Science and Technology
Options Assessment

STOA Workshop
co-organised with the European Association for Chemical and Molecular Sciences (EuCheMS)
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The energy storage challenge: which contribution from chemical sciences?

REPORT

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Background

The energy challenge is one the most critical issues that Europe is facing nowadays. The security of energy supply is intimately linked to the need of generating and storing energy in an environmentally appropriate and sustainable manner. Chemistry will be a crucial actor in designing a future energy scenario built on innovative technologies and new materials that will both save energy and protect the environment.

The workshop aim was to present the two main possibilities to store energy that require the contribution and development of the chemical sciences: firstly, physical devices, such as batteries or super-capacitors; and secondly the storage of energy from renewable energy sources in the chemical bonds of a compound, to release the stored energy at another time and place. It will thus highlight the opportunities for Europe to compete with America and Asia in this economically important field.

Event summary

MEP and STOA Chairman **António Correia de Campos** opened the workshop welcoming the participants and the speakers and stating that the energy challenge is one of the great challenges the EU is facing nowadays and that there is a need for new solutions.

Prof. Ulrich Schubert, EuCheMS President, gave an overview of the topic. Prof. Schubert highlighted that Europe is facing a great challenge in securing a sustainable, affordable and plentiful supply of energy in the future. The EU energy portfolio must be enlarged and in this sense the most abundant and versatile options are solar energy, followed by wind, biomass and hydro. With the associated trend towards more decentralised power generation, issues of energy transportation and energy storage become more pressing.

Energy storage requires transformation of electrical energy in other forms of energy and chemistry can play a big role in this process. The general idea behind chemical energy storage is to produce some substances with the help of renewable sources of energy, and then to use these substances at another time and place to release the stored energy.

Prof. Schubert explained that there are two main possibilities to store energy as chemical energy: physical devices such as batteries and super capacitors and storage of energy in chemical bonds of molecular compounds. To achieve this, substantial breakthroughs are needed in materials, electrochemistry, surface chemistry, and thermodynamics. Moreover, hydrogen will be a key energy vector in the future and instead of using fossil fuels, chemical compounds could be produced from renewable resources in order to release the stored energy by burning the compounds.

Prof. Schubert concluded by underlining that the chemical sciences are already playing a pivotal role in these future developments but also that there is still a long way to go.

In his keynote speech, **Prof. Serdar Sariciftci** stated that the lack of energy resources is one of the main problems of the EU. The EU is still widely using fossil fuels that don't allow a cyclic system of consumption. Another big problem related to fossil fuels is the fact they release CO_2 and the current levels of CO_2 in the atmosphere are causing concerns among climatologists. There are some options that suggest how to get rid of CO_2, but carbon capture and storage (CCS) and CO_2 sequestration are not cheap options. However, CO_2 can be transformed into methane and methanol.

Prof. Sariciftci pointed out that energy storage is a broad topic and can be addressed in different ways. Storage of solar energy is the next big challenge to overcome the fluctuation of renewables. Solar energy is a supply driven system so it is crucial to develop a transportable storage system and chemistry has an important role to play in solving this problem.

Methane and methanol seems to represent a good energy vector for the future thanks to the existing infrastructures.

Prof. Gabriele Centi focused its presentation on solar fuel and artificial photosynthesis. He pointed out that hydrogen is a very interesting vector, but it is difficult to store and transport. That is why it is so important to find ways to convert CO_2. The actual trend is to produce liquid fuels and the fuels that can be produced from CO_2 such as methanol and hydrocarbons represent the preferable energy vector which can be easily integrated into the actual energy infrastructure.

CO_2 is crucial to achieve energy efficiency because it can help reducing fossil fuels consumption and it introduces renewable energies in the chemical production chain.

The long term objective is to develop an artificial leave for personalised distribution of energy. In order to realise this objective, it is essential to follow a precise path and it is a long way to go. Nevertheless, some applications can be already used such as the use of renewables to produce hydrogen and methanol. The CO_2 utilisation path represents a unique opportunity to reduce GHG emissions and optimise the use of renewable energies.

