electric cars, because in practice, the energy density of Li-air batteries will be comparable to that of petrol and diesel, if you take into account that a combustion engine only has an efficiency of around 30 percent," says Tejs Vegge, senior scientist in the Materials Research Division at Risø DTU, Denmark. If batteries with an energy density this great become a reality, one could easily imagine electrically powered trucks.

The electric car was introduced by Edison as early as 1900. But, as we all know, Henry Ford's vehicle concept with a noisy, smelly combustion engine won the race to become people's most treasured individual means of transport, despite the fact that in principle, the combustion engine is hopeless.

Then, as now, the Achilles' heel of the electric car was the limited energy density of the batteries, which will only sustain short drives. Now – 110 years later – the battery technology, combined with the effect electronics and the electric engine, have come so far in performance, size and price that the electric car is again becoming interesting. The electric car does not pollute locally and it can, if used cleverly, be utilised to introduce more renewable energy into the electricity supply.

Electric cars are the perfect match for a society that has abandoned the use of fossil fuels.

This is why electric cars have been reborn as an important factor in the vision of a society without fossil fuels, and the first electric cars have already hit the roads, albeit in very limited numbers and with very short ranges between recharges.

The advantages of the electric car are first and foremost that it can be integrated into the electricity system and potentially serve as a buffer in the electricity system of tomorrow, where most of our electricity originates from fluctuating renewable energy. Where there is excess electricity from e.g. wind turbines, the electric cars can be charged. When there is a shortage of electricity, some of the power can be returned to the electricity grid. The other major advantage is that, if mass-produced, the electric car could be cheaper to produce than the current cars.

2 tonnes of batteries or 50 litres of petrol

Today, battery packs are expensive and are only able to store a relatively low amount of energy. Researchers all over the world are working to change that. In the current setting, an electric car is no good if you are taking the family on holiday to Lake Garda in Italy. For electric cars to become the consumers' preferred mode of transport, the battery capacity must be significantly increased. In Risø Energy Report 9, page 58, you can read that the energy density in today's batteries is almost two orders lower than that of fossil fuels. This means that a battery pack containing energy corresponding to 50 litres of petrol, would weigh between 1.5 and 2 tonnes.

Lithium is a soft, silver-white metal – the lightest of all metals. Lithium is extremely reactive and corrodes quickly in a humid atmosphere. There, lithium is typically stored under kerosene or in a protective atmosphere to avoid contact with oxygen and water.

The most promising electric car batteries are based on the metal lithium (Li). Lithium is a soft, silver-white metal – the lightest of all metals. Lithium is extremely reactive and corrodes quickly in a humid atmosphere. There, lithium is typically stored under kerosene to avoid contact with oxygen and water. The lightness is one of the strengths of lithium. Traditional car batteries are based on lead (Pb), which is one of the heaviest metals in existence. To reduce the weight of batteries, lithium is the way to go, which is also substantiated by the prominence of rechargeable Li-ion batteries in e.g. mobile phones, cameras and MP3 and MP4 players. These batteries have the highest energy density among rechargeable batteries.

The lithium battery market is going to grow exponentially, and a discussion has already emerged whether there is going to be enough lithium to electrify the entire world's car park. Lithium is naturally occurring with approx. 65 g per tonne in top soil and approx. 0.1 g per tonne of water and can be extracted from soil as well as water, but if the lithium content is small, the extraction is costly.

In addition to the use in batteries, lithium is used in anti-depressants, ceramics, glass, aluminium production, lubricants and synthetic rubber. In the future (after 2050), lithium will probably also be used in fusions reactors for electricity production. The world's lithium reserves are found in countries such as Chile, China, Australia, Russia, Argentina, the USA, Zimbabwe and Bolivia. Lately, large deposits have been found in Afghanistan – so large that the USA has dubbed the country 'the Saudi Arabia of lithium'. In Bolivia, lithium is found in large quantities under Salar de Uyuni – the world's largest salt lake. Last year, Bolivia's president Morales announced that the country is going to invest DKK 5 billion in extracting lithium from the dried-out salt lake that covers more than 10,000 square kilometres and contains more than a quarter of the world's total lithium deposits.

The fight over the world's lithium resources will intensify in the future, but the upside is that the lithium part of batteries can be recycled, so when the batteries are worn out, the lithium can be extracted and form part of a new battery.

Batteries, a research theme at Risø DTU

At Risø DTU, two divisions possess great expertise which can be used to develop better electric car batteries. One is the Materials Research Division and the other is the Fuel Cells and Solid State Chemistry Division.

Together, these two divisions have excellent competencies within modelling and characterisation of synthesis as well as electrochemistry, all of which are vital aspects in the development of new batteries and other forms of chemical energy storage.

Research is being conducted at Risø DTU into the development and manufacture of new battery materials, e.g. improved electrode and electrolyte materials for the next generation of Li-ion and Li-air batteries. This requires insight and 'nano-scale engineering' as well as detailed understanding of the underlying processes.

Risø DTU thus has the best possible prerequisites for delivering exactly the package required to boost battery research considerably. It's all about skills within durability and product life, energy density as well as stability and safety.

