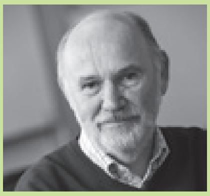
Impact Objectives

- Develop an improved understanding of the key physical and electrochemical processes occurring at the solid:solid and solid:gas interfaces in a range of devices
- Design and develop the next generation of energy storage and conversion technologies
- Encourage closer collaboration between the partner institutes, leading to further training opportunities in clean energy technologies

Collaborating towards cleaner energy

***Professors Stephen Skinner** and **John Kilner** from **Imperial College**, UK, discuss their work on the **SOIFIT** collaboration, a networking and collaboration programme focussed on furthering research into solid oxide fuel cells to provide clean, low-carbon energy storage and conversion*

Professor Stephen Skinner



Professor John Kilner

Please would you give us a brief overview of the Solid Oxide Interfaces for Faster Ion Transport (SOIFIT) project?

The SOIFIT collaboration is a five-year project that began in July 2017 and is a networking and collaboration programme with partners at leading international research organisations across the UK, Japan, the USA, Switzerland, France and Poland. The main objective is to provide a collaborative network to bring together leading researchers in the field of interfaces and further progress on the performance of electrochemical devices such as fuel cells and batteries, with an ultimate aim of improving devices for clean, low-carbon energy storage and conversion.

What features make solid oxide fuel cells (SOFCs) and solid oxide electrolysis cells (SOECs) particularly promising targets for answering the energy requirements of modern society?

The project has an initial target of understanding interfaces in SOFCs and SOECs, but we are also concerned with interfaces in solid-state batteries. These are synergistic devices, where the SOFC will convert energy contained in a fuel to power and heat. The electrolyser can use power from renewable sources to generate gaseous and liquid fuels for transport applications. An essential part of the energy infrastructure is storage, which is where high energy density solid-state batteries feature. This combination of devices offers a route to produce and store energy locally, with low- or zero-carbon emissions and with high efficiency. The technology is scalable and hence can be used in transport, domestic and grid scale applications. These technologies provide a unique pathway from a carbon-based economy to a clean economy based on renewable primary energy sources and have been recognised by the governments of Japan, the UK and the EU as priorities for R&D.

What were the outcomes of your recent electrochemical impedance spectroscopy (EIS) workshop and two mini-conferences?

We have held project workshops that are primarily internal meetings to bring the partners together and plan future research programmes to address our overall goals. These have led to the preparation of further successful funding applications to support specialist measurements (eg. PSI and Kyushu) and the exchange of researchers between the laboratories, forging closer links between the staff and students associated with the project. The EIS workshop was made available to students outside our immediate network and served to educate a wider cross-section of the community about the power of EIS in their research. We also held a large international workshop at the Royal Institution in London and a further workshop in Kyushu, where a number of invited speakers presented their work and our team presented their findings. This provided an excellent networking and dissemination opportunity for all participants and led to further informal research links.

Why are the inter-organisational exchanges such an important aspect of the project?

The key objective of the core-core programme is to foster collaboration between the partners. However, the exchange of personnel between laboratories allows knowledge transfer and generates new ideas. The creativity that results from in-depth discussions is one of the greatest advantages resulting from this type of exchange, particularly for early career workers such as postgraduate students and postdoctoral research assistants. If the industries benefiting from this research are ever to make an impact on global emissions, it will require a large number of scientists/engineers trained in this specialist area to work in the production, development and servicing of SOFCs, SOECs and battery systems. ●

Fuelling future research and energy needs

*The **Solid Oxide Interfaces for Faster Ion Transport** (**SOIFIT**) collaboration seeks to share expertise and resources to further scientific understanding of vital physical and electrochemical processes in solid oxide devices and develop clean, low-carbon energy storage and conversion technologies*

Global demand for energy is constantly rising and with concerns over global warming, never has the need for clean, renewable energy sources been greater. Solid-state electrochemical devices such as solid oxide fuel cells (SOFCs) and solid oxide electrolysis cells (SOECs) have shown great promise in fulfilling these energy needs and are expected to revolutionise the search for clean energy conversion and storage, leading the way towards minimising carbon emissions. Such devices, including solid-state sodium and lithium batteries, are set to play an increasingly vital role in economies such as those of Europe, Japan and the USA, in both domestic and industrial applications.

The Solid Oxide Interfaces for Faster Ion Transport (SOIFIT) collaboration is an ambitious five-year project that brings together partners from the UK, Japan, the USA, Switzerland, France and Poland to develop clean, low-carbon energy storage and conversion technology. Led by Professor Stephen Skinner, Professor of Materials Chemistry at Imperial College London, UK, the project's core objective is, 'to develop an improved understanding of the key physical and electrochemical processes occurring at the solid:solid and solid:gas interfaces in a range of devices, including lithium (Li) batteries, SOFCs and electrolysers.' This achievement would enable the partners to design and develop next generation energy storage and conversion technologies, providing low-carbon energy sources for electricity, heat and transport, thus alleviating our current dependence on fossil fuels.

Fourth SOIFIT Meeting at the Paul Scherrer Institute, Switzerland

AN INTERDISCIPLINARY APPROACH

The SOIFIT approach seeks to apply the complementary expertise of the international collaborators to this multiscale, interdisciplinary problem. 'We are working on very complex materials in complex operating environments,' explains Skinner, who adds: 'For example, we are dealing with multicomponent, porous ceramic materials that are used as electrodes in solid oxide devices, where they are subjected to a range of gas environments depending upon the mode of operation.' Collectively, the consortium has the skills and knowledge to tackle such a challenging problem and one of their main foci is to share this expertise, training both staff and students at other partner institutions.

