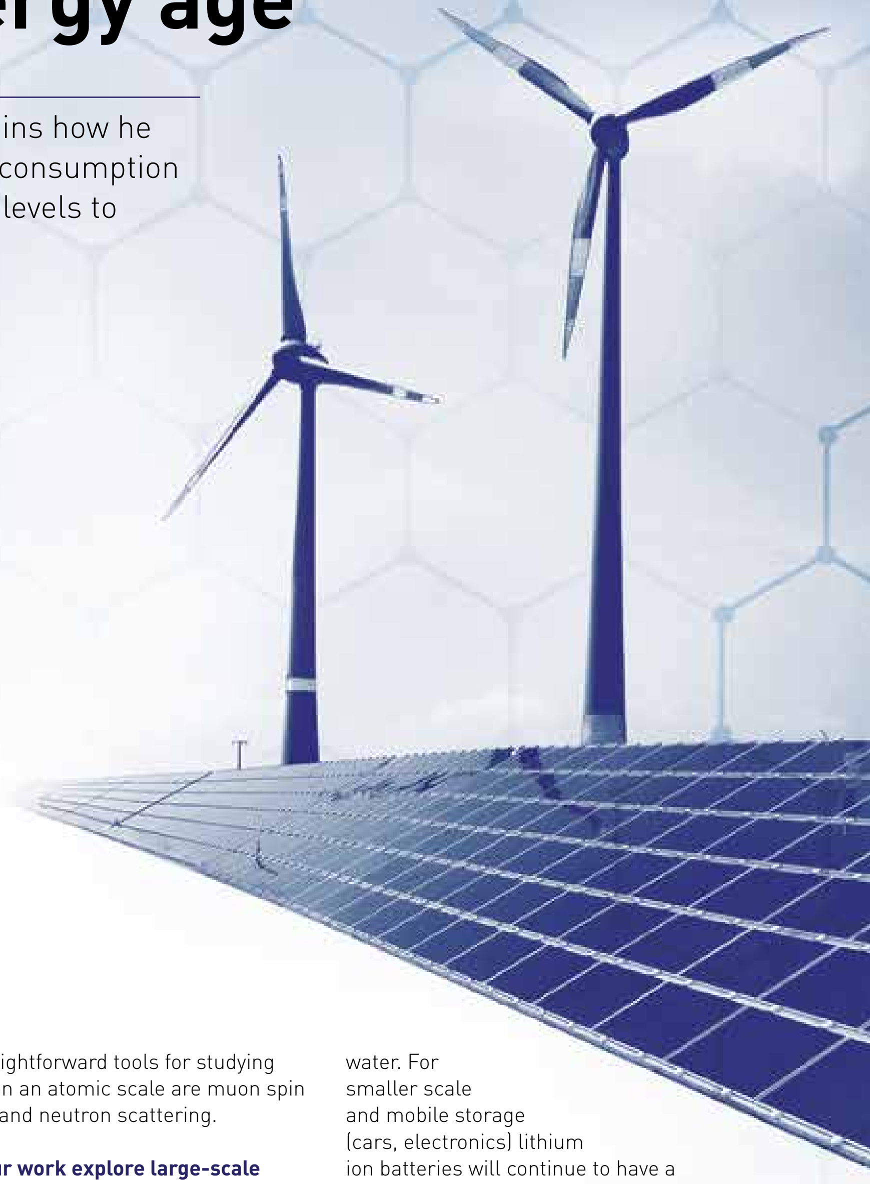
Dawn of the energy age

Assistant Professor Martin Månsson explains how he is tackling increasing worldwide electricity consumption with research at the atomic and subatomic levels to develop new sustainable alternatives



How did you become interested in materials physics, and how have your previous experiences and international collaborations fuelled your ideas?

