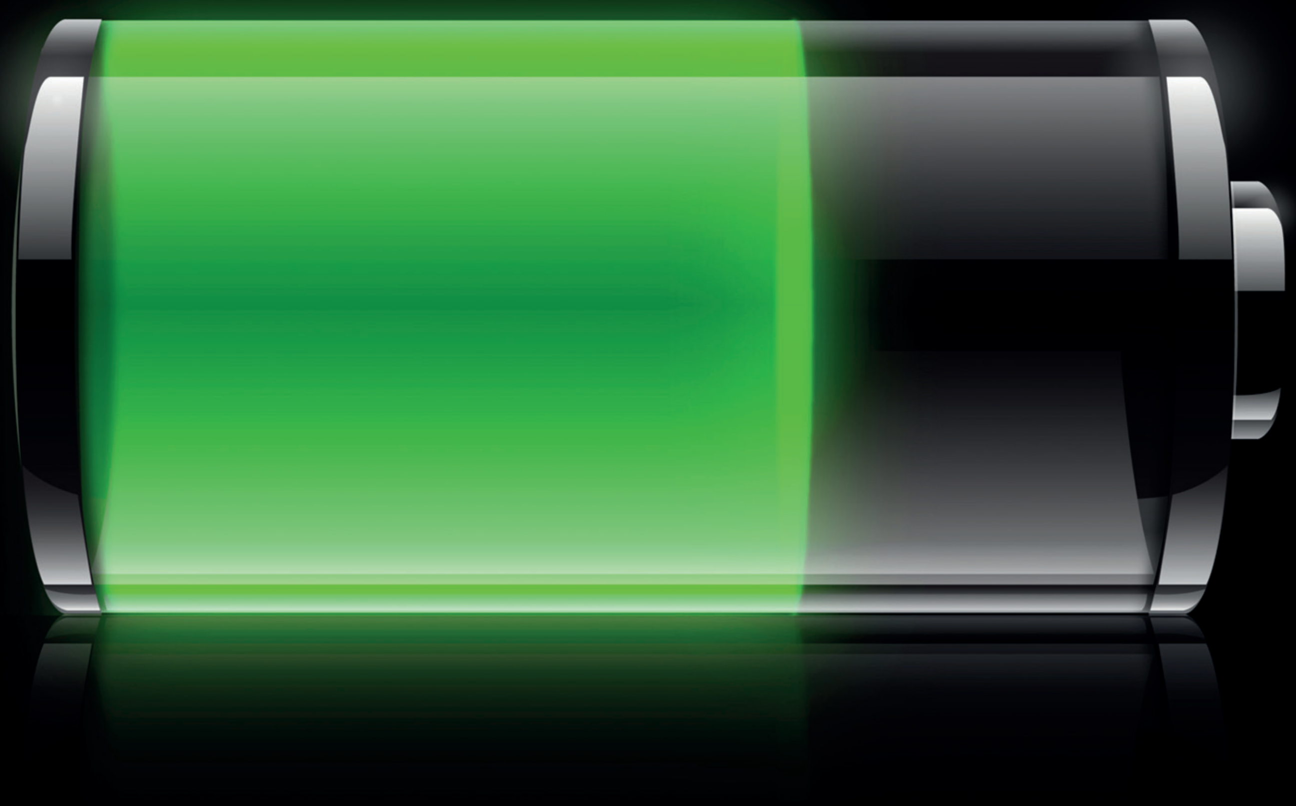
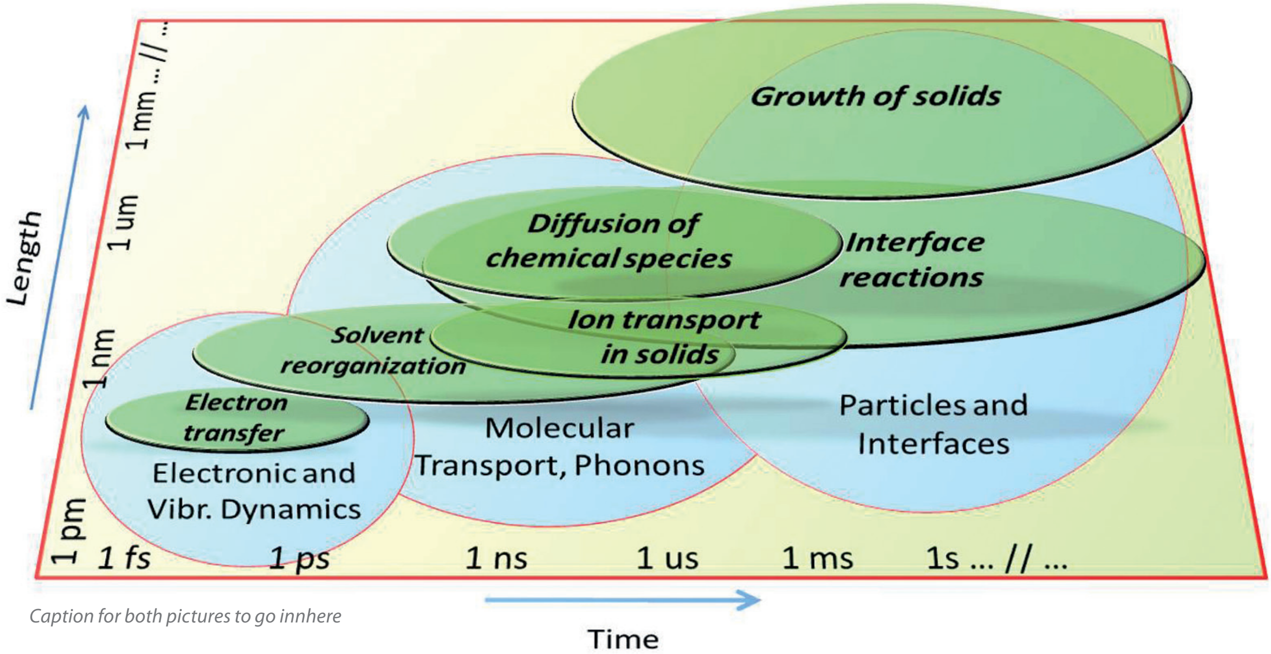
Fossil fuels have become headline news in a number of sectors over the past few years. Anna Demming speaks to Senior Scientist **Tejs Vegge** from ReLiable to find out more about lithium-air batteries, an alternative approach to energy storage that has recently seen a burst in research attention.



