The Electrochemical Society

INTERFACE

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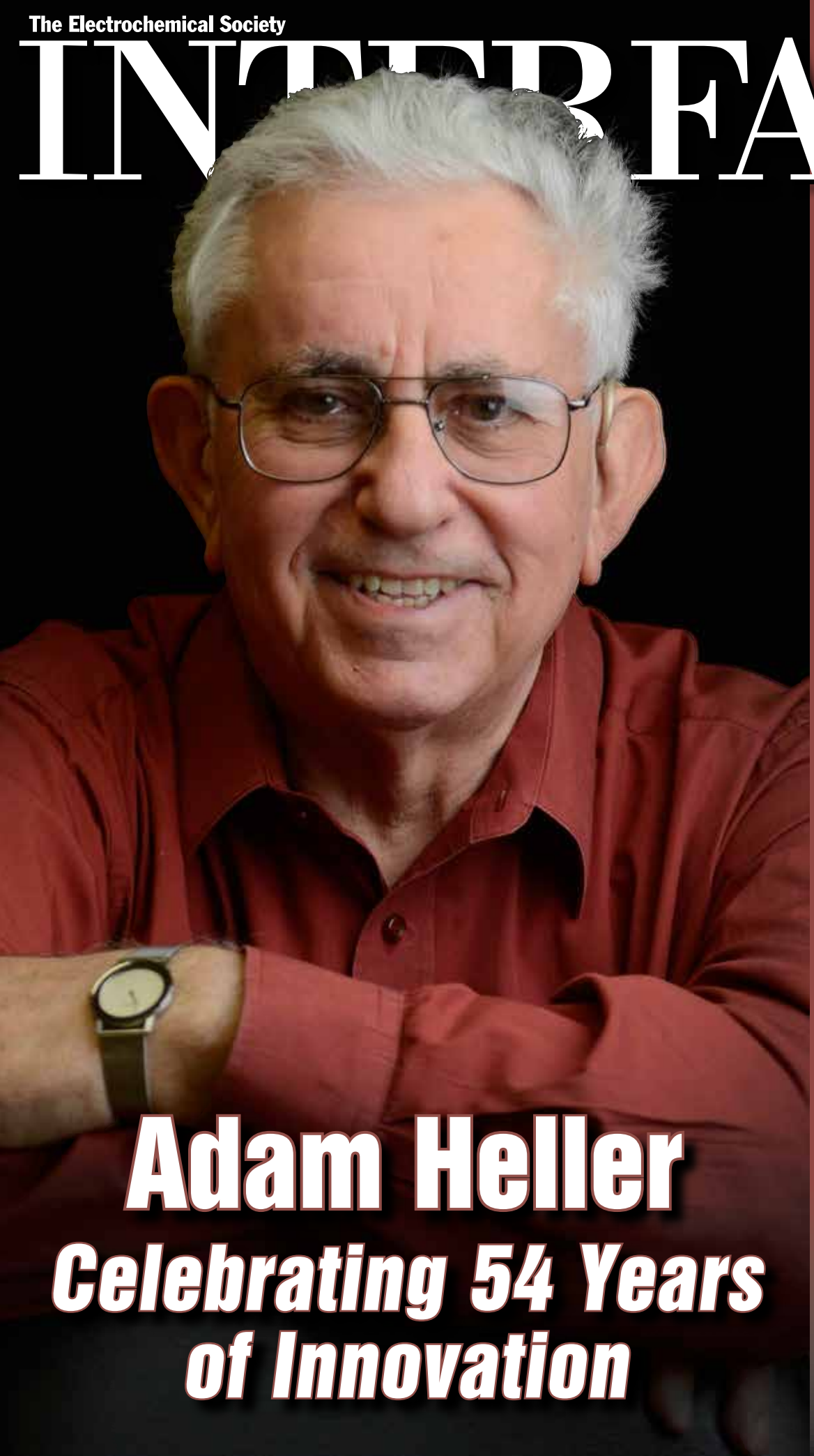
Fall 2015



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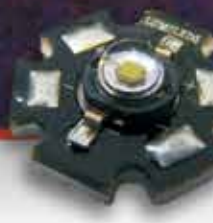

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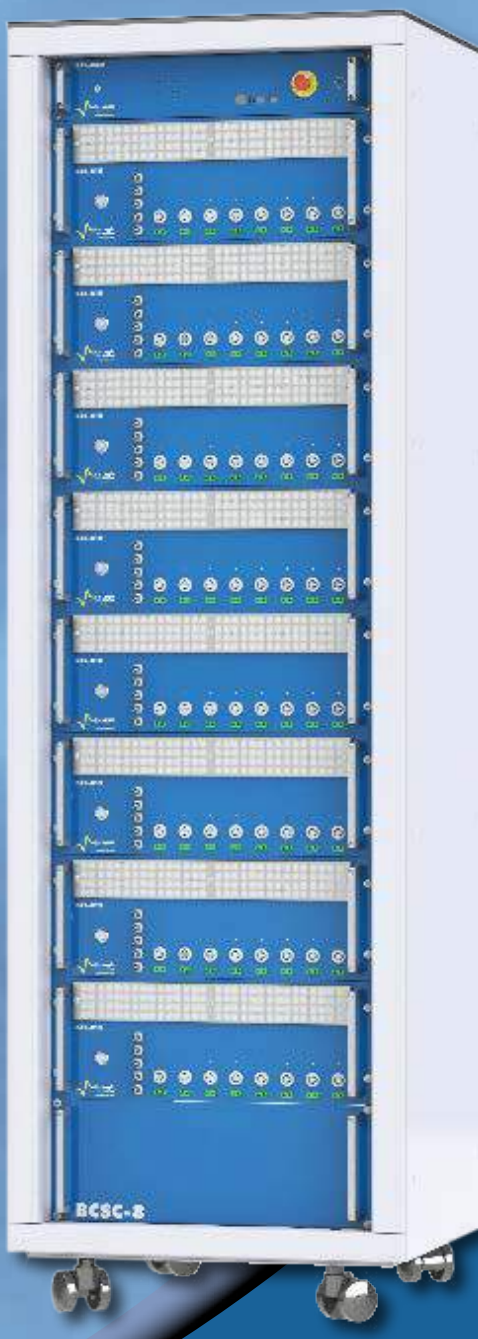

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Disingenuous Scientometrics

The precise definition of the "impact" of a research product (e.g. publication) varies significantly among disciplines, and even among individuals within a given discipline. While some may recognize scholarly impact as paramount, others may emphasize the economic impact, the broad societal impact, or some combination therein. Given that the timeframe across which said impact is assessed can also vary substantially, it is safe to say that no formula exists that will yield a standardized and reproducible measure. The difficulties inherent in truly assessing research impact appear to be matched only by the convenience of the numerous flawed metrics that are currently in vogue among those doing the assessing. Needless to say, many of these metrics are used outside the context for which they were originally developed. In using these measures, we are essentially sacrificing rigor and accuracy in favor of convenience (alas, a tradeoff that far too many in the community are willing to make!).

Perhaps the most widely misused metric is the journal impact factor (JIF). Originally conceived in the 1960s to help select journals to be included in the Science Citation Index (SCI), the JIF has morphed into a default indicator of author/scholarship impact. While there is awareness in the community of the inherent dangers of conflating the JIF with the merits of the published work, this statistically bankrupt metric is (still) widely used in advising critical decisions such as hiring, tenure and promotion, award of grants, etc. In some countries, there is even a monetary reward to authors that scales with the JIF! The unfortunate side-effect is that an increasing number of scientists, especially those starting their careers, are pressured into performing work that has a higher chance of being published in a so-called "high-impact-factor" journal. In other words, the focus is increasingly shifting to performing and publishing research that is likely to rapidly garner citations, only in the next two years, without much thought devoted to the longer-term implications of the research. Disturbingly, but unsurprisingly, a strong correlation exists between article retraction frequency and journal impact factor.

An additional concern is that the JIF is a metric that can be readily gamed to increase the numerator and lower the denominator (number of published articles over the past two years) in the JIF calculation. The numerator of course is the citation count in a given year across all indexed journals to the articles counted toward the denominator – a dubious metric in itself given that not all citations are equivalent. The inherent fallacies of using the JIF to measure the impact of an individual article or an author cannot be overstated. Some methods of gaming the JIF include: a) publishing a large number of review articles — these articles have zero new research impact, but are widely cited as a matter of convenience; b) declining to publish or even review articles that are technically sound and well within the journal scope, but are deemed insufficiently capable of rapidly gathering citations - this is an unfortunate but common practice among "high-impact-factor" journals today; c) the considerably less ethical practice of coercive citations (enough said!); and d) encouraging excessive self — citations (some authors are only too happy to oblige). As one example, a journal was able to nearly triple its JIF for the year by the simple expedient of publishing an editorial in each issue that cited every paper published by that journal in the prior two years (note that the journal editors here did this deliberately to point out the fallacies inherent in the system).

Why do these developments concern us as a Society? For one, ECS publishes *Journal of The Electrochemical Society* and *ECS Journal of Solid State Science and Technology* – both outstanding journals – that have to compete for article submissions in this environment. Unlike the so-called "high-impact-factor" journals, ECS journals do not filter articles based on their ability to garner citations rapidly. On the contrary, and to their credit, the ECS journals strive to publish each technically sound article that is within the scope of the Society's topical interest areas. The Society should continue to follow this practice and resist the dangerous temptation to conclude — as many journals have done with the motive of enhancing their JIF — that advances that are not immediately relevant (i.e. papers that are not deemed to be citation magnets) are unworthy of publication, or even review. The support and participation of all ECS members in this endeavor is essential. Secondly, and perhaps more importantly, we as a Society should encourage researchers to think more deeply (i.e. beyond immediate citations) when it comes to conceiving and executing a research project. To this end, we must ensure that we eschew dubious metrics and reclaim traditional (but sound) methods of evaluation when it comes to assessing the output of our peers. The consequences of not doing so will be the slow but sure devaluation of our governing research principles. Fortunately, many agencies and societies have acted to minimize the pernicious effects of improper research assessment (see for example the San Francisco Declaration on Research Assessment (DORA) under the aegis of the American Society for Cell Biology). ECS was an early signatory to DORA, and should continue to champion efforts to educate the scientific community on the fallacies of using the impact factor of a journal as a measure of the scientific impact of a published article.

Vijay Ramani,
Interface *Co-Editor*
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The Electrochemical Society
INTERFACE

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The Electrochemical Society is an educational, nonprofit 501(c)(3) organization with more than 8000 scientists and engineers in over 70 countries worldwide who hold individual membership. Founded in 1902, the Society has a long tradition in advancing the theory and practice of electrochemical and solid-state science by dissemination of information through its publications and international meetings.

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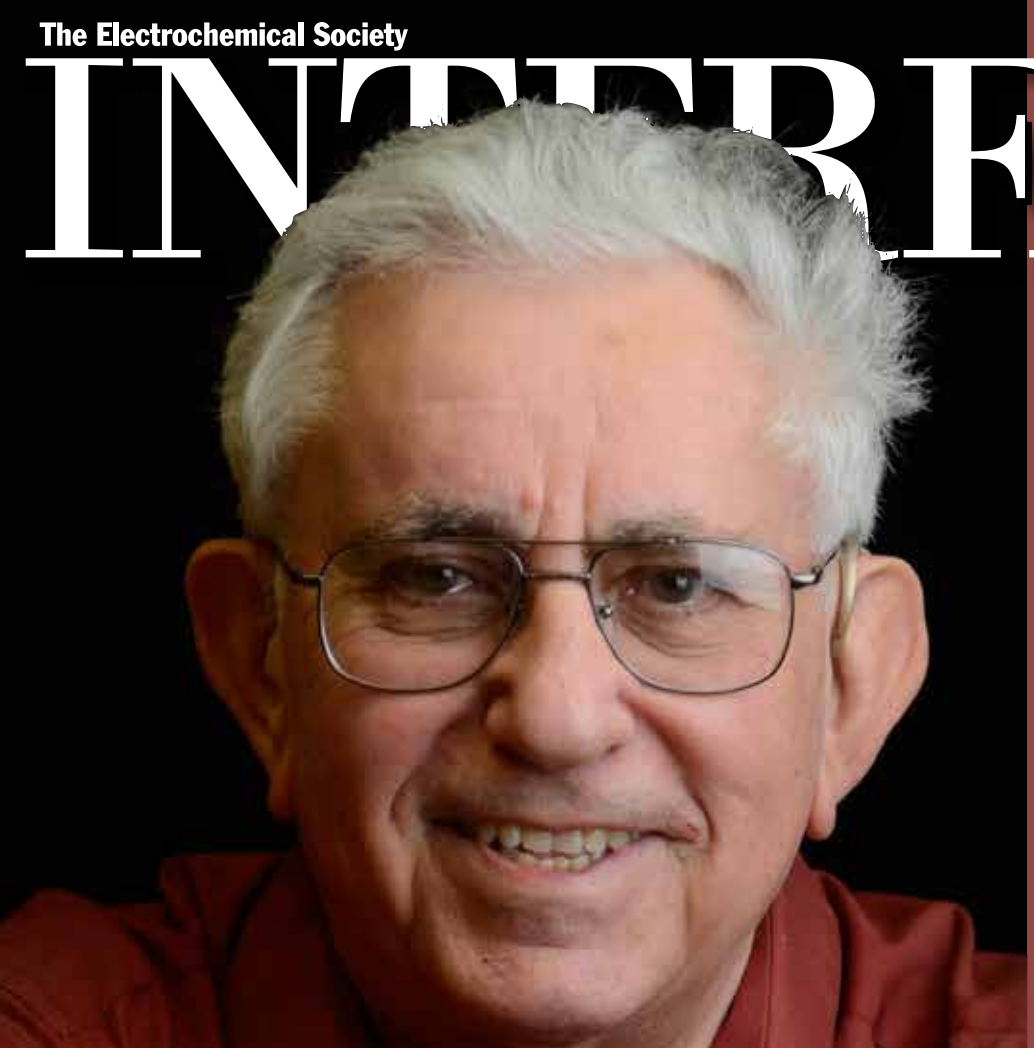

On the cover . . .
Read more about Adam Heller *on pages 25 and 27.*

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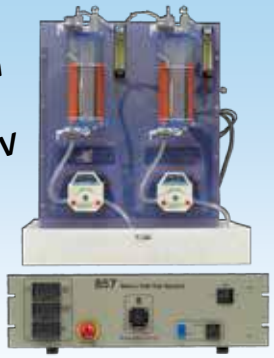

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Changing (Again)

> *When you're finished changing, you're finished.*
>
> —Benjamin Franklin

While high journal impact factor (JIF)[1] continues to be a metric of choice for many, an important, but often-overlooked metric is the journal's "cited half-life." This metric tells you if articles from a journal—that were published *before* the two years the JIF covers—are still being cited; in other words, it tells you if a journal has long-lasting impact. For the *Journal of The Electrochemical Society* (JES), the cited half-life is >10.0, where 10 is the maximum half-life a journal can have. The ECS journals clearly have lasting impact[2] in the electrochemistry and solid state communities, a fact attributable to ECS being willing and able to change to meet the needs of authors, libraries, and readers. Over the course of our 113-year history, ECS publications have transformed numerous times; and we're not finished yet.

This summer, ECS introduced the latest round of changes to its journals: streamlined journal offerings, a new article type called a "Communication" article, and the new "Editors' Choice" designation.

Communication articles are brief articles or reports that describe impactful research where dissemination prior to a full, complete study/paper will substantially benefit the electrochemical or solid state community. Communication articles will appear beginning with the 2016 issues of the *Journal of The Electrochemical Society* (JES) and the *ECS Journal of Solid State Science and Technology* (JSS). Publishing these articles in the main journals will place them in context with their full-length cohorts in one of the technical interest area sections, will enable readers to scan for the latest developments in their fields, and will streamline our offerings for libraries. As a result of this change, *ECS Electrochemistry Letters* and *ECS Solid State Letters* will cease publication by the end of 2015 and become an important part of the ECS Digital Library archive, along with *Electrochemical and Solid-State Letters*.

To be considered for a Communication article, authors must concisely describe the high impact of the research and why early dissemination is desirable for the field. Communication article submissions undergo the same rigorous peer-review process used for ECS's full-length journal articles.

Content presented at ECS meetings and manuscripts published in *ECS Transactions* may be submitted as Communication articles, after suitable modification to ensure appropriate quality for archival publication. Although there is no strict deadline for the submission of these papers, six months from the date of the symposium is considered sufficient time to revise a paper to meet the stricter standards of ECS journals.

Editors' Choice articles may be said to represent change itself. Editors' Choice articles must show a new direction, a new concept, a new way of doing something, a new interpretation, or a new field, and not merely preliminary data. The Editors' Choice appellation is highly selective: articles must be transformative: they must represent a substantial advance or discovery, either experimental or theoretical. These articles must display credible research results and yet be transformative within the electrochemical or solid state community.

Authors may request, during the submission process, that the article be considered as an Editors' Choice article; but this special designation, for Communication articles only, is made by the ECS journals' Editorial Board. There will be a limited number of Editors' Choice articles published. Only those with the highest quality, impact, significance, and scientific/technological interest will be selected for the Editors' Choice designation. In addition, Editors' Choice articles will automatically be published as Open Access and will receive special promotion.

ECS is never finished with the work of responsible publishing. Our responsibility is greater than ever for two key reasons. One, the relevance of our science makes it more critical than ever to make the published results of that research available to all as freely as possible; the ECS Open Access initiatives are a way to bring about that change.[3] Two, the sheer growth in the number of journals (and in the number of predatory publishers who publish articles as "open access" simply for the fees and without any peer review), makes it imperative for ECS to provide the best content in the field; the Society's rigorous peer review process is one way of ensuring that quality.[4]

The Society will continue to advance its Open Access initiatives, its rigorous journal standards, and its efforts to create even greater impact for authors and the science itself.

Mary Yess
Deputy Executive Director & Chief Content Officer
http://orcid.org/0000-0003-3909-6524

1. See "Disingenuous Scientometrics" in this issue, on page 3.
2. The 2014 JES JIF was 3.266, representing a 14% increase over the prior year, and was ranked #1 in Materials Science, Coatings & Films. For all ECS JIFs, see the individual journal listings at http://ecsdl.org/.
3. http://www.electrochem.org/oa/
4. Peer Review Week was September 28-October 2, 2015; stay tuned for a future *Interface* article about peer review.