The long term vision includes artificial trees that can be integrated in the cities providing a delocalised energy for buildings, mobility and industry. Prof. Centi recognised that there is still a long way to go and many aspects need to be improved to optimise the project and increase productivity.

To conclude, Prof. Centi stressed that it is important not to mimic the natural system but that it is essential to develop a radically different system that reproduces only some characteristics of the natural one. In particular, the devices of the future have to be smart, highly productive, cheap and robust.

Prof. Neil Champness explained that hydrogen is a viable fuel source but it is not widely used for two main reasons. Firstly, the public perception of hydrogen is negative. Gasoline and diesel are actually more dangerous and inflammable than hydrogen but the general public is not aware of it yet. Secondly, it is difficult to store hydrogen in a car. What is feasible on a bus is complex on a personal car because of a critical lack of space. In this respect, it is essential to develop a system to compress the hydrogen in smaller volume and to release it with little dispersion of energy. Furthermore, hydrogen storage poses problems because of the different temperatures of the earth. It is essential to find a way to store liquid hydrogen in a way in which it can cope with all the different atmospheric conditions of the earth.

Prof. Ferdi Schüth highlighted that the storage problem comprises all energy fields such as mobility, heating and electricity and that it is important to keep all the energy aspects in mind when dealing with storage. In mobility, chemical sciences have a crucial role to play in innovating small and large scale batteries. Concerning electricity, the challenge is to cope with intermittent supply and this can be done through grid extension, backup-capacity and demand side management.

Concerning chemical storage, which is seasonal storage, Prof. Schüth presented the hierarchy of chemical storage uses. He thinks that electrical energy should not be converted but used as it is in order to avoid waste of resources. If it is not possible to use it as electricity then it should be converted

in hydrogen by electrolysis and used for chemical production or stored. If it is not possible to use hydrogen as a chemical, it should be feed into natural gas system. Then, if also this option is exhausted, it is possible to convert it to liquid energy carriers such as kerosene.

Finally, heat storage is often neglected but it represents 50% of the energy sector and it is increasing its importance. There are different chemical systems for heat storage based on solar and water power that allow to store heat during summer and to use it during winter.

Prof. Kristina Edström pointed out that batteries will play an important role in the future. The positive aspect of a battery is that it is possible to store energy that will be then used in different time and place. The capacity of batteries relies on the chemical property of the material used to make them. There is a crucial need for new innovative materials for batteries and sustainability must be a prime criterion. Moreover, it is crucial to choose materials depending on the application it is to be used for. For the future, it would be good to move from lithium batteries to sodium batteries because the second can be found more easily. Recycling will become more and more important, especially for organic based batteries and more studies are needed on how to handle the recycling.

To conclude, Prof. Edström highlighted that the knowledge to create new materials that can deliver batteries with higher energy densities, better life time and higher safety characteristics is already available. For this, having active networks in the EU is very important.

Dr. Fabrice Stassin gave an overview of the industry feelings about energy storage. He recalled that the EU is facing an important energy challenge and that the energy policy has to tackle three aspects: sustainability, security of supply and competitiveness. Energy storage is bringing some value in all the three aspects. Dr Stassin explained also that in a business as usual scenario the power sector would be accountable for 30% of GHG emissions. The only way to reduce the CO2 production relies upon energy efficiency, sustainable energy harvesting and storage.

There are different class of materials to be taken into consideration. There are materials for energy harvesting, energy storage, energy distribution and energy efficiency. Concerning the materials for energy storage, multiple technologies must be considered depending on the needs and possible applications.

To conclude, a crucial aspect concerning batteries is reducing the cost for kWh/hour and increasing the amount of energy per kilo. By tackling these two challenges it is possible to obtain lower cost of energy technologies. Reducing the cost is needed in order to make these technologies deployable on the market.

