Early Career Researchers' Symposium - "Solar Fuels: moving from materials to devices", Monday 6th July
&
International Discussion Meeting – "Solar Fuels: Moving from Materials to Devices" – London, 7-8th July 2015

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Attending the Solar Fuels Network Early Career Researchers' Symposium on the 6th July and the International Discussion Meeting "Solar Fuels: Moving from Materials to Devices" on the 7-8th July in London was a very insightful and valuable learning experience. As a 1st and 4th year PhD students in the Laboratory of Dr. Erwin Reisner at the University of Cambridge we found the theme and many talks particularly interesting and closely related to our own work.

The ECRS was dedicated to the oral and poster presentations, mainly given by the PhD students. A wide range of topics was discussed by the students from many different disciplines ranging from Biology, Chemistry and Materials to Engineering and Physics. We were positively surprised that one of our poster presentations titled "*Hierarchically-Structured Inverse Opal Electrodes for Semi-Artificial Photosynthesis*" stood out and was awarded a poster prize.

The IDM speakers included big names such as Vincent Artero, Ib Chorkendorff, Michael Grätzel, Harry Gray, Matthew Kanan, Geoff Kelsall, Roel van de Krol, Akihiko Kudo, Mercedes Maroto-Valer, Daniel Nocera, Guido Saracco and John Turner. In particular, we were interested in networking with people working on material and electrode development for photoelectrochemical (PEC) water splitting: Michael Grätzel, Roel van de Krol and Daniel Nocera, whom we had a chance to meet and talk to during the poster presentation session on the 7th July. What we found most interesting about the IDM was the format of the meeting, high standard of all discussions and proactive searching for a solution and answer to key questions - *which direction should the solar fuels field move towards now? – and - what will be the role of solar fuels in meeting CO_2 reduction commitments?* Even though a clear consensus was not reached, the lively discussions and active involvement of the participants accompanied us until the end of the meeting and few important final conclusions were made and agreed on. Two talks that attracted our attention most were given by Roel van de Krol (Helmholtz Centre Berlin, Germany) discussing the "*Tandem Devices for Solar Water Splitting - Can We Reach 10% with Metal Oxide Light Absorbers?*" and Daniel Nocera (Harvard University, USA) talking about, *The Artificial Leaf*". We found the concept of employing the bio-engineered cyanobacteria cells coupled with the artificial leaf system for the conversion of solar energy to biomass/biofuel with 8% efficiency really fascinating and inspiring.

Overall, participation in the SFN ECRS and IDM 2015 in London was a developing and memorable experience, particularly useful for our research, in which we focus on developing novel hierarchical electrodes for the integration of enzymes to promote semi-artificial PEC water splitting. Both events have the influence on progressing our

career, since one of the long-term goals of our projects is exploring applications of developed electrodes in tandem PEC cells. We have expanded our scientific horizons thanks to an excellent quality talks from the top people in the field, had a chance to meet many interesting SFN members and get engaged into fascinating discussions about the future directions of solar fuels.

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The early career researchers' symposium (ECRS) and international discussion meeting organised by solar fuels network from 6th-8th July, 2015 was an excellent event, in fact one of the very best which I have ever attended. It provided me with the opportunity to listen and interact with the world leaders in the field of photocatalysis and solar fuels. The workshop introduced me with the state of the art research as well as served as an excellent networking platform.

I presented the posters in the ECRS and meeting on the enhanced photo-response and visible light activity by surface modification of titanium dioxide using molecular clusters. During the presentation, I had some discussion on my poster which enhanced my understanding of my own work and paved the way for the further work.

The meeting chair Prof. James Barber gave an superb start to the discussion meeting. All the presentations were of very high quality and few of them are summarized below. Prof. Harry Gray presented on solar driven water splitting. For the effective photocatalysis the photocatalysts should be efficient, scalable and robust, wide band-gap semiconductors satisfy the requirements except the high efficiency. Various strategies for enhanced photocatalysis including the use of molecular clusters and resolving the over-potential issue were also mentioned.

Prof. Michael Gratzel discussed the prospects in using two photosystems in water splitting. Tendem devices with both photocathode and photoanodes are promising candidate for the realisation of hydrogen economy. The introduction of new materials including Cu_2O as photocathode and Fe_2O_3 nanowires as photoanode could be an effective strategy for enhanced water splitting efficiency. I got a chance to interact with him for a short period, which was quite inspiring.

Prof. Akihiko Kudo discussed on artificial photosynthesis systems based on oxide and sulphides. He discussed a large numbers of photocatalytic systems and their pros and cons for water splitting applications. The stoichiometry of the reactants and products is an important quality check for the catalyst nature.

The scalability of the photocatalytic systems had been an important issue discussed throughout the meeting. Prof. Geoff Kelsall, Dr. Mercedes Maroto-Valer and Dr. Guido Saracco concentrated their talks on the reactor design and their scalability. Prof. Kelsall using Laplace equation demonstrated that the current density is not same throughout the reactor with edges having higher current density. The effect is profound for larger reactors. Dr. Saracco demonstrated multiple strategies for circumventing the problem. Dr. Maroto-Valer demonstrated various reactor designs for enhanced IPCE.

The usual strategy for mimicking nature for energy storage is trying to assemble plant photosystems onto electrodes. Prof. Daniel Nocera demonstrated the reverse approach by generating fuels as the product of fatty acid cycle and storing them. He also mentioned the flow batteries as a media for better energy storage than lead acid ones.

The discussion in the end provided an even bigger picture of the problem and possible solutions. Other speakers as well as the student posters also presented very high-quality work. Few posters were similar to my work and resulted in new methods of working on the same problem. Overall, this discussion meeting was an excellent event which enhanced my understanding of the subject, provided network platform and inspired me for carrying out further research in the field.