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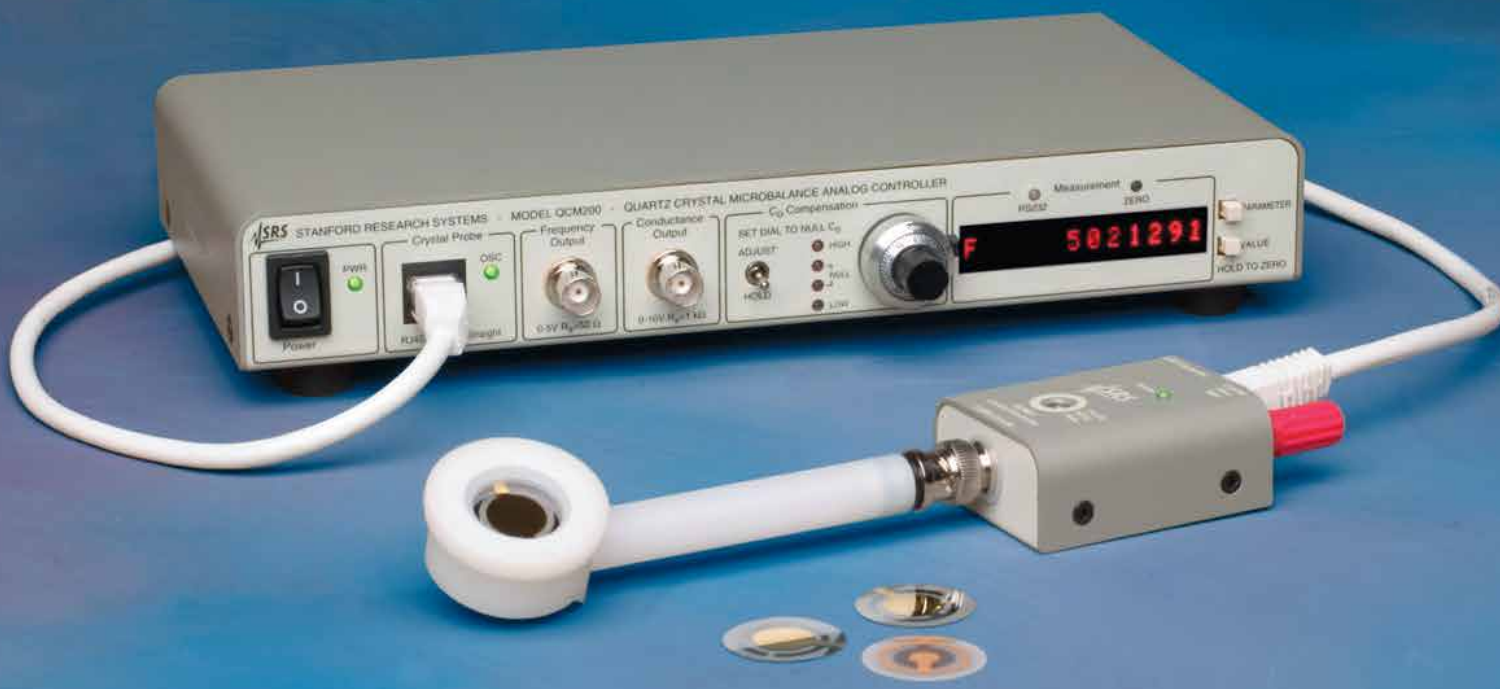

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websites of note

by Zoltan Nagy

Bioelectrochemical systems (BES) for sustainable energy production and product recovery from organic wastes and industrial wastewaters

Bioelectrochemical systems (BESs) are unique systems capable of converting the chemical energy of organic waste including low-strength wastewaters and lignocellulosic biomass into electricity or hydrogen/chemical products in microbial fuel cells (MFCs) or microbial electrolysis cells (MECs) respectively, or other products formed at the cathode by an electrochemical reduction process. As compared to conventional fuel cells, BESs operate under relatively mild conditions, use a wide variety of organic substrates and mostly do not use expensive precious metals as catalysts. The recently discovered use of BESs for product synthesis via microbial electrosynthesis has greatly expanded the horizon for these systems. Newer concepts in application as well as development of alternative materials for electrodes, separators, and catalysts, along with innovative designs have made BESs very promising technologies. This article discusses the recent developments that have been made in BESs so far, with an emphasis on their various applications beyond electricity generation, resulting performances and current limitations.

- Deepak Pant, et al. (Separation & Conversion Technologies, VITO-Flemish Institute for Technological Research, Boeretang 200, 2400 Mol, Belgium)
  http://pubs.rsc.org/en/content/articlelanding/2012/ra/c1ra00839k/unauth#!divAbstract

Minimizing losses in bio-electrochemical systems: the road to applications

Bioelectrochemical systems (BESs) enable microbial catalysis of electrochemical reactions. Plain electrical power production combined with wastewater treatment by microbial fuel cells (MFCs) has been the primary application purpose for BESs. However, large-scale power production and a high chemical oxygen demand conversion rates must be achieved at a benchmark cost to make MFCs economically competitive in this context. Recently, a number of valuable oxidation or reduction reactions demonstrating the versatility of BESs have been described. Indeed, BESs can produce hydrogen, bring about denitrification, or reductive dehalogenation. Moreover, BESs also appear to be promising in the field of online biosensors. To effectively apply BESs in practice, both biological and electrochemical losses need to be further minimized. At present, the costs of reactor materials have to be decreased, and the volumetric biocatalyst activity in the systems has to be increased substantially. Furthermore, both the ohmic cell resistance and the pH gradients need to be minimized. In this review, these losses and constraints are discussed from an electrochemical viewpoint. Finally, an overview of potential applications and innovative research lines is given for BESs.

- Peter Clauwaert, et al.
  http://link.springer.com/article/10.1007/s00253-008-1522-2#page-1

Electrochemically assisted microbial production of hydrogen from acetate

Hydrogen production via bacterial fermentation is currently limited to a maximum of 4 moles of hydrogen per mole of glucose, and under these conditions results in a fermentation end product (acetate; 2 mol/mol glucose) that bacteria are unable to further convert to hydrogen. It is shown here that this biochemical barrier can be circumvented by generating hydrogen gas from acetate using a completely anaerobic microbial fuel cell (MFC). By augmenting the electrochemical potential achieved by bacteria in this MFC with an additional voltage of 250 mV or more, it was possible to produce hydrogen at the cathode directly from the oxidized organic matter. More than 90% of the protons and electrons produced by the bacteria from the oxidation of acetate were recovered as hydrogen gas, with an overall Coulombic efficiency (total recovery of electrons from acetate) of 60−78%. This is equivalent to an overall yield of 2.9 mol H_2/mol acetate (assuming 78% Coulombic efficiency and 92% recovery of electrons as hydrogen). This bioelectrochemically assisted microbial system, if combined with hydrogen fermentation that produces 2−3 mol H_2/mol glucose, has the potential to produce ca. 8−9 mol H_2/mol glucose at an energy cost equivalent to 1.2 mol H_2/mol glucose. Production of hydrogen by this anaerobic MFC process is not limited to carbohydrates, as in a fermentation process, as any biodegradable dissolved organic matter can theoretically be used in this process to generate hydrogen from the complete oxidation of organic matter.

- Hong Liu , Stephen Grot, and Bruce E. Logan (Penn State University, University Park, Pennsylvania 16802)
  http://pubs.acs.org/doi/abs/10.1021/es050244p

About the Author

Zoltan Nagy is a semi-retired electrochemist. After 15 years in a variety of electrochemical industrial research, he spent 30 years at Argonne National Laboratory carrying out research on electrode kinetics and surface electrochemistry. Presently he is at the Chemistry Department of the University of North Carolina at Chapel Hill. He welcomes suggestions for entries; send them to nagyz@email.unc.edu.

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Highlights from the Meeting in Glasgow

The first international **ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV** convened in Glasgow, July 26-31, 2015, at the Scottish Exhibition and Conference Centre. More than 800 attendees, from over 40 countries explored three main symposium topics. **Subhash Singhal** (Pacific Northwest National Laboratory, U.S.) and **Koichi Eguchi** (Kyoto University, Kyoto, Japan) organized the section on Solid Oxide Fuel Cells, which covered all aspects of research, development, and engineering of solid oxide fuel cells. The section on Batteries was led by **Peter Bruce** (University of Oxford), **Clare Grey** (ALISTORE-European Research Institute), **Stefan Freunberger** (Graz University of Technology, Austria), and **Jie Xiao** (Pacific Northwest National Laboratory, U.S.). The Low Temperature Fuel Cells track, featuring presentations on low-temperature fuel cells, as well as electrolyzers and redox flow cells, was organized by **Hubert Gasteiger** (Technische Universität München, Germany), **Deborah Jones** (CNRS - ICGM - AIME - University of Montpellier, France), **Thomas Schmidt** (Paul Scherrer Institut, Switzerland), and **J. Herranz** (Paul Scherrer Institut, Switzerland).

The ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV served as a major forum for the discussion of interdisciplinary research from around the world through a variety of formats, such as invited and keynote oral presentations, poster sessions, and exhibits. This was the first of a series of planned biennial conferences in Europe by ECS on electrochemical energy conversion/storage materials, concepts, and systems, with the intent to bring together scientists and engineers to discuss both fundamental advances and engineering innovations. The size of the meeting and the focused topical areas allowed attendees to fully participate and listen to a broad range of new topics throughout the week while networking with fellow colleagues and associates.

The conference started off with a general plenary session on Monday morning where **Nigel Brandon**, Director of the Sustainable Gas Institute at Imperial College London, delivered his cutting edge talk, "Electrochemistry in Energy Applications: Policy Drivers, Commercial Opportunities, and Research Challenges." Prof. Brandon addressed the role and value of electrochemical technologies such as fuel cells, lithium batteries, flow batteries, supercapacitors, and electrolyzers in delivering a secure and sustainable energy system. Prof. Brandon is also Director of the UK Hydrogen and Fuel Cells Hub, and Co-Director of the UK Energy Storage Hub.

(continued on next page)

Nigel Brandon *delivering his plenary address.*

From left to right: **Nigel Brandon**, *Director of the Sustainable Gas Institute at Imperial College*, **Daniel Scherson**, *ECS President, and* **Roque Calvo**, *ECS Executive Director.*

Fergus Ewing, *Minister for Business, Energy and Tourism, addressed the audience during the ECS plenary.*

Glasgow Meeting Highlights
(continued from previous page)

Attendees gathered together to network, discuss research, catch up with colleagues, and collaborate with new associates during the daily morning and afternoon coffee breaks.

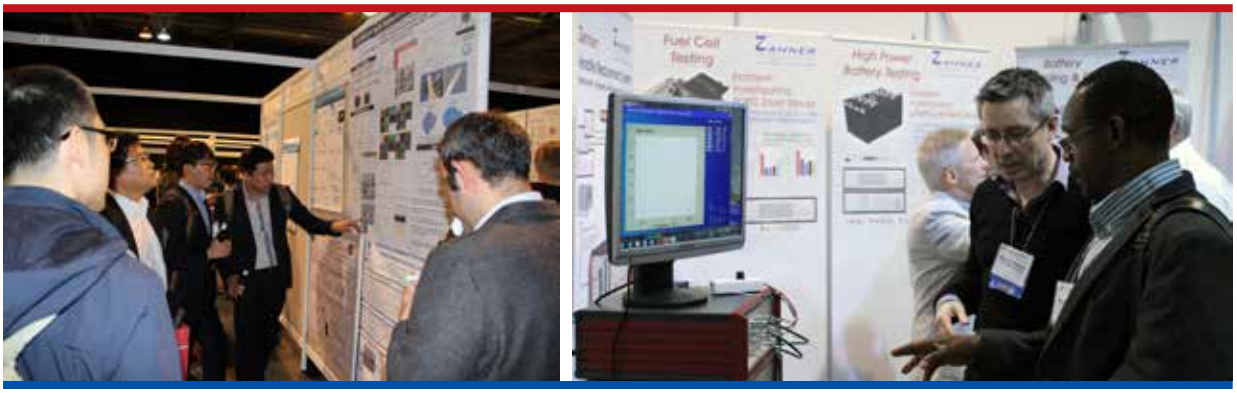
ECS President **Dan Scherson** welcomed **Fergus Ewing**, the Scotland Minister for Energy, Business, and Tourism. Minister Ewing discussed Scotland's renewable energy program and goals while welcoming attendees to Scotland. Minister Ewing explained why Glasgow, Scotland's largest city, is a fitting venue when considering the country's goal of utilizing 100 percent renewable energy by 2020. In 2012, Scotland pulled 40 percent of its power from renewable resources—a 24 percent increase over 2010. Scotland is expected to hit the half-way point on the path of obtaining 100 percent renewable energy this year, making it the perfect platform for some of the top researchers globally in fuel cells and batteries to come together and discuss fundamental advances and engineering innovations that will further enable this transition.

"I am delighted that The Electrochemical Society chose Scotland as the platform for some of the top researchers globally in fuel cells and batteries to come together and discuss advances and engineering innovations." noted Minister Ewing in his introductory address. "Events such as these are a great opportunity to showcase all that Scotland has to offer for both leisure and business and it gave me the opportunity to highlight that Scotland's universities (spearheaded by the Energy Technology Partnership) are at the leading edge of innovation in a broad range of energy storage and conversion technologies. For our part, the Scottish Government and its agencies are working together to open markets, help companies to innovate, make production efficiency savings, and safeguard jobs in order to strengthen the Scottish share of global markets. They are part of a cultural shift that brings the innovation and creativity of our academic sector to the heart of our business life and puts business drive firmly into the heart of our academic sector."

More than 400 oral presentations and 300 poster presentations added great depth to the scientific material presented in Glasgow.

The Low Temperature Fuel Cells symposium selected four student poster award winners; the awards were sponsored by Ion Power. First place was awarded to Susan Taylor, Paul Scherrer Institute (Switzerland), for her poster entitled, "Oxygen Functionalized Carbon Surfaces — A Suitable Electrode Material for Vanadium Reduction in Redox Flow Cell Applications." Second place was awarded to Jarrod Milshtein, Massachusetts Institute of Technology (U.S.), for his poster entitled, "Analytical Model for the Interdigitated Flow Field." Third place was awarded to Zakiya Al Amri, School of Physics, University of Bristol (UK), for her poster entitled, "The Catalytic Behavior of Pt Clusters on Au and Pd/Au as a Function of Their Surface Coverage and Density." Also in third place was Ludwig Asen, Technische Universität München (Germany), for his poster entitled, "Electrodeposition of Novel Catalyst Materials for the Oxygen Reduction Reaction."

ECS thanks all the presenters, exhibitors, and volunteers for their support in making the ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV a huge success. A special thanks to the meeting sponsors, Pine Research Instrumentation, Ion Power, and Metrohm U.K. Ltd.



Attendees enjoyed the week-long poster and technical exhibit sessions in the afternoons and evening. With over 300 posters and 20 exhibitors, this offered the perfect platform to socialize over refreshments while browsing unbeatable content and visiting with exhibitors to learn about their newest products.

The Low Temperature Fuel Cell student poster award winners with the Low Temperature Fuel Cell lead and co-organizers. From left to right: **Thomas Schmidt, Mike Perry, Jarrod Milshtein, Susan Taylor, Ludwig Asen, Zakiya Al Amri, Deborah Jones, Juan Salaner Herranz,** *and* **Hubert Gasteiger.**

Attendees lining up to participate in the whiskey and haggis tasting at the welcome reception hosted by Arisaig Restaurant in Glasgow.

Subhash Singhal, *co-organizer of SOFC-XIV, presenting his opening remarks at the banquet.*

A bagpiper welcomes guests to the SOFC banquet held on Wednesday evening at the Glasgow Science Centre.

Christie Knef, *ECS Director of Meetings (left), presents* **Bailie Cameron,** *Glasgow City Council Executive Member for Economic Development (right), with a certificate of appreciation for the city's generous support of the ECS meeting.*

In the NEXT *issue of* INTERFACE

- The winter 2015 issue of *Interface* will feature the **Luminescence and Display Materials Division** of ECS. The issue will be guest edited by **Uwe Happek** from the University of Georgia and **Anant Setlur** from the GE Global Research Center, and will feature the following technical articles: "Impact of Light Emitting Diode (LED) Adoption on Rare Earth Element Use in Lighting," by **A. Y. Ku**, **A. A. Setlur**, and **J. Loudis**; "Polymeric Materials in Phosphor-Converted LEDs for Lighting Applications: Outlook and Challenges," by **M. Tchoul**, **A. Piquette**, and **A. Linkov**; "Phosphors-by-Design: Computational Approaches Toward Advanced Luminescent Materials," by **J. Brgoch**.
- Highlights from the **228th ECS Meeting in Phoenix** will be presented, including news and photos from the Electrochemical Energy Summit (E2S), the general and student poster sessions, and the get-togethers.
- Biographical sketches and candidacy statements of the nominated candidates for the annual election of officers for ECS.
- **Tech Highlights** continues to provide readers with free access to some of the most interesting papers published in the ECS journals.
- The **2015 ECS Summer Fellowship Reports** including reports from the recipients of the 2015 Edward G. Weston Summer Research Fellowship, the 2015 Colin G. Fink Summer Research Fellowship, the 2015 Joseph W. Richards Summer Research Fellowship, the 2015 F. M. Becket Summer Research Fellowship, and the 2015 H. H. Uhlig Summer Research Fellowship.