I have always been fascinated by science and technology. As a child, I always asked the same question: how does it work? Important breakthroughs in technology have, historically, always been linked to materials development, ranging from the stone, bronze and iron ages to the more recent electronic revolution, where the semiconductor industry has led the world into the present silicon age. Sweden, in general, and the Royal Institute of Technology (KTH), in particular, both have a very long tradition of innovation in the steel industry, as well as modern functional high-tech materials. As a student at KTH, I realised that to find the answer to my fundamental questions and to improve everyday technology, I needed to understand nature's building blocks: the atoms, and how they affect material properties. This is exactly what materials physics is.

Why did you decide to focus your research on energy related materials in particular?

I think that everyone has realised that our planet is in need of a revolution in sustainable energy technology in order for it to survive for future generations. It is the collective responsibility for all of us to help solve this important and complex problem. My small contribution to this task is to develop a new generation of energy materials in order to reduce our dependency on fossil fuels (oil and coal). Here, one of the key goals will be to drastically improve technology for rechargeable batteries and fuel cells that are currently considered for the transport and automotive industry.

What are some of the most important technologies that you use, and how significant are they to understanding the viability of a material for use in energy storage?

Both batteries and fuel cells are devices that transform chemical energy into electrical energy in a very efficient way. During operation, ions are physically moving inside the material using dynamical processes such as diffusion. How easy and fast the ions can move is directly related to the efficiency of the device. Understanding the mechanism for diffusion is therefore a key aspect for developing better batteries and fuel cells. Here, two of the best and most straightforward tools for studying ion diffusion on an atomic scale are muon spin spectroscopy and neutron scattering.

How does your work explore large-scale energy storage?

Technologies for rechargeable batteries are feasible for storing a smaller amount of energy to supply enough power for a mobile phone, a computer or even a car. However, these technologies are not realistic for large-scale energy storage foreseen to be used in smart grids. This type of storage could conceivably be used in concert with energy production from solar cell and wind power. The most promising solution is to use electrolysis of water and to store energy in the form of hydrogen. This process is, in principle, the reverse process of a fuel cell, and is therefore directly related to developments of such technologies.

In your opinion, what type of energy storage has most promise at present as a cost-effective, safe and high-performance approach?

For large-scale energy storage (smart grids) this will most likely be based on hydrogen storage in connection with electrolysis of water. For smaller scale and mobile storage (cars, electronics) lithium ion batteries will continue to have a strong position. However, considering the environmental impact, along with depleted natural resources such as lithium metal, alternative solutions should be considered. That is why a large portion of our research is focused on finding efficient, environmentally friendly alternatives.

What research directions do you intend to pursue in the next five years or so?

I will work across a broad spectrum by studying materials properties and processes for both energy storage (batteries, hydrogen storage) as well as energy conversion (fuel cells). A special focus will, however, be placed on finding alternatives to the lithium ion battery technology. Here, sodium based batteries is a very interesting field with great potential. Another promising research area is so-called structural batteries, where multifunctional materials allow us to use construction materials, such as the body of a car or the framework of housing, as additional energy storage devices.

Leading the charge: innovations in green energy

A researcher at the **Royal Institute of Technology** in Sweden is addressing the demand for sustainable ways to store energy from alternative energy resources

ATTITUDES TOWARDS non-renewable energy consumption are changing worldwide with the continuous development of exciting 'green' technologies, such as the electric car in replacement of traditional combustion engines and solar panels instead of gas heating. The Conference of Parties (COP) 21 in Paris in December 2015 served as a reminder of the severity and damaging impact of global warming, with a climate change agreement signed by 195 countries to keep global warming below 2 °C. The question remains: what more can be achieved to address the international environmental and energy crisis?

Assistant Professor Martin Månsson and his team are working towards new solutions through their research on the internal dynamics of energy materials, such as the movement of atoms through batteries or electrons in power grids. Their goal is to improve efficiency and safety, lengthen the lifetime of energy devices, and ultimately reduce environmental impact. "The underlying mechanisms that control what happens inside a battery or fuel cells are currently not well understood," explains Månsson. "If we cannot understand a process, it is very difficult to know how to improve it". That is why his team needs to zero in on precisely what is happening within batteries and other storage devices at the atomic and subatomic levels.