Debate

After Dr Stassin presentation, the workshop entered in a more interactive session which started with some questions posed though social media. The first questions concerned the use of enzymes for energy, if the recycle of CO2 will be the smart energy of the future and if artificial energy plants pose any ethical question.

Prof. Sariciftci explained that catalyst has to fulfil two characteristics: efficiency and selectivity. Enzymes can synthetize a very specific product by themselves and that it is why they are used as bio-catalyst. It is possible to take CO2 and reduce it to methanol by using simple enzymes which are not

difficult to obtain. Bio enzymes are superior for their characteristics but sometimes artificial catalyst is more robust.

Prof. Centi replied that the architectural impact of artificial trees must be considered but at the end it is only a question of using solar energy by putting solar panels on the roofs.

Furthermore, he stated that chemistry should be used to reduce energy consumption and to expand the energy portfolio. CO2 can be relevant but, as discussed during the workshop, there is no a single solution or a single "smart energy" for the future.

Finally, the speakers agreed on the assumption made by **Prof. Schüt** that the recycle of CO2 can realise its fully potential only in a fully renewable system.

Prof. David Cole-Hamilton concluded the workshop by recalling that oil and gas are running out in 40-50 years and global warming is a reality. Only one form of energy comes into the earth, radiation from the sun. If it could be possible to convert the power from the sun into energy at 10% conversion, all the world's energy needs could be met by the sun falling on an area with the size of Libya. All type of energy (water, waves, biomass) come from solar energy conversion but they all are intermittent. That is why energy storage is so critically needed.

Then, Prof. Cole-Hamilton summarized some of the chemical methods of energy storage presented during the workshop such as batteries and compounds. He also recalled hydrogen and the main possibilities offered by hydrogen storage. To conclude, Prof. Cole-Hamilton stressed the fact the chemistry is already developing all the answers to the energy challenges.

Speakers

António Correia de Campos, MEP

Chairman of STOA

Professor Correia de Campos was born on December 14th, 1942 in Viseu, Portugal.

A university professor (Universidade Nova de Lisboa) with a law degree from Coimbra University (1966), a 'Directeur d'Hopital' diploma from ENSP, France (1969), an MPh from John Hopkins University (1978) and a PhD in Health Economics from Universidade Nova de Lisboa (1982).

For three years (1986-89) he was director for Science and Technology at the Luso American Development Foundation (Lisbon). Mr Correia de Campos was a member of the National Parliament (1991-93), Secretary of State (1976 and 1979-80) and Minister of Health (2001-02; 2005-08). He has also worked as a member of the Committee on Health Services Research, WHO/EURO (1984-88), on top ofasa Senior Health Care Management Specialist for the World Bank (1992-95). He is presently a Member of the European Parliament and Chairman of the Science and Technology Options Assessment (STOA) Panel.

Prof. Ulrich Schubert

EuCheMS President

Prof. Ulrich Schubert, EuCheMS, studied chemistry and got his PhD degree at the Technical University of Munich. His PhD thesis (1974 with E. O. Fischer) was in the area of organometallic chemistry. Following a postdoctoral year at Stanford University with W. S. Johnson on organic synthesis, he returned to the Technical University of Munich to work on his Habilitation (1980) on X-ray structure analyses of metal complexes. From 1982 to 1994 he had the position of an Associate Professor of Inorganic Chemistry at the University of Würzburg, and since 1989 additionally served in different leading positions at the Fraunhofer Institute of Silicate Research (ISC) in Würzburg. In 1994 he was appointed to the Chair of Inorganic Chemistry at the Institute of Materials Chemistry of Vienna University of Technology.

The current research interests of his group are focussed on sol-gel processes, inorganic-organic hybrid materials, and nanocomposites, ranging from fundamental research to applications. His publication record comprises more than 500 research papers and review articles, as well as 11 patents and 10 co-authored or edited books. He is member of the Austrian Academy of Sciences and the German Academy Leopoldina, and Fellow of the Royal Society of Chemistry. In 2009 he received the Wacker Silicon Award. Ulrich Schubert served the scientific community as the president of the Austrian Chemical Society from 2001 to 2004, as well as member of panels of several national and international funding organizations (including ERC) and boards of scientific journals. He is president of the European Association for Molecular and Chemical Sciences (EuCheMS) for the period 2011-2014.