Given the wide range of techniques used in the project, including spectroscopy, microscopy, diffraction and materials modelling, a considerable variety of high-end equipment is necessary. No individual site or team has the expertise or access to the quantity and quality of equipment to take on these complex, multifaceted problems. Collaboration is therefore the answer, leveraging the collective resources in equipment, expertise and financing to offer an unparalleled, robust approach to developing the knowledge and technology in this field.

CUTTING EDGE INTERNATIONAL COLLABORATION

A number of world-class research organisations fuel the research on the SOIFIT programme, forming the basis of a broad-ranging pool of leading international talent and expertise in the field of interfaces. Imperial College London, UK, and the International Institute for Carbon Neutral Energy Research (I²CNER) at Kyushu University, Japan, lead the collaboration, centred on a team that includes lead investigators Professors Stephen Skinner and John Kilner, as well as Drs David Payne and Ainara Aguadero from Imperial College London and Professors Hiroshige Matsumoto and Tatsumi Ishihara from I²CNER. Teams from Massachusetts Institute of Technology (MIT), led by Professor Bilge Yildiz; Ohio State University, led by Professor David McComb; the Paul Scherrer Institut (PSI/ETH), led by Professor Thomas Lippert; Tokyo Tech, led by Professor Masatomo Yashima; the Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB), led by Dr Jean-Marc Bassat and Gdansk University of Technology, led by Assistant Professor Aleksandra Mielewczyk-Gryń, also contribute their expertise on complementary research programmes.

Professor John Kilner, BCH Steele Chair in Energy Materials in the Department of Materials, also at Imperial College London, adds, 'We will also encourage closer collaboration between our institutes, leading to further training opportunities in clean energy technologies for our research staff and for the emergent low-carbon energy industry.'

THE IMPACT OF THE PROJECT

The work carried out on interfaces in energy technologies by the SOIFIT group may lead to deployment of SOFCs and electrolysers on a global scale, benefitting both domestic and industrial users, such as those in transport sectors. Their work will also contribute towards the development of safe, high energy density devices – technology that is vital if we are to meet the goals laid ▶

Improving the properties of energy conversion and storage materials will lead to breakthroughs in device commercialisation and could lead to the widescale deployment of next generation materials

out in the IPCC Sixth Assessment Report, recommending limiting global warming to less than 2°C.

Some interesting results have emerged through the efforts of the SOIFIT partners. Work on perovskite (ABO_3) mixed-oxide materials used as air electrodes were shown to have a surface layer of large A metal ions (thought to be inert in this process) and oxygen ions at high temperatures – an unexpected result. Using density functional theory (DFT) to try to understand the role of these surface atoms in the transfer of oxygen (O), the group was able to confirm that when the surface metal ions are alkaline earth atoms such as strontium (Sr), they are, as expected, inactive for oxygen exchange. A surface oxygen vacancy is required to expose the active small transition metal ions lying just beneath the surface. When lanthanum (La) was used as the surface ion, the team was surprised to discover that the La ions were active for surface oxygen exchange. Further consideration determined that while the Sr-O interaction is purely ionic, that of La-O has some degree of electron sharing, which is beneficial to the oxygen transfer process as a result of the weak transition metal behaviour of the La ions. Further tests on this were carried out and these results were extended and verified, providing exciting knowledge to further future design and optimisation of electrode materials.

Improving our understanding and knowledge of the processes that occur in these complex materials when in different environments at various length scales is a complex challenge that is one of the main obstacles involved in working with these devices. The collaborators are attempting to find more active, durable materials to minimise interfacial problems and Skinner explains: 'The main challenges facing the commercial deployment of most of these energy storage and conversion devices are cost and durability.' There are several ways in which researchers can approach these issues, one of which involves reducing the operating temperature of the devices, particularly the SOFCs and SOECs. Kilner tells us, 'We hope that by gaining an understanding of fundamental processes, mainly at the atomic scale, we can engineer materials and structures that optimise performance at reduced operating temperatures, thereby increasing durability and also helping towards mitigating costs.'

FUTURE PROMISE

The SOIFIT partnership of expert international collaborators is conducting vital research into interfaces to further technological advances in technology to support the ever-growing energy demands of society. Kilner tells us, 'Improving the properties of energy conversion and storage materials will lead to breakthroughs in device commercialisation and could lead to the widescale deployment of next generation materials.'

Beyond even these benefits that are set to have a major impact on the world, the partnership seeks to improve the research skills and extend the techniques of the researchers who form part of the 30-strong group. By sharing not just knowledge, but skills and resource, between established researchers and students, the collaboration is also investing in the future of interface research. ●

Project Insights

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BIOS

Professor Stephen Skinner is Professor of Materials Chemistry in the Department of Materials, Imperial College London. His research interests lie in the development of new materials for electrochemical technologies and in the characterisation of their structural and electrochemical properties. Skinner has published over 140 articles and is an associate editor for *Journal of Material Chemistry A*, covering the area of fuel cells and electrochemical systems. He was awarded the IOM^3 Kroll Medal and Prize in 2017 and was part of the team that was awarded the Daiwa Adrian Prize for Anglo-Japanese collaboration in 2016.

Professor John Kilner is BCH Steele Professor of Energy Materials and former Head of the Department of Materials, Imperial College London. He has been involved in research into ionic and mixed conducting ceramics for 30 years and has published over 400 papers in this and related fields in materials science. He is currently European Editor for the *Journal Solid State Ionics*. He is the holder of a number of patents relating to fuel cells and gas separation devices and the co-founder of a successful spinout company, CeresPower Ltd. Kilner has led two teams awarded prizes for collaboration with Japan: the IUMRS Somiya Award in 2012 and the Daiwa Adrian Prize in 2016.

SOIFIT KYUSHU UNIVERSITY EPSRC Engineering and Physical Sciences Research Council

Imperial College London JSPS