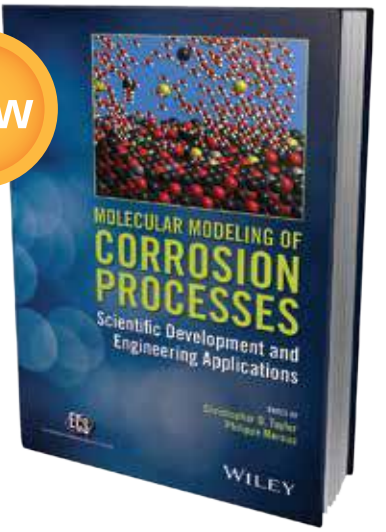
ECS MEMBERS Receive a Discount! Visit us at www.electrochem.org

Molecular Modeling of Corrosion Processes: Scientific Development and Engineering Applications

By Christopher D. Taylor & Philippe Marcus

ISBN: 978-1-118-26615-1
Cloth | April 2015 | 272pp
£83.50 / €122.00 / $125.00

New

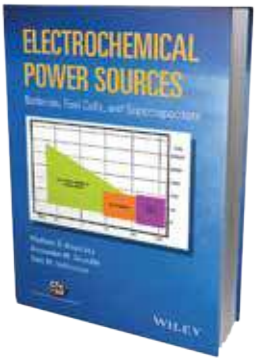


Molecular Modeling of Corrosion Processes applies an atomistic and molecular modeling approach to the study of the corrosion of metals. It offers opportunities for making significant improvements in preventing harmful effects that can be caused by corrosion.

Engineers and scientists often do not realize that corrosion has taken place until significant damage has occurred to a metal material. By using atomistic and molecular modeling these professionals can improve lifetime prediction models to predict well in advance of visual observations or other test methods when various processes will cause a metal to corrode as well as how well corrosion inhibitors will perform. There are recent examples of applications of molecular modeling to corrosion phenomena throughout the text.

- Describes concepts of molecular modeling in the context of materials corrosion
- Details how molecular modeling can give insights into the multitude of interconnected and complex processes that comprise the corrosion of metals
- Covered applications include diffusion and electron transfer at metal/electrolyte interfaces, Monte Carlo simulations of corrosion, corrosion inhibition, interrogating surface chemistry, and properties of passive films
- Presents current challenges and likely developments in this field for the future

Also available in The Electrochemical Society Series

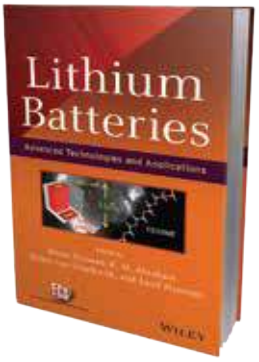


Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors

Vladimir S. Bagotsky, Alexander M. Skundin & Yurij M. Volfkovich

ISBN: 978-1-118-46023-8
Cloth | 2015 | 400pp
£66.95 / €97.90 / $99.95

Providing a concise description of batteries, fuel cells, and supercapacitors, this book reviews the design, operational features, and applications of all three of these power sources. Written in accessible language, this valuable resource for environmental engineers, chemists, energy industry members, and electrochemists examines many of the main battery types, such as zinc-carbon batteries, alkaline manganese dioxide batteries, mercury-zinc cells, lead-acid batteries, cadmium storage batteries, and silver-zinc batteries.



Lithium Batteries: Advanced Technologies and Applications

Bruno Scrosati, K. M. Abraham, Walter A. van Schalkwijk & Jusef Hassoun

ISBN: 978-1-118-18365-6
Cloth | 2013 | 392pp
£93.50 / €139.00 / $140.00

With their use in everyday electronics and their increased use in industry applications, lithium ion batteries are an important source of power. Covering the most cutting-edge advances and technology in lithium ion batteries, this book teaches readers how to develop the most efficient advanced rechargeable batteries. This timely text covers various lithium ion devices, including lithium-air batteries non-aqueous lithium-air batteries, lithium-sulfur, and batteries for medical applications.

Visit us at **www.electrochem.org** to see more titles and for your membership discount

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ECS Staff News

Casey Emilius joined ECS in January 2015 as the Meetings Coordinator. As the Meetings Coordinator, she is responsible for the development, organization, and execution of the Society's meetings logistics. This includes handling all on- and off-site logistics including the hotel blocks, catering menus, and non-technical scheduling. She also works very closely with the Society's Divisions and Sections to ensure that their time at the biannual meetings is both productive and enjoyable. Casey graduated from Monmouth University in 2011 with a Bachelor of Science degree in Business Marketing and a minor in Information Technology. She has been involved in the event planning industry for 10 years with her passion stemming from her mother, who owned an event planning business. Shortly after graduating, she took a position working as the office manager at one of the top rated restaurants in New Jersey. Just a few months after taking that position she was promoted to event manager. After spending two and a half years on the vendor side of the event planning industry, Casey joined ECS where she is flourishing within her position and proving to be a valuable addition to the staff.

Amanda Staller joined ECS in August 2014 as the Marketing Communications Assistant. In this role, Amanda is responsible for helping build ECS's online presence through the creation and use of the ECS Redcat blog (www.ecsblog.org), newsletters, podcasts, videos, and social networking tools. Additionally, Amanda works to grow the Society's exposure worldwide through online marketing campaigns and outreach to the news media.

In 2012, Amanda graduated from La Salle University in Philadelphia, PA with a BA in Communication. Prior to joining ECS, Amanda gained valuable experience in writing and digital outreach at WHYY's Newsworks and various hyperlocal papers in the Philadelphia area. She has covered topics ranging from climate change to food security, taking special interest in advocacy issues. She has also worked with *Magnet* magazine, where she explored local music culture and developed new marketing initiatives.

"Amanda is helping the Society and our members tell their stories," says Rob Gerth, Director of Marketing & Digital Engagement. "Through her interviews and new media, she's able to reveal the relevance of our science and humanity of our scientists."

Institutional Member spotlight Gamry

From webinars to short courses, Gamry Instruments has a passion for educating users about electrochemistry. "We are a bunch of scientists and engineers who enjoy seeing our instruments used in creative ways," notes Chris Beasley, Gamry Marketing Manager. To facilitate that creativity, Gamry participates in several short courses throughout the year, including the Penn State Corrosion Short Course, the Electrochemical Impedance Spectroscopy Course in Houston, and the Case Western Short Course on Electrochemistry. They also host webinars and will be conducting a workshop at the upcoming 228th ECS Meeting in Phoenix, AZ.

In addition to their hands-on education opportunities, Gamry also maintains a comprehensive library of application notes, technical support articles, and videos on their website. Free and open to all, Gamry's web resources complement their high-quality customer support and help instrument users learn more about electrochemistry and electrochemical techniques for research.

Gamry joined ECS as an institutional member in 2007. It has been a genuine pleasure working with them over the years as an institutional member, advertiser, and exhibitor. Their innovative spirit, knowledge, and commitment to electrochemistry make them a great partner.

"We are pleased to work alongside ECS to bring electrochemistry to a larger audience," comments Dr. Beasley. "Electrochemistry and the application of electrochemical technologies play a crucial role in our everyday lives without the overwhelming majority of the public even realizing it. This is a very exciting time to be involved in the electrochemistry arena, and we can't think of a better partner to be working with toward the lofty goal of educating the public about the importance of electrochemical technologies."

Five Questions for Scott Lillard

Scott Lillard is currently the Professor & Carboline Endowed Chair in Corrosion at the University of Akron, where he leads academic research and is a major contributor to the establishment the university's new Corrosion Engineering program. He has recently been appointed to the ECS Electrochemical Science & Technology (EST) Editorial Board as an Associate Editor for a two-year term beginning July 1, concentrating in the Corrosion Science and Technology Technical Interest Area.

What do you hope to accomplish in your new role as an EST Editorial Board Associate Editor?

I have some experience working on the board of some other journals, but I don't think that's what I really contribute. What I contribute is this idea of customer service. There are a number of reasons why people publish in the journal. It might be the appropriateness of the content or the impact factor, but the third reason is probably customer service. What does that mean? That means getting good peer-reviews in a timely manner and treating the authors in a professional manner.

How do you think peer-reviewed journals have changed over the years?

I think the goals of authors are the same as they were 20 years ago. They want to get their publication out to people in their field so they can read it. They want to do that in as timely a manner as possible. The way in which the process is expected to occur is much different now than it was 20 years ago. It would take you six or nine months to get reviews back. That's just not expected anymore. Everything is expected to be much more efficient now. I think efficiency, speed, and customer service are the things that are changing.

What led to your interest in corrosion engineering?

I did my undergraduate work in chemistry. I think I've always been—even when I was in high school—interested in science. I didn't really know what I wanted to do after my undergraduate work, and I went to work at the Johns Hopkins University Applied Physics Laboratory. That's when I really first got interested in academic research. I enjoyed the project I was working on there. I liked it from a technical aspect; it seemed like it was a good fit for what I liked about chemistry. It was corrosion related and I liked electrochemistry, even as an undergraduate. It kind of went from there. I went back to graduate school and it just kind of snowballed from there.

What kind of research are you currently working on?

All of my research is pretty academic, but it does have applied applications in the real world. I'm working on projects with the U.S. Department of Defense. Each project has a very specific application. For example, the alternating current project I'm working on deals with buried pipelines. The gas transmission pipelines that distribute natural gas or liquid petroleum throughout the United States are usually in what are called "shared right-of-ways" with power lines. There is some loss of that AC current from the transmission power line to the buried gas pipeline that's below it. That AC current that's running on the pipeline increases corrosion rates. If you have a buried gas pipeline, the last thing you want is increased corrosion rates—a failure that might be catastrophic in a residential or commercial area where you can have loss of lives.

Are students interested in corrosion engineering?

Yes, absolutely. When I got here, the first class that was enrolled was eight students. This fall, we have 40 students enrolled in the program. Overall between freshmen and seniors, we have 80 or 100 students enrolled in the program. I think there's a lot of excitement from students, and we have more companies that want our students for those co-op programs than we have students to supply. ■

2015 Sponsored Meetings

In addition to the regular ECS biannual meetings and ECS Satellite Conferences, ECS, its Divisions, and Sections sponsor meetings and symposia of interest to the technical audience ECS serves. The following is a list of the sponsored meetings for 2015. Please visit the ECS website for a list of all sponsored meetings..

- **10th Symposio en Ciencia de Materiales Avanzados y Nanotecnología (Advanced Materials Science and Nanotechnology Symposium, SCiMAN)**, December 7-9, 2015 — San Jose, Costa Rica
- **66th Annual Meeting of the International Society of Electrochemistry**, October 4-9, 2015 — Taipei, Taiwan
- **16th International Conference on Advanced Batteries, Accumulators and Fuel Cells**, August 30-September 4, 2015 — Brno, Czech Republic

To learn more about what an ECS sponsorship could do for your meeting, including information on publishing proceeding volumes for sponsored meetings, or to request an ECS sponsorship of your technical event, please contact ecs@electrochem.org.

New Division Officer Slates

New officers for the fall 2015–fall 2017 term have been nominated for the following Divisions. All election results will be reported in the winter 2015 issue of *Interface*.

Electrodeposition Division

Chair

Elizabeth J. Podlaha-Murphy, Northeastern University

Vice-Chair

Stanko Brankovic, University of Houston

Secretary

Philippe Vereecken, IMEC/KULeuven

Treasurer

Natasa Vasiljevic, University of Bristol

Member-at-Large (one to be elected)

Ingrid Shao, IBM Corporation

New Member-at-Large (one to be elected)

Gerko Oskam, CINVESTAV-IPN

Luca Magagnin, Politecnico di Merida

High Temperature Materials Division

Chair

Turgut Gur, Stanford University

Vice-Chair

Greg Jackson, Colorado School of Mines

Jr. Vice-Chair

Paul Gannon, Montana State University

Secretary/Treasurer

Jason Nicholas, Michigan State University

Sean Bishop, Massachusetts Institute of Technology

Members-at-Large

Stuart Adler, University of Washington

Mark Allendorf, Sandia National Laboratories

Roberta Amendola, Montana State University

Timothy Armstrong, Carpenter Technology

Sean Bishop, Massachusetts Institute of Technology

Fanglin Chen, University of South Carolina

Zhe Cheng, Florida International University

Wilson Chiu, University of Connecticut

Kiochi Eguchi, Kyoto University

Emiliana Fabbri, Paul Scherrer Institut

Fernando Garzon, University of New Mexico

Robert Glass, Lawrence Livermore National Laboratory

Srikanth Gopalan, Boston University

Ellen Ivers-Tiffée, Karlsruhe Institute of Technology

Cortney Kreller, Los Alamos National Laboratory

Xingbo Liu, West Virginia University

Torsten Markus, Mannheim University of Applied Sciences

Toshio Maruyama, Tokyo Institute of Technology

Patrick Masset, Fraunhofer UMSICHT-ATZ

Nguyen Quang Minh

Mogens Mogensen, DTU Energy Conversion

Jason Nicholas, Michigan State University

Juan Nino, University of Florida

Elizabeth Opila, University of Virginia

Emily Ryan, Boston University

Subhash Singhal, Pacific Northwest National Laboratory

Enrico Traversa, King Abdullah University of Science & Technology

Anil Virkar, University of Utah

Eric Wachsman, University of Maryland

Werner Weppner, Christian-Albrechts University

Mark Williams, National Energy Technology Laboratory

Leta Woo, CoorsTek Sensors

Eric Wuchina, Naval Surface Warfare Center

Shu Yamaguchi, University of Tokyo

Harumi Yokokawa, University of Tokyo

Luminescence and Display Materials Division

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Madis Raukas, Osram Sylvania

Vice-Chair/ Secretary/Treasurer

Mikhail Brik, University of Tartu

Members-at-Large

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Baldassare Di Bartolo, Boston College

Uwe Happek, University of Georgia

Marco Kirm University of Tartu

David Lockwood, National Research Council – Canada

Kailash Mishra, Osram Sylvania

Alok Srivastava, GE Global Research Center

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Gregory Jackson, Jr. Vice-Chair
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Petr Vanýsek, Secretary
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Sensor

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Nianqiang Wu, Vice-Chair
Ajit Khosla, Secretary
Jessica Koehne, Treasurer

Future Meetings

2016

229th ECS Meeting
San Diego, CA
May 29-June 3, 2016
Hilton San Diego Bayfront &
San Diego Convention Center

IMLB 2016
Chicago, IL
June 19-24, 2016
Hyatt Regency Chicago

PRiME 2016
Honolulu, HI
October 2-7, 2016
Hawaii Convention Center &
Hilton Hawaiian Village

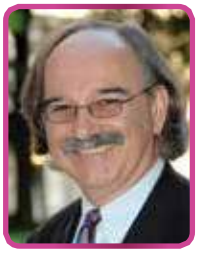
2017

231st ECS Meeting
New Orleans, LA
May 28-June 2, 2017
Hilton New Orleans Riverside

232nd ECS Meeting
National Harbor, MD
(greater Washington, DC area)
October 1-6, 2017
Gaylord National Resort
and Convention Center

ECS www.electrochem.org/meetings

ECS WELCOMES YOU TO PHOENIX



Welcome to Phoenix, Arizona! On behalf of the Board of Directors, volunteer leadership and staff of ECS, it is my pleasure to welcome you to the sunny city of Phoenix for the 228th ECS meeting. Our meeting, being held in downtown Phoenix, at both the Phoenix Convention Center and the Hyatt Regency, is an ideal location that offers convenient access to many of the city's attractions. We hope your time in Phoenix will give you an opportunity to network with colleagues, discuss important research, and discover new opportunities for collaboration.

Please join us for the Sunday Evening Get-Together at 1730h in the Hyatt Atrium to kick-off what is sure to be a successful week! Additionally, you won't want to miss the highly anticipated Plenary Session on Monday, October 12 at 1700h in the Hyatt Ballroom where we will wrap-up the first full day of the 228th ECS Meeting by welcoming all meeting attendees and recognizing the ECS Society Award recipients, and the **2015 Class of Fellows** before turning the spotlight over to Adam Heller, who will present **The ECS Lecture**, "Wealth, Global Warming, and Geoengineering." Dr. Heller is also the recipient of the ECS Europe Section Heinz Gerischer Award. The ECS Society Award recipients include Digby Macdonald receiving the **Olin Palladium Award**, and Martin Winter receiving the **Carl Wagner Memorial Award** and the **ECS Battery Division Research Award**. Be sure to take the time to attend the ECS Society, Division, and Section award talks in various symposia throughout the week. You can find further details in the technical program by using the ECS Meeting Scheduler.

This international conference includes more than 1,900 technical presentations, and features the **Fifth International ECS Electrochemical Energy Summit (E2S)**, which begins on Monday, October 12 at 0800h and runs through Wednesday, October 14. The E2S program is focused around Solar Critical Issues and Renewable Energy. The E2S sessions will be kicked off by Franklin (Lynn) M. Orr Jr., **U.S. Under Secretary for Science and Energy**, delivering the E2S keynote address at 0800h. The program on Monday will be focused on the DOE Hubs, featuring a Plenary and invited talks from the Joint Center for Energy Storage Research (JCESR), the Joint Center for Artificial Photosynthesis (JCAP), and the Energy Efficiency & Renewable Energy Fuel Cell Technologies Office (EERE FCTO). The program on Tuesday and Wednesday will include keynote talks from five Energy Frontier Research Centers (EFRC) Directors, and other relevant invited speakers, and round table discussions. *Learn more at* **www.elecrochem.org/e2s**.

In addition to the surplus of exciting technical presentations, we encourage you to take advantage of our educational short courses offered on Sunday, October 11, and our professional development sessions throughout the week, which are free of charge and provide essential information on enhancing career opportunities, résumé building, and networking. Finally, don't forget to stop by the dynamic exhibit hall where there is certainly no better way to network, or get to know the industry's leading innovators. In the exhibit hall, we have several exciting events planned including the student and general poster presentation receptions.

We encourage you to plan your schedule accordingly in order to make the most of the technical program and social events. The meeting program should be your guide to a productive and enjoyable time here in Phoenix. If you have any additional questions, please do not hesitate to stop by the ECS Registration desk in the Hyatt Atrium for further assistance. We thank you again for your continued support of ECS!