Prof. Niyazi Serdar Sariciftci

Founding Director of the Linz Institute for Organic Solarcells (LIOS) at the Johannes Kepler University of Linz/Austria

Prof. Sariciftci is Ordinarius Professor for Physical Chemistry and the Founding Director of the Linz Institute for Organic Solarcells (LIOS) at the Johannes Kepler University of Linz/Austria since 1996.

He studied at the University of Vienna (Austria) and graduated with a PhD in physics in 1989. After two years of postdoctoral study at the University of Stuttgart (Germany) he joined the Institute for

Polymers and Organic Solids at the University of California, Santa Barbara, USA, by Prof. Alan J. HEEGER, Nobel leaurate 2000 for Chemistry. He is the inventor of conjugated polymer and fullerene based solar cells. Prof. Sariciftci published over 500 publications and with over 30000 citations (h-index of 75) he is ranked in 2011, by Thompson Reuter as No: 14 of the world's material scientists. Sariciftci has composed 8 books and educated several academic and industrial scientists, initiated seven spin off companies. He is recipient of several prizes among them the National Science Prize of Turkey 2006 and the Austrian Scientists of the year Prize for Research 2008 and in 2012 Wittgenstein Prize of Austria. He is a Fellow of the RoyalSociety of Chemistry (FRSC), Fellow of SPIE, and members of American Chemical Society, Materials Research Society, Austrian Chemical Society and Austrian Physical Society. Sariciftci has been awarded an honorary doctorate by the Abo Academy in Finland in 2011 and University of Bucharest in Romania in 2012.

Prof. Gabriele Centi

President of the European Research Institute of Catalysis (ERIC)

Gabriele Centi is full professor of Industrial Chemistry at the University of Messina, Italy, and President of the European Research Institute of Catalysis (ERIC). Research interests are in the areas of applied heterogeneous catalysis, sustainable energy and chemical processes, and environment protection, including the reduction of greenhouse gas emissions by catalytic technologies. He was coordinator of the EU Network of Excellence IDECAT and a former President of the European Federation of Catalysis Societies (EFCATS). He is actually vice-President of the Int. Association of Catalysis Societies (IACS).

He received various awards, the last being the award in Frontiers of Chemical Energy Science (2013). He is Chair of editorial board of Wiley-VCH journal ChemSusChem, Chief Editor of the Book Series Studies in Surface Science and Catalysis (Elsevier) and Green Energy (De Gruyter). He is also member of the International Committee of various scientific journals and conferences.

Prof. Neil Champness

Professor of Chemical Nanosciences at the University of Nottingham, UK

Neil Champness is the Professor of Chemical Nanosciences at the University of Nottingham, UK. His research spans chemical nanoscience and all aspects of molecular organization. His research achievements have been recognised by the award of a number of Royal Society of Chemistry prizes including the Corday-Morgan Medal and Prize (2006), Supramolecular Chemistry Award (2010) and a Royal Society Wolfson Merit Award (2011). He has been a Visiting Professor at Institute Of Chemistry–UNESP, Brazil (2009), the Institut Le Bel, University of Strasbourg, France (2011) and the University of Adelaide (2014). Neil is a Senior Advisor to the British Council on matters relating to science and Engineering, a Fellow of both the Learned Society of Wales (FLSW) and the Royal Society of Chemistry (FRSC). In 2011 he was identified as one of the top 100 most cited chemists of the previous decade.