A light-weight match for fossil fuels

The total power consumption worldwide was 15 TW in 2008 and forecast to triple by 2050. Oil, the primary source for 34% of that energy, has become an increasingly valuable commodity. In the face of soaring prices, environmental pollution concerns and the politics surrounding harvesting the limited reserves, an alternative and sustainable source of stored energy is in high demand.

Powering the transportation sector accounts for the majority of the world's oil consumption. A new project, ReLiable, is looking at the potential of batteries based on lithium (Li) and oxygen (O2), possibly extracted directly from the air (Li-air), as an alternative that could ultimately replace gasoline and diesel. The batteries available at present, such as nickel metal hydride and the Li-ion batteries used in mobile phones, yield a very limited energy density. An automobile or truck powered in this way will only have a limited range. Li-air batteries can provide an energy density up to 10 times higher than a regular



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battery. As Senior Scientist Tejs Vegge from the Technical University of Denmark points out, "This is basically the only way you can compete with the energy density in fossil fuels."

Vegge heads the project ReLiable, which aims to demonstrate the potential of Li-air batteries as an alternative to gasoline and diesel. Two companies and three universities contribute to the project: Haldor Topsøe A/S, a large catalyst producer; Lithium Balance, a Danish company that supplies battery management systems for Li-ion batteries; Stanford University in the US; the University of Southern Denmark; and the Technical University of Denmark, where Vegge heads the Section for Atomic scale Modelling and Materials at the Department of Energy Conversion and Storage. The collaboration is funded by the Danish Council for Strategic Research and officially started on 1st January 2012.

There are many approaches to renewable energy currently under development, such as solar power and wind farming, predominantly generating electricity. For many applications, such as powering light vehicles, the generated electrical power must be stored. "You can make synthetic liquid fuels," says Tejs. "But every time you go from electricity to a chemical fuel you lose energy." Energy is also lost when converting chemical fuel back into electricity, but batteries can do this with high energy efficiency.

A conventional Li-ion battery operates by the transfer of Li ions between electrodes, from one Li-storing material – the anode – to another material that can store Li – the cathode. The electrochemical properties of the materials give rise to a potential difference, and as a result Li ions move, during discharge, from anode to cathode while the electrons pass through an external circuit generating electric current, and reversely during recharge.

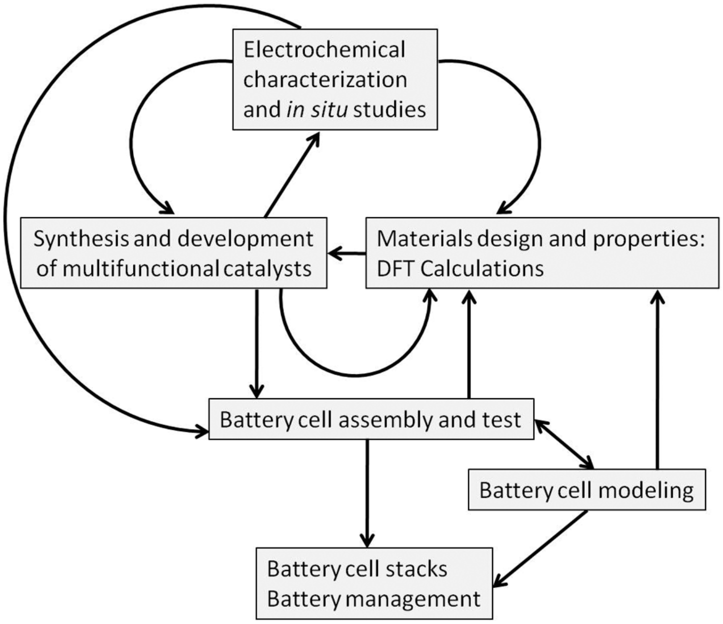
The Li-air battery uses a Li anode and a light porous cathode, possibly carbon, in an open structure, so that in effect the oxygen from the air acts as the cathode; as the battery discharges lithium peroxide is formed. This makes the battery much lighter and less expensive than conventional batteries using transition metal oxides. And above all, Li-air batteries provide a much higher energy density.