FEATURED EVENTS

MEETING EVENTS-AT-A-GLANCE

Sunday, October 11
0700h..... Registration Opens, Atrium
0800h..... Technical Sessions
(Check Technical Program for exact time)
0800h..... Short Course Breakfast, Regency B
0900h..... Short Courses Begin
1400h..... Professional Development Workshop: Part 1–Essential Elements for Employment Success, Suite 324
1730h..... Sunday Evening Get-Together, Atrium

Monday, October 12
0700h..... Registration Opens, Atrium
0700h..... Session Chair Orientation Breakfast, Sundance
0800h..... Professional Development Workshop: Part 1–Essential Elements for Employment Success, Suite 324
0800h..... E2S- ECS Electrochemical Energy Summit Keynote Address, 101-A&B&C (PCC)
0845h..... E2S – ECS Electrochemical Energy Summit Sessions Begin, 101-C (PCC)
0900h..... Technical Sessions
(Check Technical Program for exact time)
0930h..... Technical Session Coffee Break
1200h..... Professional Development Workshop: Part 2–Résumé Review, Suite 324
1410h..... Digby Macdonald's Olin Palladium Award Address, 102-A (PCC)
1500h..... E2S Breakouts 1 and 2 Begin, 106-B&C (PCC)
1700h..... Plenary Session and The ECS Lecture by Adam Heller, Regency Ballroom
1830h..... Student Mixer (invitation only), Atrium

Tuesday, October 13
0700h..... Registration Opens, Atrium
0800h..... Technical Sessions
(Check Technical Program for exact time)
0800h..... E2S – ECS Electrochemical Energy Summit: EFRC's, 101-C (PCC)
0800h..... Professional Development Workshop: Part 2–Résumé Review, Suite 324
0930h..... Technical Session Coffee Break
1245h..... Leveraging the Labs sponsored by the Fuel Cell Technologies Office, 213-A (PCC)
1300h..... Technical Exhibit, West Hall 1 (PCC)
1400h..... Matteo Bianchini's Battery Division Student Research Award Address, 106-B (PCC)
1400h..... David Shoesmith's Corrosion Division H. H. Uhlig Award Address, 102-A (PCC)
1430h..... Eric Schindelholz's Corrosion Division Morris Cohen Graduate Student Award Address, 102-A (PCC)
1650h..... Martin Winter's Carl Wagner Memorial and Battery Division Research Award Address, 106-B (PCC)
1730h..... Lab Showcase sponsored by the Fuel Cell Technologies Office, 2nd Floor Lobby (PCC)
1735h..... Adam Heller's Heinz Gerischer Award Address, 104-B (PCC)
1800h..... Technical Exhibit and General and Student Poster Session, West Hall 1 (PCC)

Wednesday, October 14
0800h..... Registration Opens, Atrium
0800h..... Technical Sessions
(Check Technical Program for exact time)
0800h..... E2S – ECS Electrochemical Energy Summit: EFRC's, 101-C (PCC)
0800h..... Professional Development Workshop: Part 2–Résumé Review, Suite 324
0800h..... Ashok Shukla's Battery Division Technology Award Address, 106-B (PCC)
0900h..... Technical Exhibit, West Hall 1 (PCC)
0930h..... Technical Session Coffee Break
1400h..... Daniel Schwartz's Electrodeposition Division Research Award Address, 103-A (PCC)
1500h..... Panel of Professionals: Career Exploration in Electrochemical and Solid State Science and Technology, Suite 318
1800h..... Technical Exhibit and General Poster Session, West Hall 1 (PCC)

Thursday, October 15
0800h..... Registration Opens, Atrium
0900h..... Technical Sessions
(Check Technical Program for exact time)
0900h..... Technical Exhibit, West Hall 1 (PCC)
0930h..... Technical Sessions Coffee Break

(PCC) This event will be held in the Phoenix Convention Center.

To get additional information on the 228th ECS meeting events, please visit **www.electrochem.org/228**.

PLENARY SPEAKER AND SOCIETY AWARD WINNERS

JOIN US FOR THE PLENARY SESSION

When: Monday, October 12 at 1700h
Where: Hyatt Regency Ballroom

ECS President **Dan Scherson** will wrap up the first full day of the 228th Meeting by welcoming the ECS meeting attendees and introducing the highly anticipated ECS lecturer, **Adam Heller**.

The Plenary Session is one of the highlight events of the meeting, allowing participants from every symposium to come together and recognize some of the greatest minds in the field. This year in addition to Dr. Heller's lecture "Wealth, Global Warming, and Geoengineering," the Olin Palladium Award will be presented to **Digby Macdonald** in recognition of his contributions to the development of the modern theory of passivity and passivity breakdown, in the form of the Point Defect Model (PDM), and in the development of the deterministic corrosion damage protocol, Damage Function Analysis (DFA). The Carl Wagner Memorial Award will be presented to **Martin Winter** for his highly prolific work, leadership, and important contribution to the fields of energy storage and conversion, development of unique electro-analytical tools, and spectro-electrochemical tools for fundamental studies related to power sources. The Norman Hackerman Young Author Award will be presented to **Nathaniel D. Leonard** for the paper, "Analysis of Adsorption Effects on a Metal-Nitrogen-Carbon Catalyst Using a Rotating Ring-Disk Study," in the *Journal of The Electrochemical Society* (JES, Vol. 161, No. 13, p. H3100). The Bruce Deal and Andy Grove Young Author Award will be presented to **Pengfei Guo, Ran Cheng,** and **Wei Wang** for the paper, "Silicon Surface Passivation Technology for Germanium-Tin P-Channel MOSFETs: Suppression of Germanium and Tin Segregation for Mobility Enhancement," in the *ECS Journal of Solid State Science and Technology* (JSS, Vol. 3, No. 8, p. Q162).

The **2015 Class of Fellows of The Electrochemical Society** will be recognized for their contributions to the advancement of science and technology, for leadership in electrochemical and solid state science and technology, and for active participation in the affairs of The Electrochemical Society: Simon Deleonibus, Raymond Gorte, Ellen Ivers-Tiffée, Deborah Jones, Robert Kostecki, Kailash Mishra, Mogens Mogensen, Emanuel Peled, E. Jennings Taylor, John Turner, and Steven Visco.

Don't miss the opportunity to honor and support your friends and colleagues. Also, be sure to use the meeting app to add the Society and Division and Section award winner's talks to your agenda, they are scheduled in various symposia throughout the week.

5 Questions for Adam Heller

Tell us about the beginning of your interest in science.
I went to—like all the young Israelis—to serve in the Israeli army. And at that time I was interested in a medical career. When I was in boot camp and they learned that I wanted to be a physician, they sent me to the medical corps to work in the pathology institute of a military hospital. There I very quickly discovered at the time, medicine was not yet science. And I saw—being in the pathology institute—mistakes. I decided that I'd rather be a scientist working toward better medicine.

When did you become involved in solar technology?
At GTE Labs, my colleague Heinz Gerischer was interested in electroluminescence. He was teaching me the elements of semiconductor electrochemistry and telling me that we can make a semiconductor liquid junction solar cell. At GTE, I couldn't do much work on these—my responsibilities were totally different and mostly lighting product related. I returned to Bell Laboratories in 1975 and then I really started to work seriously on the semiconductor liquid junction solar cells. And over five years we published a series of papers on efficient, more than 10 percent efficient, electrochemical solar cells.

Tell us about the development of the painless diabetes blood monitor.
People were pricking their fingers, getting large blood drops. It was painful: get a strip, touch it, get a blood sample, measure the glycemia (the blood glucose concentration). Five percent of the people of the world are diabetic. One percent of the people need these measurements. If they don't do it, they go blind, they lose their kidneys, they develop neuropathy, their legs are amputated. It can become a horrible disease, if they don't monitor their blood sugar. [My son] observed that if he pricks his skin in the arm, he can painlessly get a much smaller sample of blood. By pricking his finger, he got, painfully, a large drop of blood. So he asked me, "Can we make a sensor for such a small sample of blood?" I knew that it could be done if I used a small enough electrode.

What does the future of electrochemistry look like?
You see wonderful things in electrochemistry: shrinking down power sources, making electrical car batteries. Sooner or later we will have a long-lived, moderate temperature, high-power-density fuel cell that uses methane instead of hydrogen, followed by one that uses higher boiling hydrocarbons. I think in electrochemistry, that's the greatest challenge that I can imagine. I know that this will come. It's up to the next generation. So pretty soon—on a historical scale of 100 years—there's no question in my mind that we will drive liquid fuel-based fuel cell powered cars.

How was receiving the National Medal of Technology and Innovation?
It certainly was the highlight of my professional life—to be in the White House, to spend time with the president. And it's indeed pretty rare for an individual to get that medal. I feel that it is absolutely wonderful, considering that I come from Cluj, Romania, and passed through a concentration camp. Now that I was allowed to survive, I was honored by the president of the United States. What can I do next to pay Society for this? I am doing my best.

ecstransactions

Volume 69—Phoenix, Arizona

from the Phoenix meeting, October 11—October 15, 2015

The following issues of ECS Transactions are from symposia held during the Phoenix meeting. All issues are available in electronic (PDF) editions, which may be purchased by visiting http://ecsdl.org/ECST/. Some issues are also available in CD/USB editions. Please visit the ECS website for all issue pricing and ordering information. (All prices are in U.S. dollars; M = ECS member price; NM = nonmember price.)

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7/2/15

THE ECS LECTURE

When: Monday, October 12 at 1700h
Where: Hyatt Regency Ballroom

Wealth, Global Warming, and Geoengineering

by Adam Heller

Adam Heller's work in electrochemical engineering has touched the lives of people across the globe. As the inventor of the painless diabetes blood monitor, his developments in healthcare have had enormous societal and economic impact. Heller's work spans a range of technologies, touching areas related to battery and energy—including solar cells, the lithium battery, and photoelectrocatalysis.

Heller's journey through the sciences took flight in 1961, when he received his PhD from Ernest David Bergmann at the Hebrew University. From there, he had research related stints at such notable establishments as GTE Laboratories and Bell Laboratories, where he headed the Electronic Materials Research Department from 1977-1988.

His research soon transcended into teaching when he became a professor of engineering at the University of Texas in Austin. During this time, Heller invented what would be one of his most significant contributions to science—the painless blood glucose monitoring system.

It began in 1996 when Heller and his son Ephraim Heller founded TheraSense, which has transitioned to become a major part of Abbott Diabetes Care of Alameda, CA. Here, the FreeStyle™ system of TheraSense was developed, which made the monitoring of blood glucose painless by accurately monitoring the glucose concentration in just 300 nanoliters of blood.

Heller also established the field of the electrical wiring of enzymes (1988-2005), the electrical connection of their catalytic redox centers to electrodes and built, with wired enzymes subcutaneously implanted miniature glucose sensors, which became the core technology of the 2008 FreeStyle Navigator™ and of the 2014 FreeStyle Libre™. This continuous glucose monitoring system of Abbott Diabetes Care intended to replace the 16 billion annual strip assays requiring blood. Its disposable part is factory calibrated, requires no blood samples, and operates for two weeks.

His study of the physical chemistry of inorganic oxyhalide solutions resulted in the first neodymium liquid lasers (1964-1967) and in the publication of the first paper on the lithium thionyl chloride battery with James J. Auborn in 1973, which would be used in implanted medical and defense systems that required a shelf life of greater than 20 years or a higher than average energy density.

Similarly, Heller continued his research in energy by exploring solar cells, which resulted in 11.5% efficient solar cells in 1980 and in 11 % efficient hydrogen evolving photoelectrodes in 1981. Along with Heinz Gerischer, Heller was able to show that the rate of photo-assisted oxidation of organic matter on photocatalytic titanium dioxide particles was controlled by the rate of reduction of adsorbed oxygen by trapped electrons.

Heller has been recognized for his scientific achievements by some of the top establishments in the world. Most notably, he received the United States National Medal of Technology and Innovation in 2008—the top technology award in the U.S.

He has been recognized many times by The Electrochemical Society, including its David C. Grahame Award, Vittorio de Nora Gold Medal, and the Heinz Gerischer Award of its Europe Section. He is an ECS Fellow.

Among Heller's other awards and achievements are his induction to the U.S. National Academy of Engineering (2009) and the American Academy of Arts and Science (2009), Spiers Medal and Faraday Medal of the Royal Society of Chemistry UK, Fresenius Gold Medal of the Society of German Chemists, and the Torbern Bergman Medal of the Swedish Chemical Society—an award he shared with ECS Fellow Allen J. Bard.

PLENARY SPEAKER AND SOCIETY AWARD WINNERS

SOCIETY AWARDS

The ECS Society Awards being given during this meeting at the Plenary Session on Monday, October 12 at 1700h in the Hyatt Regency Ballroom are the Olin Palladium Award of The Electrochemical Society to Digby Macdonald, the Carl Wagner Memorial Award of The Electrochemical Society to Martin Winter, the Norman Hackerman Young Author Award to Nathaniel Leonard, and the Bruce Deal & Andy Grove Young Author Award to Pengfei Guo, Ran Cheng, and Wei Wang.

Olin Palladium Award of The Electrochemical Society

Monday, October 12, 1410-1450h
102-A Phoenix Convention Center

Some Critical Issues of the Breakdown of Passive Films
by Digby Macdonald

Digby D. Macdonald is currently a Professor in Residence at the University of California, Berkeley's Departments of Nuclear Engineering and Materials Science and Engineering. After obtaining his Bachelor's degree in New Zealand, Macdonald moved to Canada to receive his PhD in Chemistry from the University of Calgary.

Throughout his career, Macdonald has held numerous positions at Ohio State University and Pennsylvania State University. He has received many awards for his scientific work, including the 2014 Frumkin Memorial Medal from the International Society of Electrochemistry for his work on passivity and passivity breakdown. His work on the properties of aqueous solutions at high temperatures and pressures also earned him the 2013 Gibbs Award.

Additionally, ECS has presented Macdonald with the Wagner Memorial and Uhlig Awards. Aside from his ECS Fellowship, he also holds fellow status at NACE-International, Royal Society of Canada, Royal Society of New Zealand, ASM International, World Innovation Foundation, Institute of Corrosion, and International Society of Electrochemistry.

Carl Wagner Memorial Award of The Electrochemical Society

Tuesday, October 13, 1650-1730h
106-B Phoenix Convention Center

Anodes for Lithium Ion Batteries Revisited: From Graphite to High-Capacity Alloying- and Conversion-Type Materials and Back Again
by Martin Winter

Martin Winter has focused on R&D of new materials, components and cell designs for batteries and supercapacitors—in particular for lithium-ion batteries—for nearly 25 years. Currently, he holds a Chair for Applied Materials Science for Electrochemical Energy Storage and Conversion at the Institute of Physical Chemistry at Münster University, Germany.

Aside from his position at Münster University, Winter is the Director of the Münster Electrochemical Energy Technology (MEET) Battery Research Center. The center combines outstanding equipment with an international team of 140 scientists, engineers, and technicians. Winter has also been named Director of the new Helmholtz Institute Münster, as well as serving as an associate of the National Platform E-Mobility, where he consults the German chancellor and government.

Additionally, Winter is the head of the research council of the Battery Forum Germany, which advises the German Federal Ministry of Education and Research in the field of electrochemical energy storage. His strides in battery technology have yielded him much recognition, including ECS's Battery Technology Award and the Research and Technology Award of the International Battery Materials Association.

PLENARY SPEAKER AND SOCIETY AWARD WINNERS

2014 ECS YOUNG AUTHOR AWARDS

The Norman Hackerman Young Author Award was established in 1928 for the best paper published in the *Journal of The Electrochemical Society* for a topic in the field of electrochemical science and technology by a young author or authors. The Bruce Deal & Andy Grove Young Author Award, established in 2013, is being presented for the best paper published in the *ECS Journal of Solid State Science and Technology* for a topic in the field of solid state science and technology by a young author or authors.

Norman Hackerman Young Author Award

Awarded to Nathaniel D. Leonard for "Analysis of Adsorption Effects on a Metal-Nitrogen-Carbon Catalyst Using a Rotating Ring-Disk Study" (JES, Vol. 161, No. 13, p. H3100).

Nathaniel D. Leonard received his PhD in Chemical Engineering from Michigan State University under the supervision of Scott Calabrese Barton. Nathaniel's work focused on synthesis, characterization, and modeling of non-precious metal catalysts for oxygen reduction in proton-exchange membrane fuel cells. During his time at Michigan State University he was selected to be a Transatlantic Program Young Technology Leader in automotive research and development. He completed his undergraduate studies in Mechanical Engineering and German from Valparaiso University where he found his appreciation for electrochemistry while conducting high temperature electrolysis studies in molten salt electrolytes. He was also a German Academic Exchange Service (DAAD) undergraduate scholar. His research interests include electrode design and optimization for non-precious metal catalysts, modeling of transport phenomena in porous electrochemical systems, and rotating ring-disk electrode studies of metal-nitrogen-catalysts.

Bruce Deal & Andy Grove Young Author Award

Awarded to Pengfei Guo, Ran Cheng, and Wei Wang for "Silicon Surface Passivation Technology for Germanium-Tin P-Channel MOSFETs: Suppression of Germanium and Tin Segregation for Mobility Enhancement" (JSS, Vol. 3, No. 8, p. Q162).

Pengfei Guo received the Bachelor of Engineering (Electrical, first class honors) degree and the Doctor of Philosophy degree from the National University of Singapore (NUS), in 2008 and 2013, respectively. His PhD dissertation was focused on investigation of advanced transistors with low supply voltage, including tunneling field-effect transistors and high-mobility transistors. He has authored or co-authored over 40 journal and conference papers during his PhD study. He is now working in the Technology Development department in GLOBALFOUNDRIES, Singapore. Dr. Guo was a recipient of the Ministry of Education (Singapore) scholarship in 2003 and the NUS Graduate School scholarship in 2008.

Ran Cheng received the BEng (with honors) and PhD degrees in Electrical Engineering from National University of Singapore (NUS), Singapore. Her research interests include advanced strain engineering, Si, Ge, and GeSn transistors with advanced structures. She has authored and co-authored over 20 papers during her PhD study. She is now working as a research fellow in Zhejiang University in China. Dr. Cheng was awarded the Bachelor's scholarship from the Ministry of Education (Singapore, 2005-2009) and the fellowship from Zhejiang University (China, 2014-2016).

Wei Wang received the BS degree in Electronic Science and Technology from Huazhong University of Science and Technology, in 2006, and PhD degree in physical electronics from the Institute of Semiconductors, Chinese Academy of Sciences, in 2011. From 2011 to present, he is a Research Fellow in Department of Electrical and Computer Engineering, the National University of Singapore (NUS). His research interests are in semiconductor epitaxial growth, semiconductor devices and device physics.