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Michael Sachs
Imperial College London

Attending the event "Solar Fuels: Moving from Materials to Devices", which was organised by the Solar Fuels Network in London, was a very valuable experience for me. The addressed topic of moving towards practical devices for solar water splitting is crucial to demonstrate the applicability of our research to a wider audience, such as potential partners in industry. The event consisted of an Early Career Researchers' Symposium on 6th of July 2015 at the Royal School of Mines at Imperial College and the main International Discussion Meeting on 7th and 8th of July at the Royal Society of Chemistry. I presented my first poster at an international meeting and got the chance to meet some of the most renowned scientists in the field.

At the Early Career Researchers' Symposium, I particularly enjoyed a talk by Jan Rongé from KU Leuven (Netherlands), who addressed the pH gradient formation during operation of monolithic devices for solar water splitting. To this end, pores were introduced and optimised in terms of diameter and spacing. These pores acted as ion channels and helped to counteract ionic transport limitations, which is very interesting for large scale devices.

At the International Discussion Meeting, there were numerous interesting talks on a variety of topics. Harry Gray from Caltech discussed the materials that he sees closest to incorporation in devices, namely WO_3, $BiVO_4$, and TaN, decorated with catalysts of different stability such as Ni_2P, CoP, and Ni-Mo. He also emphasized the potential of molecular catalysts, although they require further research to improve stabilities. Roel van de Krol from Hemholtz Centre Berlin addressed the use of metal oxide-based semiconductors as photoelectrode materials. These materials are inexpensive and can exhibit favourable band gaps and long-term stabilities, however, their application is often limited by low charge carrier mobilities and short lifetimes. He stated that, if these latter parameters are found to be unfavourable for a potential candidate, it is preferable to look for different materials before spending much time on optimisation. Mercedes Maroto-Valer from Heriot-Watt University discussed the scale-up process of sunlight driven fuel generation in photoreactors. Central topics that have to be considered here are photon management and mass transfer limitations. She raised the important point that engineers need to be included very early in the process of developing devices for sunlight-driven water splitting in order to prevent complications that can hardly be corrected at later stages. This seems more reasonable than only dealing with the scale-up of devices after they have been completed on a small scale. Other very interesting talks were given by, among others, Daniel Nocera, Michael Grätzel, John Turner, and Ib Chorkendorff.

At both the Symposium and the Discussion meeting, I presented my current work with a poster, which was a great opportunity to discuss various aspects of my research and receive valuable feedback. Overall, I am looking back to a very inspiring conference with great talks and conversations, and can only recommend future SFN events.

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David Palm
University of Cambridge

For any young researcher in the Solar Fuels community, the International Discussion Meeting on solar fuels devices was almost a dream conference. It was a wonderful opportunity to hear from the leading investigators in the field – the very people from which we have learned the science involved in photoelectrochemical (PEC) systems – and interact with them over the course of three days. For those of us who participated in the Early Careers Researchers' Symposium, or presented posters at the meeting itself, it was an invaluable chance to garner feedback from those who best understand the complex issues involved in moving our lab-scale investigations toward real working technology.

Personally, I had the chance to present a poster about my work on developing reactors and working devices for tandem dual-photoelectrode PEC water splitting. The response from other young researchers was encouraging, as several were excited to see a complete working tandem PEC device we constructed by combining a bismuth vanadate ($BiVO_4$) photoanode with a silicon photocathode in a state-of-the-art reactor. The response from the experts was positive as well, with Dr. John Turner agreeing that using tandem devices is certainly the most promising approach for harnessing solar energy.

However, more enlightening than speaking about my own work was seeing the field's leaders take the stage to discuss their most recent work and realisations regarding the steps the scientific community should be taking in order to attain a meaningful technology. A key for me was that that it did often feel like an actual discussion, with the short presentations immediately followed by plenty of time for queries and responses from anyone in the room who had the best information (or opinion) to share.

The most intriguing talk for me came from one of the few speakers of whom I had not been aware prior to the meeting: Professor Guido Saracco from Torino. His presentation focused on the applications and projects that his group and collaborators have been undertaking with industrial partners; even after the meeting had reached its conclusion, he was the only expert to present functioning technology-scale PEC projects. Given my current work on up-scaling the $BiVO_4$ material, I was astounded to see that his group had constructed a working 1 m_2 PV-biased water splitting panel using the materials as photoanode. Additionally, he offered many intriguing insights about what it will take to realise water splitting technologies from an engineering perspective – including the fact that these gas-producing systems will ultimately need to operate under pressures that can only be achieved with current densities generated by concentrated solar PEC or concentrated PV/electrolysis.

Another eye-opening moment for me was hearing Dr. Turner speak about the inherent thermodynamic instability of metal oxide semiconductors in the operating solutions we use in PEC studies; I had never before considered that each electronic excitation in these systems is from a bonding to an anti-bonding orbital (band), thus the crystal lattice is essentially deformed and reformed with each excitation and relaxation. His point about the ultimate unsustainability of subjecting these materials to difficult aqueous solutions while constantly cycling them through unstable electronic arrangements was well taken.

In conclusion, I cannot imagine having a better introduction to the field of photoelectrochemical energy conversion than this week proved to be. Everyone in attendance, experts included, was forced to face some complex issues and daunting challenges that stand between our science's current position and the technology that stores solar energy as chemical fuel, of which we all dream. However, I am encouraged that through meetings like this that bring together the brightest and most driven minds working on the issue, we will succeed in finding the most promising solution for applying solar-driven photoelectrochemistry to real-world issues.