Li-air batteries could have the same efficient energy density as petrol

Li-air batteries are a promising opportunity in the long term. "If we succeed in developing this technology, we are facing the ultimate break-through for electric cars, because in practice, the energy density of Li-air batteries will be comparable to that of petrol and diesel, if you take into account that a combustion engine only has an efficiency of around 30 per cent," says Tejs Vegge, senior scientist in the Materials Research Division. If batteries with an energy density this great become a reality, one could easily imagine electrically powered trucks.

Li-air batteries are thus a promising research area, but there are many research challenges to overcome before the batteries find their way to the electric cars.

The development of rechargeable batteries has moved slowly since the invention of the traditional lead-acid batteries, which are still used in the majority of e.g. starter batteries for conventional cars. The development of the Li-ion batteries marked a significant leap in the energy density of the rechargeable batteries. The final break-through may belong to the Li-air batteries which, in practice, could have the same efficient energy density as petrol. Source: Lithium – Air Battery: Promise and Challenges, G. Girishkumar, B. McCloskey, A.C. Luntz, S. Swanson and W. Wilcke, IBM Research, published in J.Phys.Chem.Lett. 2010, 1, 2193-2203.

The Li-air battery is designed with a lithium electrode (the anode), and electrolyte and a porous carbon electrode (the cathode), which attracts the oxygen from the air when the battery is in operation. The battery is therefore, so to speak, open at one end, or it has an oxygen supply of its own. During discharge, oxygen reacts with lithium to form lithium peroxide (Li2O2), and during charging, this process is reversed to release oxygen. Both reactions take place on the surface of the porous carbon electrode.

Battery resembles humans: Gains weight and

becomes short of breath

The interaction with air requires the electrode to have a very large surface area. The prototypes being worked on now have a current density of approx. 1 milliamp per square centimetre surface area, and this has to be increased by at least one order before the batteries are ready to be used in real life.

The fact that the battery absorbs oxygen atoms from the air means that the battery gains weight as it being discharged. Theoretically, the battery can more than double its weight.

At the same time, the electrode could become short of breath, so to speak. The oxygen absorbed by the battery reacts with lithium to form lithium peroxide, which may cause clogging of aggregates in the battery's channels, causing them to become blocked and preventing the supply of further oxygen. "In our trials, we use pure oxygen, so we are okay, but the problems accumulate when the oxygen has to be extracted from ordinary air," says Søren Højgaard Jensen from the Fuel Cells and Solid State Chemistry Division. Ordinary air also contains moisture, and it must be taken into consideration that, as mentioned above, lithium and humidity do not make an attractive combination.

Difficult to charge

En extremely high overvoltage is required to recharge the battery again after a discharge. The so-called equilibrium voltage for the Li-air battery is 3 volts. When the battery is discharged, the voltage drops to 2.6-2.7 volts. But when you want to recharge the battery, the voltage must be increased to 4.5 volts. In comparison, a Li-ion battery can be recharged at an overvoltage of only 10 per cent.

"The discharge process is proceeding really well. Our problem is that the reverse process has a very high energy loss," says senior scientist Poul Norby, Materials Research Division. "The high overvoltage for recharging is hard going for the current battery components, which limits the number of times the battery can be recharged," says Poul Norby. The cyclic energy loss in charging/recharging is about 40 per cent in Li-air batteries. The challenge is to reduce this number to 10 per cent, corresponding to Li-ion batteries.

In order to solve this issue, Tejs Vegge performs extensive computer calculations, so-called DFT calculations (Density Functional Theory), on the Li-air batteries. Using this method, it is possible – at atom level applying an approximation to the famous Schrödinger equation, to calculate how the lithium and oxygen atoms interact. "In this way, we hope to find an explanation of the high overvoltage and a solution to what we can do to reduce it, e.g. by adding an appropriate catalyst," says Tejs Vegge.

In addition to the computer calculations, the batteries are examined using X-ray and neutron rays. These techniques allow the scientists to study how ions and electrons move in the electrode-electrolyte interfaces when the battery is charged and discharged. "We focus particularly on solid-state electrolytes because they offer safety and transport advantages. Large lithium batteries with liquid electrolytes could pose a safety risk in the event of accidents," says Tejs Vegge.

Finally, the battery properties are tested in practice. Testing of large lithium batteries takes place in a converted chest freezer in the laboratories of the Fuel Cells and Solid State Chemistry Division. "The batteries have to be able to withstand heavy frost and extreme heat, and we can subject them to that in our converted chest freezer, which is able to cool objects down to -60°C and heat them to around 50°C," says Søren Højgaard Jensen.

Must recharge quickly – and at least 300 times

Today, metal-air batteries are only used as disposable batteries for special purposes with high energy density requirements, e.g. for military equipment, and zinc-air batteries are used as disposable batteries in e.g. hearing aids.

If the battery is to withstand a car running e.g. 250,000 kilometres during its lifetime, and the battery is able to deliver approx. 800 kilometres from one charge, it must be able to handle full charging and discharging at least 300 times. Li-air battery prototypes can currently handle 50 charges, so the researchers are faced with other scientific challenges.

In addition to the number of charges the battery must be able to withstand, it must also be possible to charge it quickly. "Think about the volume of energy transferred when you put petrol into your car. It takes a couple of minutes, and then you can go another 800-1000 kilometres. This is a true challenge for the Li-air batteries, because they may potentially be able to contain the same amount of energy as petrol, but it takes considerably longer to refuel," says Tejs Vegge.

Provided by Technical University of Denmark

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