PLENARY SPEAKER AND SOCIETY AWARD WINNERS

2015 CLASS OF FELLOWS

Established in 1989 for advanced individual technological contributions in the field of electrochemical and solid-state science and technology. These members are being recognized for contributions to the advancement of science and technology, for leadership in electrochemical and solid state science and technology, and for active participation in the affairs of The Electrochemical Society.

Simon Deleonibus began his career at Thomson Semiconductors, where he co-invented the contact/via plug technology principal in 1984. This technology is used today as a standard by the microelectronics industry in all integrated circuits produced worldwide. Deleonibus went on to join CEA Leti in 1986, where he currently serves as the Research Director. Here, he developed a recognized expertise on process modules like filed isolation, especially on Flash memories.

Earlier in his career, Deleonibus realized the world's smallest transistor at the Electronic Nanodevices Laboratory. During this time, he and his team pioneered numerous breakthrough process modules for future miniaturization of integrated circuits.

Among his many accomplishment, Deleonibus was awarded the IEEE Fellow award in 2006 for his "contributions to nanoscaled complementary metal oxide semiconductor (CMOS) devices technology." He has served as Associate Editor for *IEEE Transactions on Electronic Devices* (2008-2014) and the *European Physical Journal* (2008-2014). He has recently edited two books on nanodevices and integrated nanosystems and has been a Visiting Professor at the Tokyo Institute of Technology since 2014.

Raymond J. Gorte is currently the Russell Pearce and Elizabeth Crimian Heuer Professor of Chemical & BIomolecular Engineering—with a secondary appointment in Materials Science & Engineering—at the University of Pennsylvania. Since joining the university in 1981, Gorte's esteemed research has focused on electrodes for solid oxide fuel cells and the catalytic properties of core-shell materials. He is also known for his research on zeolite acidity and for metal-support effects, especially with ceria-supported precious metals, used in automotive emissions control.

Gorte is currently an Associate Editor of the *Journal of The Electrochemical Society* and has chaired numerous conferences, including the Gordon Conference on Catalysis (1998).

Among the many honors attributed to him, Gorte has received the Parravano Award of the Michigan Catalysis Society (1997), the Philadelphia Catalysis Club Award (1998), the Paul Emmett Award of the North American Catalysis Society (1999), the Penn Engineering Distinguished Research Award (2001), and the AIChE Wilhelm Award (2009).

Ellen Ivers-Tiffée has been a researcher in the field of functional ceramics for the energy sector for more than three decades, with her focus being on electrochemical energy storage and conversion devices. Currently, she heads the Institute of Applied Materials – Materials for Electrical and Electronic Engineering at Karlsruhe Institute of Technology in Germany. Previously, she has worked with such notable companies as Siemens AG, Corporate Research and Technology, and the Center of Applied Materials Research.

Her research aims at characterizing electrical/electrochemical reactions & transport processes, developing nanoscaled functional layers & interfaces and modelling/simulating materials properties in solid oxide fuel cells, lithium-ion batteries and oxygen-permeation membranes. Through her career, she has published 350 full research papers and conferences proceedings, as well as many book contributions including a German-language standard textbook on materials for electrical engineering.

Since joining ECS in 2003, Ivers-Tiffée has served in the High Temperatures Materials Division and is co-organizer of the ECS "Solid-Gas Electrochemical Interfaces" symposium. She is a member of many additional societies, including the German Academy of Science & Engineering.

Deborah Jones has been dedicated to innovation in fuel cell and electrolyzer materials for the past 20 years, introducing new concepts for fuel cell membrane compositions and architectures and contributed to understanding of membrane degradation mechanisms. Currently, she is the Full Senior Researcher of the French National Scientific Research Council and the Associate Director of the Institute for Molecular Chemistry and Materials, where she has co-authored more than 200 international journal articles and 17 review articles and book chapters.

Jones has been involved in collaborative research across Europe for many years, initiating the European Coordination Action on Membrane Electrode Assemblies and the biennial international CARISMA conferences on materials for medium and high temperature polymer electrolyte fuel cells. She has led several large European collaborative efforts, and is currently member of the European Fuel Cells and Hydrogen Joint Undertaking Scientific Committee.

Additionally, Jones has served as Senior Editor of the journal *Fuel Cells*, co-edited volumes of *ECS Transactions*, and was the co-organizer of the 2015 ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV.

Robert Kostecki is often recognized for his groundbreaking work in the field of electrochemical energy storage and conversion systems, photocatalysis, and water treatment technologies, which often helped bridge the gap between fundamental science and applications of significant technological importance. As a pioneer in advanced characterization of electrochemical interface in lithium-ion batteries, his research interests focus on fundamental interfacial phenomena that determine the function and performance of electrical energy storage systems, including degradation modes and failure mechanisms.

Among his many scientific achievements, Kostecki is most recognized for developing and deploying novel characterization methodologies, including *in situ* and *ex situ* optical far- and near-field spectroscopy and imaging techniques to probe basic properties of materials, interfaces and interphases at the atomic, molecular, and nanoparticulate levels.

Kostecki is currently a Senior Scientist in the Energy Storage and Distributed Resources Division at Lawrence Berkeley National Laboratory, where he contributes to areas of energy and environment through research initiatives and partner relationships. Additionally, he has served as officer and Chair of the ECS San Francisco Section and he is currently Chair of the Battery Division of ECS.

PLENARY SPEAKER AND SOCIETY AWARD WINNERS

Kailash C. Mishra is engaged in the research and development of luminescent materials, working in close collaboration with various phosphor research groups, as well as within academia and national labs. Currently, he is the Head of Technology Scouting of Osram Corporate Innovation at Central Research and System Laboratories of Osram Sylvania.

Mishra's area of expertise includes theory of electronic structures and associated properties of materials, theory of luminescence, and optical and luminescence properties of III-V semiconducting materials. He has published extensively on luminescence of solids, and on the electronic structures and associated properties of atoms, molecules, metals, semiconductors and ionic crystals.

Since joining ECS in 1998, Mishra has served as Chair of the ECS Luminescence and Display Materials Division, co-organized several ECS symposia, and co-edited multiple volumes of *ECS Transactions*. Additionally, he is currently one of the technical editors of the *ECS Journal of Solid State Science and Technology* and *ECS Solid State Letters*.

Mogens Mogensen's research focuses on electrochemistry, materials science, solid and liquid electrolytes, electrochemical kinetics, electrolysers, reversible fuel cells, and energy conversion and storage. He is currently a professor at the Technical University of Denmark's Department of Energy Conversion and Storage. In addition to his involvement in academia, Mogensen has been involved in electrochemistry research and development for 42 years, continuously leading Danish and European electrochemical projects.

Mogensen has co-authored more than 350 scientific papers, of which over 200 were published in international refereed journals. He has participated in a large number of international conferences and given more than 40 invited talks, some of which were keynote and plenary talks.

Throughout his career in academia, he has supervised over 10 Master students, more than 20 PhD students, and approximately 25 postdoctoral researchers. Among his many honors, Mogensen has received the Christian Friedrich Schönbein Medal of Honour in 2008 and the Science of Hydrogen & Energy Award in 2012.

Emanuel Peled is known among the scientific community as the inventor and developer of the solid electrolyte interphase (SEI) model for nonaqueous alkali-metal batteries. His in-depth exploration of batteries has allowed him to develop unique state of charge meter (residual capacity) for lithium batteries in his laboratory that was manufactured by a startup company Chemtronics, for which he was a co-founder. While here, he and his team also developed high power hydrogen bromine fuel cells, direct methanol and direct ethylene glycol fuel cells with world record power.

Peled is also a co-founder of EnStorage, a startup company aimed at the development and commercialization of very large energy storage systems based on regenerative fuel cell and a co-founder of a start-up company (Honeycomb) aimed at the development and commercialization of a novel 3D lithium battery. He has since broadened his industrial roots and delved into academia, joining the staff at Tel Aviv University's School of Chemistry as an emeritus professor.

ECS's Battery Division has previously awarded Peled their Research Award for his outstanding achievements in the field of energy.

E. Jennings (EJ) Taylor's 35 year career in industrial electrochemistry has been focused on developing innovative electrochemical technologies both as an "intrapreneur" while employed at corporate R&D laboratories and as an entrepreneur at Faraday Technology. As Faraday Technology's Founder and Chief Technical Officer, his approach to technology development is based on a careful balance between fundamental understandings combined with the rational acceptance of evolving observations that do not necessarily fit the current electrochemical paradigm. Taylor has created a culture at Faraday that encourages teamwork across a variety of science and engineering disciplines, to enable technology development from conception to beta-scale demonstration.

Taylor's involvement with ECS over the years has been immense, serving on many committees and co-organizing numerous symposia. Currently, he serves as ECS's Treasurer.

Taylor has over 190 publications and is a recipient of the 2008 Blum Scientific Achievement Award of the National Association of Surface Finishers based on Faraday Technology's Contributions to the field of pulse/pulse reverse electrolytic surface finishing. In conjunction with a team from Faraday Technology, Taylor also received a 2013 Presidential Green Chemistry Challenge Award for electrodeposition of functional chromium coatings from a trivalent electrolyte.

John A. Turner started his scientific career working on sodium and potassium amalagam batteries as an undergraduate student at Idaho State University. Throughout his academic career, he worked with such pillars of electrochemistry as Bob and Janet Osteryoung, Fred Anson, and Heinz Gerischer.

Upon joining the National Renewable Energy Laboratory in 1979—where he is currently a Research Fellow—Turner began to work on photoelectrochemical water splitting for hydrogen production. His research topics include the direct conversion (photoelectrolysis) systems for hydrogen production from sunlight and water, catalysts for the hydrogen and oxygen reactions, materials for advanced fuel cell membranes, and corrosion studies of fuel cell metal bipolar plates. Other work involves the study of electrode materials for high energy density lithium batteries and fundamental processes of charge transfer at semiconductor electrodes

Turner has co-authored over 160 peer-reviewed publications in the areas of photoelectrochemistry, fuel cells, batteries, general electrochemistry and analytical chemistry. He has received a multitude of awards, including the Midwestern Research Institute President's Award for Exceptional Performance in Research and the Hydrogen Technical Advisory Panel Award for Research Excellence.

Steven Visco is currently the Founder and Chief Executive Officer of PolyPlus Battery Company, which he co-founded in 1991 to research and develop next generation batteries. Visco's company was selected by TIME magazine in its "50 Best Inventions" issue, as well as awarded the Gold Edison Award in 2012.

Aside from his role at PolyPlus Battery Company, Visco also serves as a Guest Scientist in the Materials Science Division at the Lawrence Berkeley National Laboratory, where his research interests have included advanced batteries and fuel cells. He currently holds 103 U.S. patents, more than 200 international patents, and has authored over 70 publications.

His immense impact in battery technology and industry has yielded Visco the City of Berkeley's Visionary Award. Additionally, he was awarded the 2011 International Battery Association Award for "outstanding contributions to the development of lithium-air and lithium-water batteries."

DIVISION & SECTION AWARD WINNERS

Take the time to honor and support your friends and colleagues, be sure to add the Division and Section award winners' talks to your calendar, they are scheduled in various symposia throughout the week.

ECS Battery Division Student Research Award

Tuesday, October 13, 1400-1440h
106-B Phoenix Convention Center

Real-time Diffraction Studies of Electrode Materials for Li-ion and Na-ion Batteries
by Matteo Bianchini

Matteo Bianchini began his scientific career at the Polytechnic University in Milan, where he obtained his Bachelor's degree (2009) and Master of Science (2012) in Physics Engineering. During this time, he had many transformative experiences in the sciences, including a semester spent at the University of Amsterdam in 2010 as part of the Erasmus Programme.

Bianchini's PhD focused on advanced characterization of electrode materials for lithium-ion and sodium-ion batteries in a shared program among three French institutions: the Institut Laue-Langevin (ILL, Grenoble), the Laboratoire de Réactivité et de Chimie de Solides (LRCS, Amiens) and the Institut de Chimie de la Matière Condensée (ICMCB, Bordeaux). Research focuses primarily on real-time (operando) diffraction experiments using neutrons, x-rays, and synchrotron radiation to student lithium and sodium (de)intercalation processes inside rechargeable batteries. Through the collaboration, Bianchini has been able to access different domains of electrochemical and diffraction fields.

ECS Corrosion Division H. H. Uhlig Award

Tuesday October 13, 1400-1430h
102-A Phoenix Convention Center

Application of Electrochemistry in the Development of Performance Assessment Models for High Level Nuclear Waste Disposal
by David Shoesmith

David Shoesmith's research interests cover a wide range of areas in corrosion science and engineering, with an emphasis on electrochemical and surface analytical methods, the development of techniques to analyze corroding surfaces, and the development of deterministic and probabilistic models to describe and predict corrosion performance. After a 25 year career at Atomic Energy of Canada Limited's Whiteshell Laboratories, Shoesmith moved to the University of Western Ontario where he currently holds the position of Canadian Natural Science and Engineering Research Council/Nuclear Waste Management Organization Industrial Research Chair.

Shoesmith has a substantial body of work with over 290 journal articles and refereed conference proceedings published, including 27 book chapters and review articles, and approaching 150 commercial and company reports.

His main research area of focus shows an emphasis on corrosion issues (containers, wasteforms) related to the storage and disposal of high level nuclear waste. Outside of this area, he has funded research programs in the areas of gas transmission pipelines, the automotive industry and a fundamental research grant to investigate the basic science

ECS Corrosion Division Morris Cohen Graduate Student Award

Tuesday, October 13, 1430-1500h
102-A Phoenix Convention Center

Impact of Salt Deliquescence on the Humidity-Dependence of Atmospheric Corrosion
by Eric Schindelholz

Eric Schindelholz is a senior member of technical staff at Sandia National Laboratories. He received his PhD in Materials Science at the University of Virginia in 2014 under the direction of Professor Robert Kelly. His graduate work focused on understanding the interrelationship between the hygroscopic behavior of marine atmospheric particles and the humidity dependence of steel corrosion associated with these particles.

Prior to his studies, Schindelholz served as a conservator in both federal and private institutions, specializing in the corrosion assessment and mitigation of historic artifacts and monuments.

His present work includes electrochemical measurement and modeling of atmospheric corrosion, corrosion in supercritical fluids and advanced materials.

ECS Battery Division Research Award

Tuesday, October 13, 1650-1730h
106-B Phoenix Convention Center

Anodes for Lithium Ion Batteries Revisited: From Graphite to High-Capacity Alloying- and Conversion-Type Materials and Back Again
by Martin Winter

Martin Winter has focused on R&D of new materials, components and cell designs for batteries and supercapacitors—in particular for lithium-ion batteries—for nearly 25 years. Currently, he holds a Chair for Applied Materials Science for Electrochemical Energy Storage and Conversion at the Institute of Physical Chemistry at Münster University, Germany.

Aside from his position at Münster University, Winter is the Director of the Münster Electrochemical Energy Technology (MEET) Battery Research Center. The center combines outstanding equipment with an international team of 140 scientists, engineers, and technicians. Winter has also been named Director of the new Helmholtz Institute Münster, as well as serving as an associate of the National Platform E-Mobility, where he consults the German chancellor and government.

Additionally, Winter is the head of the research council of the Battery Forum Germany, which advises the German Federal Ministry of Education and Research in the field of electrochemical energy storage. His strides in battery technology have yielded him much recognition, including ECS's Battery Technology Award and the Research and Technology Award of the International Battery Materials Association

DIVISION & SECTION AWARD WINNERS

ECS Europe Section Heinz Gerischer Award

Tuesday October 13, 1735-1815h
104-B Phoenix Convention Center

A Perspective of Photoelectrochemistry: Past Expectations and Present Realities
by Adam Heller

Adam Heller's work in electrochemical engineering has touched the lives of people across the globe. As the inventor of the painless diabetes blood monitor, his developments in healthcare have had an enormous societal and economic impact. Heller's work spans a range of technologies, touching areas related to battery and energy—including solar cells, the lithium battery, and photoelectrocatalysis.

Heller's innovation and research has impacted both industry and academia. He began his career with such notable companies as GTE Laboratories and Bell Laboratories, where he headed the Electronic Materials Research Department. He transitioned into academia soon after when he joined the staff at the University of Texas in Austin. During this time, Heller invented what would be one of his most significant contributions to science—the painless blood glucose monitoring system.

Aside from this development, Heller's research also resulted in the first paper on the lithium thionyl chloride battery, which would be used in implanted medical and defense systems that required a shelf life of greater than 20 years or a higher than average energy density. Additionally, his early work in solar resulted in 11.5% efficient solar cells in 1980 and in 11 % efficient hydrogen evolving photoelectrodes in 1981. These achievements and many others earned him the U.S. National Medal of Technology and Innovation in 2008.

ECS Battery Division Technology Award

Wednesday, October 14, 0800-0840h
106-B Phoenix Convention Center

Lead-Carbon Ultracapacitors: How, Why, and Where Is the Technology
by Ashok Shukla

Ashok Shukla's creative, interdisciplinary, and cutting-edge research has made extensive fundamental and applied contributions to the fields of storage batteries, fuel cells, and supercapacitors. In particular, his research works on novel electrocatalysts, lithium-ion cathodes/anodes, lead-carbon ultracapacitors, nickel-iron batteries, and tropical lead-acid batteries are truly path breaking.

As the current Honorary Professor at Indian Institute of Science, Bangalore, Shukla has pioneered work in electrochemical storage science and technology. His research has also been actively engaged in innovative engineering of self-supported polymer electrolyte, direct methanol and direct borohydride fuel cell systems.

Shukla is a member of many editorial advisory boards of several international journals. Among his many honors, Shukla also been named fellow of the Indian National Science Academy, Indian National Academy of Engineering, National Academy of Sciences India, India Academy of Sciences, and The International Society of Electrochemistry.