SWEDEN: A COUNTRY OF OPPORTUNITY

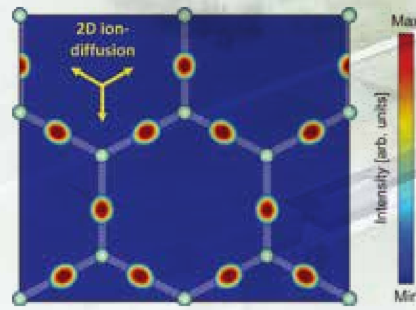
Of course, scientists are in need of new methods and tools for studying what actually happens inside the materials on the atomic scale, such as when a battery is charged and recharged or when a fuel cell is operating. One such unique facility is the world's most advanced materials microscope, the European Spallation Source (ESS) that is currently being constructed in Sweden. The country also boasts the MAX IV synchrotron, a world-leading instrument designed to study, for instance, energy dynamics. With both of these facilities scheduled to launch in 2019 and 2016, respectively, this chilly Nordic nation will truly become a hotspot for materials research.

Naturally, Månsson and his colleagues are very excited about the prospects of these new facilities: "For the first time, we will be able to clearly see where nature's smallest building blocks – atoms – are when a mobile phone battery is charged or how the atoms move when we operate a fuel cell of a car," he explains. The output of these research facilities will evolve the team's current work, and doubtless aid in developing new and more efficient energy materials that can improve device performance and reduce the environmental impact.

THE DARK SIDE OF GREEN ENERGY

However, even with a better understanding of new fuel technologies, a shift away from existing methods may come at a cost. Today, one of the most efficient ways to temporarily store energy is in lithium batteries. However, this alkali metal is exceedingly rare, and can only be mined in a few countries worldwide. As demand grows, could lithium become as depleted as worldwide oil reserves? Månsson believes that there may be a simpler solution, right in our planet's backyard: "Batteries made with sodium (Na), which is chemically closely related to lithium (Li), have a very strong development potential". Sodium is also one of the most abundant materials in the earth's crust, and, of course, in the ocean in the form of sodium chloride (NaCl), or salt. The obvious benefits of a shift towards sodium-ion batteries include the widespread availability, reduced financial cost, and also the fact that they are more environmentally friendly than the alternatives.

These new batteries are ideal for temporary, small- to medium-scale energy storage, but Månsson's team is also investigating how to store energy from large-scale renewable sources, such as wind or solar power stations. These solutions need to encompass huge and fluctuating (think cloudy, windless days) energy storage needs. Here, next-generation batteries are not the answer: "The main issue is the capacity, since such large volumes of energy need to be converted and stored". For this line of research, the team is currently investigating another familiar chemical compound: water (H_2O). The group suggests that splitting up water molecules by electrolysis, and subsequently harvesting and storing the resultant hydrogen (H), they could create new, efficient ways of temporarily storing large amounts of electricity in smart grids.



Ion diffusion paths inside a sodium battery material.

ENERGY EFFICIENCY

Another branch of Assistant Professor Martin Månsson's research relates to developing materials that have the potential to drastically improve the energy efficiency of electric power transmission as well as electronic components and devices.

This group of materials belongs to the so-called superconductors that are compounds that have the ability to conduct electrical current without resistance and, therefore, without any losses. One example of such a material is $LiTi_2O_4$ (the only known spinel oxide superconductor), which has the intriguing properties of working as a novel battery material at room temperature, while also being a superconductor at low temperatures. Through a series of scientific publications, Månsson has revealed details regarding both the magnetic and electronic properties of numerous superconducting materials.