Prof. Dr. Ferdi Schüth

Director of the Max-Planck-Institut für Kohlenforschung

Prof. Ferdi Schüth was born in 1960 in Warstein. He studied Chemistry and Law in Münster. He received his doctorate in Chemistry in 1988 and passed the First State Exam in Law in 1989. In 1995 he became Professor in Chemistry and worked till 1998 as such at the University in Frankfurt. Since 1998 he is Director of the Max-Planck-Institut für Kohlenforschung (Mülheim an der Ruhr). Ferdi Schüth received several awards, e.g. Award of the Stifterverband der Deutschen Wissenschaft, Gottfried-Wilhelm-Leibniz-Award, Wöhler-Award and Hamburger Wissenschaft-Award. He is member of numerous editorial boards and committees, e.g. Dechema, DFG, selection committee of the German Future Award, Professor h.c. at the Dalian University (China) and founder of the hte AG. His research field comprises energy, biomass conversion, crystallization processes, synthesis of catalyst materials, catalysis, zeolites, ordered mesoporous materials and hydrogen storage materials.

Prof. Kristina Edström

Ångström Advanced Battery Centre, Uppsala University, Sweden

Kristina Edström is professor in inorganic chemistry and director of the Ångström Advanced Battery Centre, Uppsala University, Sweden. She heads a team of 40 battery scientists with a history of scientific and industrial success. All aspects of lithium battery materials, new cell concepts (Li-O2, Li-S) and sodium batteries are studied with a wealth of different techniques. Special emphasis is on battery stability and the reactivity occurring at battery material interfaces. She has authored more than 125 international publications. Edström is in the board of the European Institute of Technology KIC InnoEnergy and coordinating StandUp for Energy (an energy research alliance between four

universities). She is frequently invited as speaker at international conferences and a board member of the Battery Division of the Electrochemical Society. She is a member of FP7 and ERA-NET programs focused on lithium-batteries and of the ALISTORE-ERI network since its start in 2003. She is a board member of the Swedish Foundation of Strategic Research and of the MAXIV Laboratory. She is a member of The Royal Academy of Engineering Sciences and The Royal Society of Sciences.

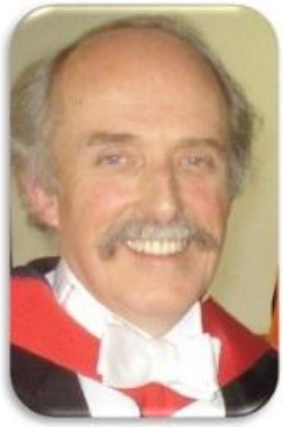
Dr. Fabrice Stassin

Managing Director of the EMIRI Association (Energy Materials Industry Research Initiative)
Represents Umicore

Dr Fabrice Stassin is Managing Director of the EMIRI Association (Energy Materials Industry Research Initiative–www.emiri.eu). He holds a Diploma and PhD in Chemistry from the University of Liège in Belgium. Fabrice Stassin joined Umicore in 2008 as Innovation Project Manager covering the scope of clean technologies of interest to Umicore with later a focus on thin-film photovoltaics . Since 2012, he is part of the Brussels-based team of Umicore Government Affairs focusing on Energy Materials. Fabrice Stassin was instrumental in the development of the EMIRI Association which he now manages. EMIRI aims at establishing Industrial Leadership in EU in the field of Advanced materials for low-carbon energy technologies through involvement of all stakeholders in strategic research & innovation programmes.

Prof. David Cole-Hamilton

President of the Royal Society of Chemistry's Dalton Division and President-elect of EuCheMS



Following studies in Edinburgh (BSC, 1971; PhD, 1975), David Cole-Hamilton worked with Sir Geoffrey Wilkinson at Imperial College as a Postdoctoral Fellow and Temporary lecturer. A lectureship and Senior Lectureship in Liverpool were followed by appointment to the Irvine Chair of Chemistry at the University of St. Andrews in 1985. His research interests concern the applications of Organometallic Compounds to solving problems in Homogeneous Catalysis and Materials Science. He is interested in the chemical manipulation of waste bio-oils, in developing new catalytic reactions and in carrying out catalysis flow systems. He is currently President of the Royal Society of Chemistry's Dalton Division and President-elect of EuCheMS.

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