ECS Electrodeposition Division Research Award

Wednesday October 14, 1400-1440h
103-A Phoenix Convention Center

The Scanning Bipolar Cell: Design Principles for Patterning of Diverse Metals without Contact to the Substrate
by Daniel Schwartz

Daniel T. Schwartz's interest in chemical engineering was first kindled in the mid-1980s when he began working for the Silicon Valley start-up Cybernex Corporation. He then transitioned from industry to a national lab setting when he joined the team at Lawrence Berkeley National Laboratory for his postdoc.

In 1991, Schwartz joined the University of Washington as an assistant professor, where he founded the Electrochemical Materials and Interfaces Laboratory. Schwartz still resides at the University of Washington where he now holds the position of Boeing-Sutter Professor of Chemical Engineering and Director of the Clean Energy Institute. Here, his students combine electrochemical fundamentals and engineering principles to understand, design, and improve a wide range of electrochemical systems.

He has served the ECS as Chair of the Electrodeposition Division, Chair of the Council of Sections, and as a member of several other committees. Select honors include the University of Washington Marsha Landolt Distinguished Graduate Mentor Award and ECS's Henry B. Linford Award.

ELECTROCHEMICAL ENERGY SUMMIT 2015

SOLAR CRITICAL ISSUES AND RENEWABLE ENERGY

October 12-14, 2015

With population growth and industrialization, global energy needs continue to grow as well. Economic, political, and environmental issues are largely dictated by energy needs. The **Fifth International ECS Electrochemical Energy Summit (E2S)** is designed to foster an exchange between leading policy makers and energy experts about society needs and technological energy solutions.

The E2S program will be focused around Solar Critical Issues, and Renewable Energy. It will begin on **Monday, October 12** and run **through Wednesday, October 14, 2015**. The program on Monday will be focused on the DOE Hubs, featuring a keynote address, and invited talks from the Joint Center for Energy Storage Research (JCESR), the Joint Center for Artificial Photosynthesis (JCAP), and the Energy Efficiency & Renewable Energy Fuel Cell Technologies Office (EERE FCTO). The program on Tuesday and Wednesday will include keynote talks from five Energy Frontier Research Centers (EFRC) Directors, relevant invited speakers, and round table discussions.

ORGANIZERS

- Daniel Scherson, Case Western Reserve University
- Adam Weber, Lawrence Berkeley National Laboratory
- Krishnan Rajeshwar, University of Texas, Arlington

KEY PARTICIPANTS

David Wesolowski
Oak Ridge National Laboratory

The Fluid Interface Reactions, Structures and Transport (FIRST) Energy Frontier Research Center

The overarching goal of the FIRST Center, which is in its sixth year of operation, is to develop fundamental understanding and validated, predictive models of the unique nanoscale environment at fluid-solid interfaces, that will enable transformative advances in electrical energy storage and electrocatalysis.

In order to achieve our goal, we integrate novel substrate and electrolyte synthesis and characterization, advanced electron (TEM) and scanning probe microscopies (SPM), neutron and X-ray scattering, and multiscale computational modeling ranging from quantum Monte Carlo to classical density functional theory approaches. Electrolytes investigated include aqueous, polar organic and room temperature ionic liquids (RTILs), representing increasing cost and electrochemical stability, and decreasing viscosity, competing factors in device performance.

Our recent efforts have focused on predicting the functionality of interfacial systems for capacitive and pseudocapacitive electrical energy storage in microdevice to grid scale applications.

M. Stanley Whittingham
Binghampton University

NorthEast Center for Chemical Energy Storage (NECCES)

The mission of the NorthEast Center for Chemical Energy Storage (NECCES) is to develop an understanding of how key electrode reactions occur, and how they can be controlled to improve electrochemical performance, from the atomistic level to the macroscopic level throughout the life-time of the operating battery.

The processes that occur in batteries are complex, spanning a wide range of time and length scales. The team of experimentalists and theorists will make use of, and develop new methodologies to determine how model compound electrodes function in real time, as batteries are cycled.

The specific goals of NECCES are to close the gap between the realized and the theoretical energy density for intercalation compounds, to attain reversible multi-electron transfer in a cathode material using lithium, and to understand performance limiting transport in positive electrode structures from the local through the meso to the macroscale.

Gary Rubloff
University of Maryland

Nanostructures for Electrical Energy Storage (NEES) Energy Frontier Research Center

NEES seeks to understand the electrochemical behavior of nanostructures, particularly in dense mesoscale architectures, for their use in energy storage: how to precisely control the multiple components of the nanostructures; how to densely pack and connect them to optimize their performance; how they behave–individually and collectively–during charging and discharging, and why; and how to make them safe and long-lasting over thousands of charging cycles.

With its past achievements creating and characterizing precise multi-component (heterogeneous) nanostructures, NEES now focuses on four areas: (1) understanding and controlling interfaces in storage nanostructures; (2) revealing new mesoscale challenges which dense assemblies of nanostructures pose, and the correlation of these architectures with electrochemical performance and degradation; (3) identifying the fundamental degradation mechanisms which accompany storage nanostructures and architectures; and (4) pursuing advances in the synthesis and characterization of 3D nanostructured solid state storage configurations.

Esther Takeuchi
Stony Brook University

The Center for Mesoscale Transport Properties, m2M, (molecular to mesoscale)

Understanding the underlying ionic and electronic conduction phenomena is needed to further improve energy storage systems in order to bridge the gap between theoretical and achievable values.

During the operation of an energy storage system, ions and electrons are transported over multiple size domains where the sum of these processes leads to complex physics. Exploration of local conduction and transport phenomena is needed, encompassing investigations from the molecular to nano to mesoscale.

The vision of the m2M center is to minimize heat and maximize work of electrical energy storage devices. The center will accomplish this through understanding and ultimately controlling transport properties in complex battery systems with respect to multiple length scales. Redox active materials from several families are under investigation including 1D, 2D, and 3D structures. Further, the influences of the electrode environment as well as the battery system on the electrochemical performance are key considerations.

Paul Fenter
Argonne National Laboratory

Center for Electrochemical Energy Science (CEES)

CEES seeks to develop a fundamental understanding of the lithium ion electrochemistry of oxides in lithium ion battery systems, through coordinated studies of three types of chemistries with a focus on model materials: Li ion insertion reactions, Li ion conversion reactions, and Li-O_2/Li-ion hybrid reactions.

One broad theme in these studies is the role of interfaces in these reactions and I will also summarize recent work in which we seek to isolate and understand the role of interfacial reactivity in these systems using X-ray based approaches (e.g., X-ray reflectivity).

Harry Atwater
Director JCAP

Joint Center for Artificial Photosynthesis-Progress and Prospects (JCAP)

JCAP is pioneering revolutionary methods of synthesizing transportation fuels simply by combining three of Earth's most abundant resources: carbon dioxide, water, and sunlight.

The goal is to generate liquid hydrocarbon or alcohol fuel products whose heating value equals or exceeds that of methanol, using selective and efficient chemical pathways.

The grand challenge at the heart of solar fuels production is controlled catalysis. Over the last five years, JCAP made significant advances in solar-driven catalytic production of hydrogen from water - but as yet there remains no known catalyst, whether electrochemical or photoelectrochemical, which can reduce carbon dioxide with high efficiency and selectivity under mild conditions.

To tackle CO_2 reduction, JCAP's efforts are aligned along four fronts: experimental and theoretical discovery of fundamental electrocatalysis mechanisms and materials, experimental and theoretical discovery of photocatalysts and light absorbers, systems integration, and testbed prototyping.

George Crabtree
Director JCESR

The Joint Center for Energy Storage Research (JCESR)

The Joint Center for Energy Storage Research (JCESR) seeks to establish next-generation electricity storage through a new research paradigm that unites discovery science, battery design, research prototyping, and manufacturing collaboration.

JCESR focuses exclusively on beyond-lithium-ion batteries. Its vision is to transform transportation and the electricity grid with high performance, inexpensive electricity, storage that enables widespread deployment of electric cars, broad penetration of wind and solar electricity and breaks the century-old constraint of matching instantaneous electricity generation with instantaneous electricity demand. Its mission is to deliver two prototypes, one for transportation and one for the grid, which when scaled to manufacturing are capable of delivering five times the energy density at one-fifth the cost of the commercial batteries available at its launch in 2012.

JCESR intends to leave three legacies: a library of fundamental science of the materials and phenomena of energy storage at atomic and molecular levels; two prototypes, one for transportation and one for the grid, that when scaled to manufacturing are capable of meeting JCESR's aggressive performance and cost targets; and a new paradigm for battery research and development that integrates discovery science, battery design, research prototyping, and manufacturing collaboration.

Franklin (Lynn) M. Orr, Jr.
Oak Ridge National Laboratory

U.S. Under Secretary for Science and Energy

Franklin (Lynn) M. Orr was sworn in as the Under Secretary for Science and Energy on December 17, 2014.

As the Under Secretary, Dr. Orr is the principal advisor to the Secretary and Deputy Secretary on clean energy technologies and science and energy research initiatives.

Dr. Orr is the inaugural Under Secretary for the office, which was created by Secretary of Energy Ernest Moniz to closely integrate DOE's basic science, applied research, technology development, and deployment efforts. As Under Secretary, he oversees DOE's offices of Electricity Delivery and Energy Reliability, Energy Efficiency and Renewable Energy, Fossil Energy, Indian Energy Policy and Programs, Nuclear Energy, and Science. In total, these programs steward the majority of DOE's National Laboratories (13 of 17).

ELECTROCHEMICAL ENERGY SUMMIT 2015

PROGRAM

The full technical program can be viewed online, and within the meeting scheduler. Unless noted otherwise, all E2S events take place in room 101-C (PCC).

Monday, October 12, 2015

0800h-0845h.....Electrochemical Energy Summit Keynote Address, 101-AB&C (PCC)

Speaker: U.S. Under Secretary for Science and Energy, F. (Lynn) M. Orr Jr.

Chair: D. Scherson

0845h-0955h.....Electrochemical Energy Summit Session 1–JCESR Talks

Speakers: G. Crabtree, K. R. Zavadil, F. R. Brushett

Chair: D. Scherson

1005h-1125h.....Electrochemical Energy Summit Session 2–JCAP Talks

***Speakers*:** H. A. Atwater, M. T. McDowell, I. D. Sharp

Chair: K. Rajeshwar

1135h-1300h.....Electrochemical Energy Summit Session 3–Industry Talks

Speaker: S. Satyapal

Chair: A. Z. Weber

1245h-1400h.....Leveraging the Labs: This session will demystify the process of working with national labs and discuss the mechanisms put in place to put labs to work on industry problems,
213-A (PCC)

1500h-1600h.....Electrochemical Energy Summit Breakout Session 1: Public-Private Partnerships for Research and Development

Chair: J. P. Chamberlain

1500h-1600h.....Electrochemical Energy Summit Breakout Session 2: Team Science

Chair: G. Crabtree

1730h-1800h.....Lab Showcase: The second session, during the Business-2-Business Product Theater, will highlight technologies developed at the national labs, their unique capabilities, and opportunities for collaboration,
2nd Floor Lobby (PCC)

Tuesday, October 13, 2015

0800h-1010h.....Electrochemical Energy Summit Session 4–EFRC Talks

Speakers: P. Fenter, A. C. Marschilok, C. Lian, K. W. Chapman, C. Wang

Chair: E. S. Takeuchi

1030h-1220h.....Electrochemical Energy Summit Session 5–EFRC Talks

Speakers: G. W. Rubloff, A. A. Gewirth, J. Come, S. Meng

Chair: D. J. Wesolowski

1400h-1550h.....Electrochemical Energy Summit Session 6–EFRC Talks

Speakers: M. S. Whittingham, Y. Wang, A. Ulysal, J. W. Elam

Chair: P. Fenter

Wednesday, October 14, 2015

0800h-1010h.....Electrochemical Energy Summit Session 7–EFRC Talks

Speakers: E. S. Takeuchi, M. Beidaghi, H. Iddir, K. Leung, L. F. J. Piper

Chair: G. W. Rubloff

1030h-1220h.....Electrochemical Energy Summit Session 8–EFRC Talks

Speakers: D. J. Wesolowski, S. P. Ong, A. A. Talin, M. K. Y. Chan

Chair: M. S. Whittingham

(PCC) This event will be held in the Phoenix Convention Center.

The Electrochemical Society

electrochemical energy summit 2015

Featuring Hydrogen Fuel Cells

Sponsored by the Fuel Cell Technologies Office

Phoenix Convention Center, Phoenix, AZ

PLENARY SPEAKER

Monday, October 12, 2015 at 0800h

Lynn Orr
Under Secretary for Science and Energy
U.S. Department of Energy

DOE EERE LAB TECH TO MARKET SHOWCASE

LEVERAGING NATIONAL LAB CAPABILITIES TO SOLVE INDUSTRY PROBLEMS

TUESDAY, OCTOBER 13

On Tuesday, October 13, join us at these two one-day-only events to increase collaboration between national labs and industry:

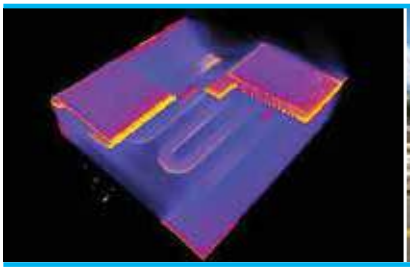
LEVERAGING THE LABS | 1245-1400h

The first session will demystify the process of working with national labs and discuss the mechanisms put in place to put labs to work on industry problems.

LAB SHOWCASE | 1730-1800h

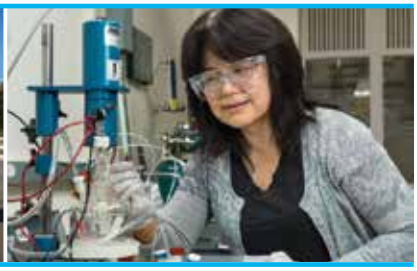
The second session, during the Business-2-Business Product Theater, will highlight technologies developed at the national labs, their unique capabilities, and opportunities for collaboration.

Following presentations from each lab, representatives will be available in the room to further discuss their industrial solutions.



3-D X-ray Tomography of a mixed-potential hydrogen sensor at LANL. Sensor response is controlled by the kinetics of the electrode reactions occurring at the gas-electrode-electrolyte interface.

NREL has received four Fuel Cell Hybrid Vehicles—Advanced (FCHV-adv) on loan from Toyota, enhancing their research capabilities related to hydrogen fueling infrastructure.



Xiaoping Wang of Argonne National Laboratory prepares a cell for testing the activity of fuel cell catalysts.

U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

EERE-funded research has:

- Reduced cost of fuel cells by more than 50% since 2006 and 30% since 2008
- Achieved a more than five-fold reduction in the platinum content of fuel cells
- Led to more than 500 patents, 45 commercial technologies, and 65 emerging technologies that will be commercialized in the next 3-5 years
- http://energy.gov/eere/fuelcells/downloads/2014-pathways-commercial-success-technologies-and-products-supported-fuel

www.energy.gov/eere/fuelcells

228TH MEETING EXHIBITORS & SPONSORS

TECHNICAL EXHIBIT

The ECS Technical Exhibit is always the talk of the meeting—technical exhibits are popular networking opportunities, as attendees gather together with colleagues and meet new contacts. The exhibitors in Phoenix will provide demonstrations and showcase instruments, materials, systems, publications, and software, as well as other products and services. Complimentary coffee breaks are scheduled on Wednesday and Thursday at 0930h in the Exhibit Hall. In addition, the Poster Sessions and receptions will be held in the Exhibit Hall on Tuesday and Wednesday evenings, beginning at 1800h. **The Exhibit Hall will be located in West Hall 1 in the Phoenix Convention Center.**

EXHIBIT HOURS

Tuesday, October 13, 2015

0800-1300h ..... Exhibitor Move-In
1300-1600h ..... Technical Exhibit
1800-2000h ..... Technical Exhibit, General & Student Poster Session

Wednesday, October 14, 2015

0900-1400h ..... Technical Exhibit
0930-1000h ..... Coffee Break in Exhibit Hall
1800-2000h ..... Technical Exhibit & General Poster Session

Thursday, October 15, 2015

0900-1200h ..... Technical Exhibit
0930-1000h ..... Coffee Break in Exhibit Hall
1200-1600h ..... Technical Exhibit Tear Down

EXHIBITORS

Asahi/America, Inc.

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The Department of Energy Fuel Cell Technologies Office

Booth 401

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www.energy.gov/eere/fuelcells

The U.S. Department of Energy's Fuel Cell Technologies Office is a comprehensive portfolio of activities that address the full range of barriers facing the development and deployment of hydrogen and fuel cells with the ultimate goals of decreasing our dependence on oil, reducing carbon emissions, and enabling clean, reliable power generation.

ECOTEC Solutions, Inc.

Booth 403

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As the leader in gas and humidity analysis equipment for PEM fuel cell testing, greenhouse gas measurement at landfills, and many other applications, **ECOTEC** continues to provide innovative solutions with superior service and support. The ECOTEC HS-1000 solves the challenges of accurately measuring humidity levels in fuel cell gas conditions.

El Cell

Booth 116

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ESL ElectroScience

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ESL ElectroScience specializes in providing solutions to enable customers to take technologies from concept through high volume production using thick film pastes and ceramic tapes. ESL products can be found in hybrid microcircuits, multilayer microelectronics, transformers, thick film heaters, sensors, and fuel cells. For more information visit us at www.electroscience.com

Gamry Instruments

Booths 100 & 102

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Booths 200 & 202

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Ivium Technologies designs electrochemical instrumentation for the most demanding experiments. We are demonstrating the new CompactStat.h™ and IviumStat.h™ Potentiostats with 24-bit resolution. We're also exhibiting the Vertex™ Potentiostat for labs on a budget, the nStat™ MultiChannel Potentiostat with up to 16 potentiostats, and the handheld pocketSTAT™ Potentiostat for portability.

(continued on next page)

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Exhibitors
(continued from previous page)

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Maccor manufactures testing equipment for the battery and energy storage market (i.e. batteries, capacitors, fuel cells, etc.). Maccor Inc. was the pioneer, and is the world's largest commercial manufacturer for this type of equipment. More companies rely on Maccor every day for their battery and cell test equipment needs. Today Maccor has thousands of systems in operation in more than 50 countries.