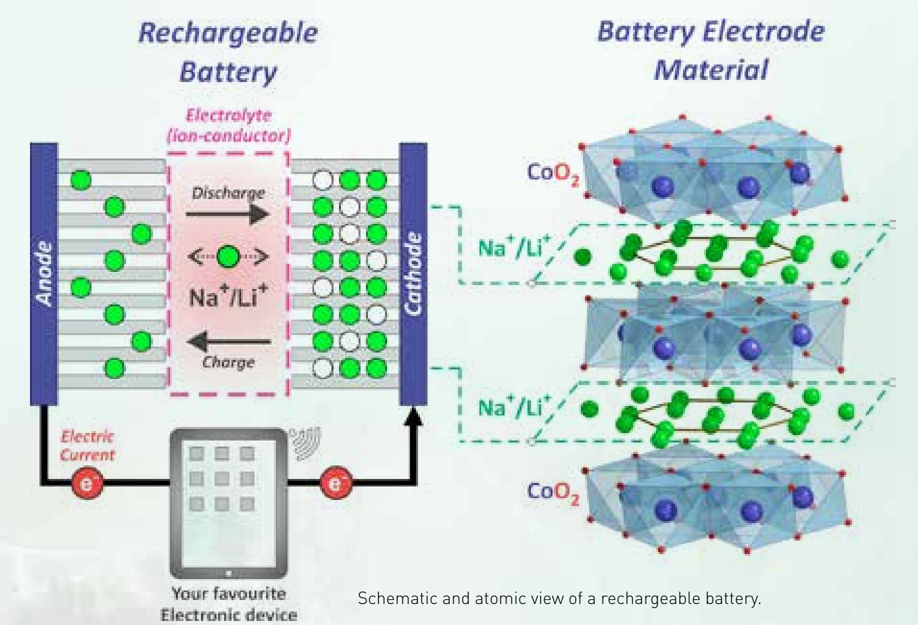
Illustration: European Spallation Source (ESS).

Could lithium become as depleted as worldwide oil reserves?

HIGH-POWER PARTNERSHIPS

Moving beyond traditional energy sources also means moving beyond traditional spheres of collaboration. For Månsson, having innovative, stable partnerships is absolutely fundamental: "No matter the research field, a collaborative effort is absolutely crucial for achieving breakthroughs that are so important for the technological development and survival of our modern society". His team currently works closely with the Paul Scherrer Institute and ETH Zürich in Switzerland, the Rutherford Appleton Laboratory in the UK and Toyota Central R&D Labs in Japan. In this way, some of the brightest minds from academia, industry, and state-of-the-art large-scale experimental facilities can work together on understanding the fundamental physics that literally power our world. This type of collaboration provides a unique opportunity for efficiently translating bench findings into direct benefits for the consumer.

With both his collaborators in mind, and exciting new experimental sites in Sweden in the pipeline, it seems that Månsson's work is set to reach new heights. Yet, despite all of the hype, he manages to keep things in perspective, and never forget his projects' core goals: improving global energy use and efficiency. Though the team's approaches concentrate on disentangling the tiniest aspects of energy dynamics, the researchers know that the findings of their atomic studies can have immense consequences. Imagine living in a world powered by green energy that can rely on stable and sustainable technology. Indeed, this means a brighter future for everyone.



Schematic and atomic view of a rechargeable battery.

FUTURE ENERGY MATERIALS

OBJECTIVE

To develop a new generation of energy materials in order to reduce our dependency on fossil fuels by significantly improving technology for rechargeable batteries, fuel cells and energy efficiency.

KEY COLLABORATORS

Professor Christian Rüegg, Paul Scherrer Institute, Switzerland

Dr Jun Sugiyama, Toyota Central R&D Labs Inc., Japan

Professor Johan Chang, University of Zurich, Switzerland

PARTNERS

Paul Scherrer Institute; **ETH Zürich**; **EPF Lausanne**, Switzerland

Rutherford Appleton Laboratory, UK

Toyota Central R&D Labs Inc., Japan

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MARTIN MÅNSSON started his scientific career as a PhD student in materials physics at the Royal Institute of Technology (KTH) in Stockholm. Subsequently, he spent seven years in Switzerland as a scientist at the Swiss Spallation Neutron Source, ETH Zürich and EPF Lausanne. Since the end of 2014, he has been back in Sweden at KTH, where he currently holds the position of Assistant Professor in neutron scattering and energy materials.