So what is preventing wide rapid uptake of Li-air batteries? As Tejs Vegge explains, the amount of energy required to recharge the battery is an issue. "It is still a key challenge to get the charging done with a higher efficiency," he explains. Applying a sufficiently high voltage will reverse the discharge process, but more research is needed to find the right combination of materials that will lower the losses, resulting from the over-potentials required for recharging the Li-air batteries.

Drawing a high current from present-day Li-air batteries increases the energy losses, which limits the practically available power density, and may also cause "sudden death" of the battery. "At the moment the current densities are too low," says Senior Scientist Vegge. "That is another big issue."

> *"There are a lot of groups worldwide starting this activity up now. Because it's basically the only battery alternative you can say is a direct competitor to chemical fuels"*

In addition, as the battery discharges an insulating layer of lithium peroxide grows on the cathode, introducing problems with the electronic conductivity. The nanostructure of the cells is one area very likely to affect this aspect of the battery performance. "If you have a very high surface area you



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can grow more of your discharge products before you become limited by electronic conduction," says Vegge.

ReLiable aims to tackle all the main factors that limit the present performance of Li-air batteries. The researchers in the project use a fundamental atomic-level understanding of the reaction mechanisms to design new materials. "In order to make new materials we really need to understand the rate limiting steps – what is limiting for instance the current density," says Senior Scientist Vegge. "And when we know this we can design a catalyst or an electrolyte that can improve it." The project combines large-scale computational methods with experimental techniques such as x-ray techniques and synchrotron or neutron radiation studies and electrochemical analysis to identify the mechanisms at work in the batteries.

The project is structured around five work packages. A designated institution heads each work package, with the other institutions providing input as well. Senior Scientist Vegge emphasises that integrated computational and experimental techniques are at the core of the project. "We build on each group's strength in either simulations or experiments and then combine them in an integrated materials design loop."

Although the researchers have already made considerable progress in understanding the fundamental mechanisms, overcoming the factors that limit the performance of Li-air batteries is a big challenge. The project's end goal is to make a Li-air pack of 2 ? 4 battery cells that operate in a controlled manner. "We can make reversible Li-air batteries now but they're just not good enough," says Vegge. "At the end of the 4 years if we successfully make a pack of Li-air batteries that we can charge and discharge cyclically at a high current density with a low over-potential we will be ecstatic," he smiles.

Activity in Li-air battery research has surged over recent years, which makes the field highly competitive. "There are a lot of groups worldwide starting this activity up now. Because it's basically the only battery alternative you can say is a direct competitor to chemical fuels. There are a few others that come close but nothing as high as this."

ReLiable is still in its early stages, and the people working in the project are keen to expand, particularly with companies to work on the applications side and European groups. Vegge also stresses the need for policy makers to fully appreciate research in this field. "The fact is there are no real alternatives to fossil fuels at this point. For an increase in renewable energy in our infrastructure we also need efficient ways of storing that energy."

At a glance
Project Information

Project Title:
ReLiable: Reversible Lithium-Air Batteries

Project Objective:
To develop new, high capacity, reversible Li-air batteries for use in a sustainable energy infrastructure by:
* Designing and synthesizing novel electrode materials from an atomic-scale understanding of the fundamental reaction mechanisms.
* Characterizing the electrode-electrolyte interfaces in situ and identifying degradation mechanisms.
* Producing, testing and optimizing Li-air cells and BMS systems.

Project Duration and Timing:
4 years, January 2012 to December 2015

Project Funding:
The Danish Council for Strategic Research, Programme Commission on Sustainable Energy and Environment has funded the project with 18.9 MDkr. or 2,5 MEuro over 4 years.

Project Partners:
* Technical University of Denmark (DTU)
* University of Southern Denmark
* Stanford University
* Haldor Topsøe A/S
* Lithium Balance

Tejs Vegge

Tejs Vegge is head of the section "Atomic scale Modelling and Materials" at DTU Energy Conversion.
He specializes in integrated computational and experimental design of materials for energy storage and conversion. From an atomic level understanding of the fundamental mechanisms, they design novel (electro)catalysts, membranes and materials for energy storage.

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