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MTI Corporation

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Netzsch Instruments NA LLC

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NETZSCH offers calorimeters and thermal analysis instruments for battery characterization, from component level to full cell. Adiabatic, accelerating rate, scanning, and isothermal battery calorimeters for thermal safety studies and hazard screening including during battery charge & discharge. Featuring the new MMC 284 Coin Cell Calorimeter plus DSC, TGA, STA (Simultaneous DSC-TGA) with coupling to FTIR, MS, and GC-MS to analyze evolved gases, thermal expansion by TMA, and also thermal conductivity by the Laser Flash technique.

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PalmSens BV

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PalmSens was the first company producing research grade potentiostats in pocket size. The PalmSens3 is one of the most compact frequency response analyzers (EIS capable devices) in the market. We also developed the first Android App to control a potentiostat. PalmSens makes electrochemistry more accessible for novice and advanced researchers.

Pine Research Instrumentation

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Princeton Applied Research/Solartron Analytical

Booths 302 & 304

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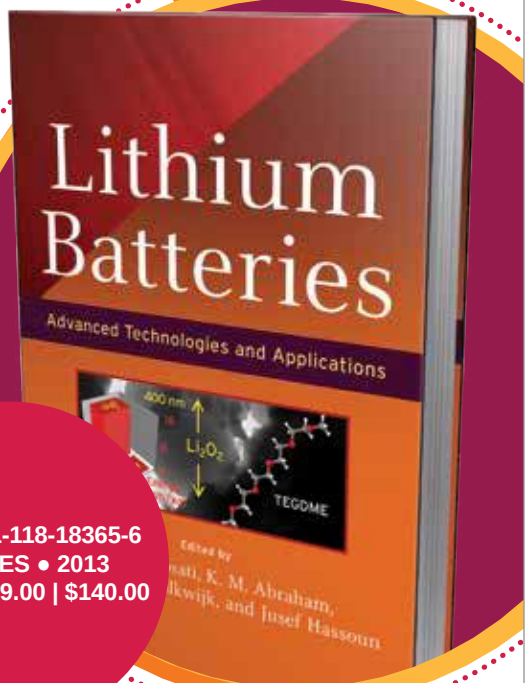

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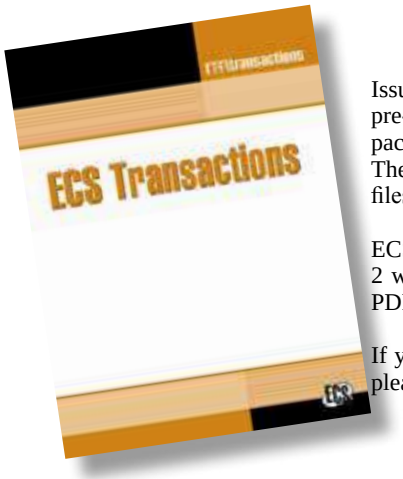

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ECS will begin publishing papers in the ECST issues for the remaining symposia approximately 2 weeks after the Phoenix meeting. These issues and individual articles will be available as PDFs only.

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> *The Fellow of The Electrochemical Society was established in 1989 for advanced individual technological contributions in the field of electrochemical and solid-state science and technology; and active membership and involvement in the affairs of The Electrochemical Society.*
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To celebrate the the twenty-fifth anniversary of the establishment of the ECS Fellow award Petr Vanýsek, Co-editor of *Interface*, interviewed Jerry Woodall, who was in at the birth of the award.

***Interface*: The first Fellows of ECS were named twenty-five years ago. I understand that you were instrumental in establishing the Fellows concept for the ECS. What made you think to try to establish it?**

Woodall: ECS is a unique professional society. Unlike both APS and IEEE, which had existing Fellows programs that rewarded mostly academic-type excellence rather than proprietary industrial R&D excellence, ECS has a very broad-based membership across many professional disciplines, and varied venues of accomplishment. My view was that excellence at all levels of professionalism should have external and global recognition. Therefore, I thought if ECS could create a Fellows program that recognized not only academic type excellence, but also recognized professional excellence done in a highly proprietary environment, it would serve the career recognition needs of highly-motivated and talented professionals in a way that none of the other Fellows programs were doing.

***Interface*: When did you get this idea?**

Woodall: Hard to pin that down. The embryo probably occurred in the mid-to late ’80s.

***Interface*: How long did it take from the idea to put this in place and have the first class of Fellows named?**

Woodall: It happened surprisingly fast. I was on the ECS Executive Committee at the time and I formed a subcommittee composed only of those who were in favor of the idea. (Not very democratic, but who cares now?) I got buy-in from the entire executive committee. I don’t have records of it in my files, but I would say it did not take longer than a couple of years to get it passed by the ECS Board of Directors.

***Interface*: What was your function within ECS when you began your effort to establish the Fellows award? Did that help in establishing your goals?**

Woodall: Because I was ECS President for ’90-91, I was on the Executive Committee during the crystallization and final committee actions to realize the operational document. This was of great advantage because it allowed me to control attacks against the idea from nay-sayer members. It is incredible that there were “prominent” (and influential) members opposed to a Fellows program. I remember the very last committee meeting that finalized the document, one vociferous member showed up to suggest that we needed to have conversation about the worthiness of the program. Gerry Blom quipped “You’re too late, it’s a done deal.”

***Interface*: How important are awards, in general, within a scientific society?**

Woodall: As long as they are considered prestigious, they are extremely important. They must be given out credibly to assure that they continue to be prestigious. When I joined IBM Research, I thought my career would be cradle-to-grave. That notion ended when the Pacific Rim started eating the U.S. lunch. Being an IBM Fellow along with my awards profile allowed me to pick and choose a desirable academic career. The National Medal of Technology even allowed me to go University of California-Davis as a distinguished professor at the age of 74. Therefore, awards are a way for professionals to vet their accomplishment when looking for a new job.

***Interface*: Just about every honor and award is accompanied by a scroll and the ECS Fellow is no exception. However, each fellow also receives a lapel pin, which is not as common. Were the details of the award also a part of the original discussion, or was it worked out later?**

Woodall: Here again my lack of records test my memory. My belief is that details about the “trappings” were left to be worked out after the program was accepted by the Board.

***Interface*: And what about the detail in which the formula was developed to limit the total of the Fellows as well as the number awarded each year? Was that also worked out during the initial discussion?**

Woodall: Again, from memory I believe that most of the criteria for Fellow awards along with the by-laws were worked out before presentation to the Board.

***Interface*: The means of dissemination of science have changed dramatically over the past years and the sense of belonging to a certain community is perhaps waning. Can a membership in a scientific society be equally attractive now, compared to how it was twenty-five years ago?**

Woodall: Good point. However, I never went to an ECS meeting just to receive the dissemination of science or present technical papers. I also went to avail myself of networking with colleagues. Therefore, in my humble opinion, in order for ECS to remain vitally important and sustainable, it needs to play this card big time. So, leave the sessions alone. They will take care of themselves. But you need to have the major international players show up at the spring and fall meetings so they can talk to each other. You need them there so the new tenured track professors and new company hires can meet them. This also means more plenary sessions of emerging science and technology topics given by the gurus. Get them to come even if you have pay for them.

***Interface*: What would you suggest to a person who would now like to come up with a similar idea as you had with the Fellows? What is required to go from an idea to completion?**

Woodall: Well, I think having a bright person work out the methodologies of bringing new and old gurus working in emerging areas of interest to the mission of ECS to the biannual meetings is a worthy new idea and get buy-in by the Executive Committee. For example, ECS should own electric vehicle (EV) R&D at all levels. Bring in Elon Musk, Leaf's CEO, etc., and all the engineers who are working on them. Either fix or replace Li ion etc. This is especially important now that the R&D on semiconductor technology is rapidly maturing.

***Interface*: There was clearly some resistance at the beginning to establishing the program outside the Executive Committee. Did you ever think it was not worth the political effort or did you always know this was a good idea that needed to be pursued and that it would eventually win?**

Woodall: I know this sounds arrogant, but there was never any doubt in my mind that the Fellows program would win. Why? When I was president of ECS, I convinced Ralph Gomory, IBM's Chief Scientist and Director of IBM Research, to give the plenary lecture at one of the meetings. He hesitated at first. Then I showed him a laptop computer and pointed out that every hardware component in it was a topic of R&D interest to and coverage by the ECS. Acceptance to speak followed in a few seconds.

***Interface*: How does one win, anyway?**

Woodall: By developing a compelling idea that you really believe in and stacking the political movers and shakers deck in your favor.

***Interface*: Looking at the program and the classes of the Fellows now, how satisfied are you with the program that you put (or helped to put) in place? Is there anything you would have done differently?**

Woodall: I see a fair and well-balanced list of high achievers from both the wet and dry sides that almost unanimously deserve to be called ECS Fellows. I offer now a word of caution vis-à-vis metrics for electing new Fellows. As a field matures, the highly visible "breakthroughs" occur with less frequency. So the selection committee needs careful and inclusive due diligence to identify and reward those loyal and long-term members who have in fact done highly impactful work in both academe and industry.

***Interface*: Thank you very much for giving us the time for this interview. And thank you for your service to ECS and for your life-long work in science and technology.**

Find out more about ECS Fellows at www.electrochem.org/Fellows.

About the Guest

Jerry M. Woodall was born and grew up in Washington, D.C. He attended MIT where he received a BS degree in metallurgy in 1960. He earned his PhD degree in Electrical Engineering at Cornell University in 1982, and has been a member of ECS since 1968. He was active in the Electronics Division and a cofounder of the Energy Technology Division. He served as the President of ECS (1990-1991) and was elected Fellow of The Electrochemical Society in 1992. He is also a Fellow of the American Physical Society, IEEE, and AVS, is a member of the National Academy of Engineering, and Fellow of the National Academy of Inventors. Woodall spent most of the early and middle parts of his career at the IBM Thomas J. Watson Research Center, where he rose to the rank of IBM Fellow. His academic career included the invention and seminal work on compound semiconductor heterojunction materials and devices, including high efficiency red LEDs, the heterojunction bipolar transistor (HBT), and high efficiency solar cells. In 1998 he received the ECS Edward Goodrich Acheson Award. As a professor at Yale University he received the 2002 National Medal of Technology. Currently, he is Distinguished Professor of Electrical and Computer Engineering, University of California-Davis. Prof. Woodall may be reached at jwoodall@ucdavis.edu.

In Memoriam

Alvin J. Salkind
(1927-2015)

ALVIN J. SALKIND

ALVIN SALKIND, an emeritus member of ECS, died on June 9, 2015, in New Brunswick, New Jersey, at the age of 87. He received his PhD in Chemical Engineering and X-Ray Physics from the Polytechnic Institute in New York and had additional graduate training at Penn State University and at the Harvard Business School. He was an author of more than 120 technical papers and patents and he was an author or editor of 17 books. He published extensively in the *Journal of The Electrochemical Society* beginning in 1959. He joined The Electrochemical Society in 1953 and became an ECS Fellow in 2014. He was also a Fellow of the American College of Cardiology, AAAS, AIMBE, and New Jersey College of Medicine. He had over 40 years of experience in the electrochemical battery field in his dual academic-industrial career. He was a professor at Rutgers University, President of the Electric Storage Battery Company, and the Executive Director of the Yeager Center at Case Western Reserve University. An ECS blog of June 10, 2015 first announced his passing to the ECS members.

Forrest Trumbore wrote the following about Alvin Salkind:

Upon my retirement from Bell Labs, I found a new home as an adjunct professor in Prof. Salkind's battery group in the Bioengineering Division of the Department of Surgery at the University of Medicine and Dentistry of New Jersey (UMDNJ), Robert Wood Johnson Medical School. The group was housed in a succession of trailers, in whose relatively cramped quarters another professor and his students worked on bone growth and such problems. Al was a truly unique individual who it seemed knew virtually everybody in the battery field. To say the atmosphere in the group was informal is an understatement; Informal dress was the rule and as likely as not Al's shirttail was hanging out. Al was keenly devoted to batteries and science and, even when he initiated conversations of a personal nature, the subject would soon become one related to some technical problem or subject.

Some of the most interesting times with Al and his group involved teaching courses on battery science and technology for the Army, Navy, and for Corning. But the most enjoyable were yearly three-day short courses that Al, I, and another colleague gave yearly for a decade in New Jersey and in Amsterdam for the Center for Professional Advancement. Although I was the course director, there was no question as to who was the most popular lecturer in the course. At the end of each course, the students were given evaluation forms and Al inevitably got the highest ratings. Often, as he was giving his lectures, I would think to myself "Come on Al, stop rambling and get back to the subject." At which point, virtually every time, he would drop a pearl of battery wisdom that I had not heard before. That pearl alone would justify the money the students had spent to attend the course! It was never boring working with Salkind and I am indebted to him for providing a stimulating environment in my later years.

Tom Reddy contributed this tribute:

I first met Al Salkind in the early 1960s when he was at the Electric Storage Battery (ESB) Lab in Yardley, PA where he worked in association with Paul Reutchi , the famous Swiss Battery Scientist, who was the Lab Director. Following Dr. Reutchi's return to Switzerland, Al became Lab Director and a Vice-President of ESB. Following ESB's acquisition by International Nickel, Al left ESB and began his academic career.

Initially, he taught at Case Western Reserve and later joined the Faculty of the Rutgers Medical School and the Rutgers School of Engineering. His contributions to lead-acid and alkaline battery technology in this era are legendary. Our paths crossed on numerous occasions and as my retirement at Yardney Technical Products approached, Al arranged for appointments for me in the Dept. of Materials Science and Engineering at Rutgers and in Bio-Engineering in the Rutgers Medical School. These appointments allowed me to continue my career in battery R&D and by consulting. I also taught in a number of short courses given by Rutgers. On one occasion at US Army TACCOM in Warren, MI, when I was using up my allotted time giving a lecture on lithium-ion battery technology using material from an ECS short course, Al asked me to stop, since he believed I was boring the audience. This was the only time I was ever told I was boring an audience.

At the time of his death, Al Salkind was embarking on a new venture to make significant improvements in battery technology. He was a unique individual as both a person and as a scientist. He will be long remembered.

The ECS blogs about Dr. Salkind, including a video interview and podcast with him, can be found at: www.ecsblog.org/tag/salkind.

In Memoriam

H. Russell "Russ" Kunz
(1931-2015)

H. Russell Kunz

H. Russell "Russ" Kunz passed away on March 4, 2015, in Hartford, CT. Russ obtained all his degrees from Rensselaer Polytechnic Institute. He spent most of his career working with various divisions of United Technologies Corporation, and especially at International Fuel Cells (IFC). During his long career in engineering and research, Russ worked on disparate technologies such as turbine engines, fuel cells, and rockets. While at IFC, Russ published a number of seminal papers on alkaline, phosphoric acid, and molten carbonate fuel cells and conceived new concepts for commercial, space, and military fuel cells that have significantly influenced the current U.S. fuel cell program. Concurrently during his career in industry, he served as an Adjunct Professor in the Hartford Graduate center of RPI. After retirement, Russ served as a Professor in Residence in the Department of Chemical Engineering at the University of Connecticut for about two decades, wherein he conducted research on various fuel cell and other electrochemical technologies and mentored numerous graduate students and faculty members, many of whom are active in ECS today. Russ was an exceptional researcher and mentor and a superb role model for several generations of scientists and engineers. He was an emeritus member of ECS (joined in 1976) and a regular at the biannual meetings. Russ received the Research Award of the Energy Technology Division of ECS in 1998 for his contributions to advancing fuel cell technology.

Richard A. Oriani
(1920–2015)

Richard A. Oriani, an ECS member since 1983, passed away on August 11, 2015 in Edina, Minnesota. An undergraduate of College of the City of New York, he received his PhD in Physical Chemistry from Princeton University in 1948. He worked as a research associate for Union Carbide and Carbon and then for General Electric R&D Center. From 1959-1980 he was an Assistant Director at U.S. Steel Research Laboratory. In 1980 he joined the faculty at University of Minnesota, Department of Chemical Engineering and Materials Science, where he served as the Director of the Corrosion Research Center. There he pioneered the use of the Kelvin probe to study metal corrosion. He formally retired from the faculty appointment in 1989, and officially retired from the University in 1999, but enjoyed emeritus status since. He was the world's expert on hydrogen embitterment in steels. He published close to 170 papers listed in *Chemical Abstracts* on a number of subjects of physical chemistry and materials science. He was also interested in the study of nuclear particles generated during electrolysis. Well along into his retirement he served in his community as a member of the Alternative Energy Working Group. He was a member of the Twin Cities Section and the Corrosion Division. In 1994 he was elected a Fellow of ECS.

New & Notable

Chennupati Jagadish (ECS member 1996, Life) of the Australian National University, in Canberra, was honored by the Institute of Electrical and Electronics Engineers Nanotechnology Council (NTC) for "For pioneering and sustained contributions to compound semiconductor nanowire and quantum dot optoelectronics." He received the 2015 NTC Pioneering Award on July 29, 2015.

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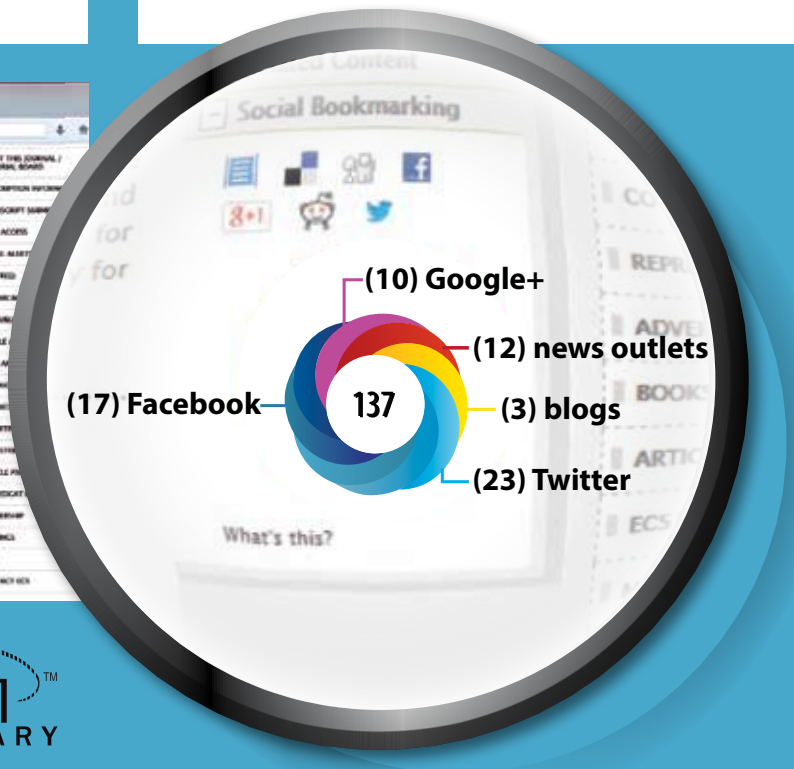

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Towards Implantable Bio-Supercapacitors: Pseudocapacitance of Ruthenium Oxide Nanoparticles and Nanosheets in Acids, Buffered Solutions, and Bioelectrolytes

Since the early 1990s when ruthenium oxide-based electrode materials were found to have pseudocapacitive properties, they have been extensively investigated as promising supercapacitor electrodes. A best benchmark example is $RuO_2 \cdot nH_2O$ in combination with H_2SO_4 as the electrolyte, being able to operate with high voltage window, high capacitance and long cycle life. As the research continues in this area, researchers at the Shinshu University of Japan recently explored the pseudocapacitive behavior of ruthenium oxide nanoparticles and nanosheets in environmentally benign electrolytes near neutral pH, and reported their findings in the JES Focus Issue on Electrochemical Capacitors: Fundamentals to Applications. In acetic acid-lithium acetate (AcOH-AcOLi) buffered solutions (pH = 5.4, 5 M solution), the authors found that highly-crystalline RuO_2 nanosheets could achieve a capacitance value as high as 1038 F/g, which is over 40% higher than in the widely quoted benchmark value of 720 F/g in H_2SO_4 electrolyte. The authors also studied the effects of ionic strength and pH, as well as the role of weak acid in Li_2SO_4 electrolyte. These different electrolyte conditions affected the surface redox behavior of RuO_2 nanomaterials, resulting in different pseudocapacitive behaviors. Furthermore, comparable performance was obtained with RuO_2 nanosheets in phosphate-buffered saline (837 F/g) and fetal bovine serum (772 F/g) electrolytes. The results demonstrated possible future applications of these materials toward implantable bio-supercapacitors.

From: J. Electrochem Soc., ***162**, A5001 (2015).*

Influence of the Altered Surface Layer on the Corrosion of AA5083

Aluminum alloys are increasingly replacing heavier materials in transportation, military and other applications, oftentimes in environments demanding of exceptional corrosion performance. In this regard, AA5083 has served as one of the alloys of choice for marine applications. This alloy, and some others in the 5xxx series, contains greater than 3 wt% Mg, making it inherently vulnerable to in-service sensitization involving precipitation of β-phase (Mg_2Al_3) at grain boundaries. Preferential intergranular corrosion (IGC) of β and, relatedly, stress corrosion cracking can severely compromise mechanical integrity. Despite the in-service occurrence of IGC, its initiation has typically not been observed under freely corroding conditions in laboratory studies. Researchers at Ohio State University have provided explanation for this discrepancy. Through electrochemical and microstructural characterization, they demonstrated that heat generated by grinding and polishing of sensitized AA5083 samples is capable of creating a recrystallized surface layer deficient in precipitated β. This surface layer blocks environmental access to the underlying sensitized microstructure, leading to corrosion behavior similar to that of the solutionized microstructure in certain cases. The authors demonstrated an etching method for removal of this altered surface layer. These findings will aid in future efforts to understand IGC initiation of 5083 and, potentially, other sensitization-prone 5xxx alloys.

From: J. Electrochem Soc., ***162**, C209 (2015).*

Advances in 3D Printing of Functional Nanomaterials

The intense and widespread interest in additive manufacturing techniques, including 3D printing, has resulted in an approximately $5 billion industry today with projections for growth to $15-20 billion by 2018. The commercial availability of 3D printing equipment, and the development of flexible additive manufacturing platforms in R&D laboratories, has provided a foundation for researchers to perform fundamental research in the materials science and engineering of polymers, organic materials, ceramics, inks, pastes, and other materials. Further, this fundamental understanding has been followed by technology maturation efforts to produce applications for 3D printing in biotechnology, electronics, photonics, photovoltaics, sensors, automotive, aerospace, chemical sensing, and numerous other fields. In the JSS Focus Issue on Printable Functional Materials for Electronics and Energy Applications, authors from Arizona State University, Freescale Semiconductor, Korea Institute of Science and Technology, and the University of Nevada-Reno published a review article on 3D printing and roll-to-roll manufacturing. The article cites exciting applications in bone tissue engineering, bone regeneration, radio frequency identification tags, chemical and biological sensors, flexible electronics (e.g., for wearable devices), and other fields. The incorporation of nanomaterials (carbon nanotubes, metals, dielectrics, etc.) in 3D-printed parts is also an active area of research, as these nanofillers can be tailored to improve materials performance for additively manufactured devices.

From: ECS J. Solid State Sci. Technol., ***4**, P3001 (2015).*

A Critical Assessment of $X_{H_2O_2}$ as a Figure of Merit for Oxygen Reduction Electrocatalysts in Aqueous Electrolytes

In the assessment of electrocatalysts for the oxygen reduction reaction (ORR), the $X_{H_2O_2}$ figure of merit is commonly determined. This $X_{H_2O_2}$ parameter is the fraction of disk current in a rotating ring-disk electrode (RRDE) experiment attributable to hydrogen peroxide generated and subsequently lost to solution. The $X_{H_2O_2}$ parameter is commonly calculated by an equation that is based on the assumption that the disk electrode material is inactive toward peroxide reduction. In this paper, scientists from Case Western Reserve University provide a rigorous assessment of the reaction schemes and assumptions used in deriving expressions for currents and ultimately the $X_{H_2O_2}$ parameter. The authors base their examination on the 1966 work of Damjanovic et al., wherein the ratio of disk to ring currents for ORR exhibits a linear relationship to the reciprocal square root of rotation rate. The y-intercept may be used to extract the $X_{H_2O_2}$ parameter, and the slope to obtain the rate constant for the reduction of peroxide in solution at the disk. The authors used data from the literature and their lab to illustrate how use of a single rotation rate without satisfying the underlying assumptions of the expression leads to unreliable values of $X_{H_2O_2}$.

From: ECS Electrochem. Lett., ***4**, F39 (2015).*

Self-Aligned Fin-On-Oxide FinFETs on Si Substrates

Bulk-silicon (Si) FinFETs have become recognized as one of the most promising device architectures for advanced CMOS integration circuits. FinFETs are well known to have a controlled electrostatic integrity even with short channel lengths, and can be multi-gated. When fabricated on Si, punch-through stopper (PTS) doping is needed to suppress sub-channel leakage current. This doping also causes carrier mobility degradation and threshold voltage variability in transistors. FinFET formation on SOI substrates can provide a channel at the buried oxide, but integration costs are prohibitive using such substrates. Researchers at the Institute of Microelectronics at the Chinese Academy of Sciences in Beijing propose a new way to form Fin-On-Oxide (FOO) FinFETs on Si, and in this Letter they describe how they made this possible with just a few modifications to typical bulk-Si FinFET integration processing. Based on conventional bulk-Si FinFET integration flow, the team introduced fin notch etching with liner oxidation and isolation-oxide filling, isolating the fin from the substrate. When applied to 14 nm devices, they achieved a sub-threshold swing of 86 mV/dec and drain-induced barrier lowering of 106 mV/V, better than bulk-silicon FinFETs. The researchers suggest that the method provides a promising approach for ultra-low power circuits using scalable FinFETs on Si substrates without complicated process technologies.

From: ECS Solid State Lett., ***4**, Q13 (2015).*

Tech Highlights was prepared by Mike Kelly and Eric Schindelholz of Sandia National Laboratories, Zenghe Liu of Google Inc., Colm O'Dwyer of University College Cork, Ireland, and Donald Pile of Nexeon Limited. Each article highlighted here is available free online. Go to the online version of Tech Highlights, in each issue of Interface, and click on the article summary to take you to the full-text version of the article.

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Bioelectrochemical Energy Conversion Technologies

by Ramaraja P. Ramasamy

Biology, despite being the largest field of science, has not attracted much interest or attention from electrochemists for reasons I am yet to find out. However, electrochemistry does not receive the same treatment, as most biologists have a fairly good understanding of the Nernstian potentials and electrochemical gradients across a biological cell membrane and its implications for cellular bioenergetics. Biologists recognize that "electron transport" is the universal mechanism of energy conversion. When we eat our food, we extract the energy in the food through a series of biological oxidation reactions, each transferring electrons to a corresponding biological reduction reaction. These biological redox reactions are catalyzed by a set of fuel oxidizing enzymes on one end and a set of oxidant reducing enzymes on the other end, by utilizing the driving force created by the proton transport gradient across the biological membranes, be it mitochondria or chloroplast. If we take a closer look at these biological electron transport processes, we would quickly realize that this scenario is identical to a fuel cell, where the fuel oxidation and oxidant reductions are carried out on two different electrodes separated by an ion-exchange membrane. The principles are the same, regardless of whether it is nature or humans who execute the above described energy capture and conversion.

The field of bioelectrochemistry has been in existence for nearly a century, yet the term "bioelectrochemistry" is rarely used without a hyphen between the words "bio" and "electrochemistry." While I was writing this article, Microsoft Word tried to autocorrect me by splitting the two words. This led me to wonder when was the last time the term "electrochemistry" was used with a hyphen between the words "electro" and "chemistry." (Certainly not in the recent decades.) Perhaps this is one indication that the field of bioelectrochemistry has been overlooked by vast majority of electrochemists. Or perhaps I am exaggerating based on my intrinsic viewpoints on this issue. My point however is that bioelectrochemistry offers unique solutions to many of the important problems we face in the areas of corrosion, electrochemical sensing, chemical production, energy storage and conversion, CO_2 capture, and even electronics, and that the field deserves more than a cursory glance by the majority of electrochemists. While reading this issue, I encourage you to look past the "main stream" electrochemical energy technologies, by which I mean conventional fuel cells, batteries, etc., and explore how nature-inspired bioelectrochemistry could address ongoing challenges in energy storage and conversion.

There are three modes of bioelectrochemical energy conversion — microbial-based, enzyme-based, and photosynthesis-based — each of which operate under similar principles. Microorganisms of a certain type can transfer the excess electrons from their metabolic pathways to a metallic surface via exocellular respiration. This interesting physiological property of electrogenic microorganisms has been utilized to generate electricity in "microbial fuel cells." A microbial fuel cell uses microorganisms as biological electrocatalysts that oxidize any organic matter on the anode and reduce oxygen or a suitable electron acceptor compound on the cathode, resulting in a net voltage under load. The most interesting feature of the microbial catalyst is its ability to grow nanowire appendages for the sole purpose of electron conduction. As the father of aquatic chemistry Werner Stumm pointed out, "Microbes are the best chemists in the world."

The biological process is scaled down in enzymatic fuel cells, where individual enzymes or a group of enzymes replace the whole cell microorganisms as electrocatalysts. Due to the high specificity of enzymes, only the desired "fuel" is oxidized from a complex substrate, resulting in the generation of electrons that can be reduced at the cathode. The concept of enzymatic fuel cells was derived from glucose biosensors, one of the highly successful electrochemical innovations in the past century. Unlike glucose biosensors, in which the generated electrons are processed as an analytical signal, these electrons are transported in an enzymatic fuel cell to a terminal electron acceptor (usually O_2) at a second electrode (cathode) resulting in power generation.

The third mode of bioelectrochemical energy conversion, namely photosynthesis-based bioelectrochemical energy conversion, offers prospects for clean, renewable production of electricity and fuels using sunlight. Here, the native reactions occurring during photosynthesis are manipulated or modified to harvest electrons for electrochemical reactions occurring at electrode surfaces. The catalysts are either individual photosynthetic reaction centers, or thylakoids or whole cells of photosynthetic algae.

These three seemingly unrelated technologies have one thing in common — they all work on the same familiar fundamental electrochemical principles that govern the operation of a conventional fuel cell or electrolyzer.

This issue of *Interface* features three articles on the topic of bioelectrochemical energy conversion based on the three different modes described above. The intent of this issue is to introduce the principles of biology behind these energy conversion technologies to the electrochemical community. The first article focuses on microbial fuel cells and electrolyzers and is written by Abhijeet Borole. The second article, written by Scott-Calabrese Barton, is on the theory and modeling of enzymatic fuel cells. The third article is on electrochemical energy conversion based on natural photosynthesis to generate electricity or chemical fuels written by Narendran Sekar, a PhD student from our group. It is true that the power and energy densities of these bioelectrochemical systems are presently far too low when compared to the established mainstream technologies. But with only a handful of researchers working in the field, breakthroughs do not occur very frequently. It is my hope that the articles in this issue of *Interface* will stimulate new thoughts and gather more interest from the broader electrochemical community to work with biologists and biochemists to further advance the field of bioelectrochemistry.

 doi:10.1149/2.F01153if.

About the Issue Guest Editor

Ramaraja Ramasamy received his Bachelor of Technology in chemical and electrochemical engineering from Central Electrochemical Research Institute, India in 2001 and his PhD in chemical engineering from the University of South Carolina in 2004. His PhD research was focused on novel materials for lithium-ion batteries. After serving as a post-doc at the University of South Carolina for a year, Ramasamy joined Penn State University as a Research Associate in 2005 and worked on PEM fuel cells until 2008. Later that year he moved to the Air Force Research Laboratory as Senior Research Scientist to work on bioelectrochemical energy conversion technologies. In 2010, he joined the University of Georgia as an Assistant Professor of Biochemical Engineering, where he founded and directs the Nano Electrochemistry Laboratory. Earlier this year he was promoted to Associate Professor with tenure. His current research focuses on applying nanoscale science and engineering principles to improve the performance of electrochemical and bioelectrochemical systems including fuel cells, batteries and biosensors. He may be reached at rama@uga.edu.

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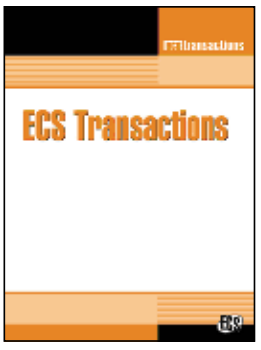

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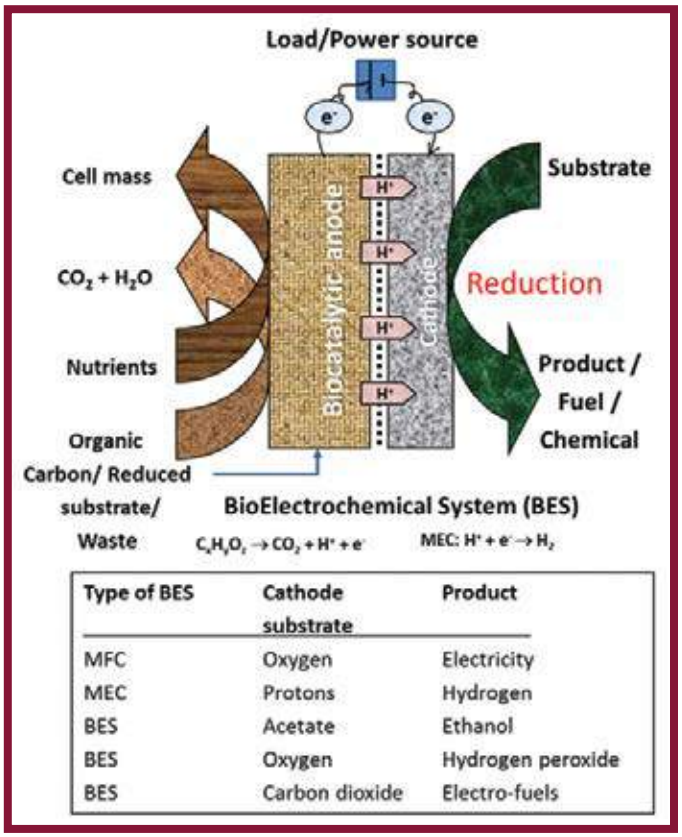
Microbial Fuel Cells and Microbial Electrolyzers

by Abhijeet P. Borole

Microbial fuel cells are electrochemical devices that use microbes as catalysts instead of inorganic catalysts to drive the anodic and/or cathodic reactions to produce electricity.[1] The field of microbial fuel cells (MFCs) was initially focused on wastewater treatment, but has evolved into a much more diverse field of research called Bioelectrochemical Systems (BES). Microbial electrolyzers or microbial electrolysis cells (MECs) are a different manifestation of BES that generate hydrogen using less than half the voltage or electrical energy needed for conventional water electrolysis. The reduced electrical input is enabled by the chemical energy that comes from organic or reduced inorganic substrates that serve as the feedstock for hydrogen production in MECs. Electrons are extracted from the substrates and converted into hydrogen at the cathode, operating at room temperature. The cathode catalysts can be metal-based or biological in nature. Figure 1 shows a generalized configuration of the BES. The versatility of the BES platform shown in the figure illustrates the potential of this approach to produce not only electricity and hydrogen but also biofuels, chemicals and bioproducts.

Electrocatalysis-Biocatalysis Synergy

Fuel cells have set a high mark for energy efficiency among the various renewable energy production options that have evolved over the last few years. The high efficiency comes from the molecular nature of electrocatalysis. In comparison to thermocatalysis, where vibrational energy is used to increase the rate of reaction, electrocatalysis has a significant advantage, because voltage is the driving force for reactions in addition to temperature, which minimizes the energy losses to the environment, thereby improving the conversion efficiency. Biocatalysis is another low temperature catalytic process that works at the molecular level by overcoming the energy of activation via structural re-combination of reactants that self-assemble into catalytic sites. Combining electrocatalysis with biocatalysis in the bioelectrochemical approach employed in BES results in a significant synergy, improving efficiency significantly. This is because of the continuity of the electron flow from the substrate to the product, afforded first, via the biocatalytic reaction, and then by the electrocatalytic reaction, resulting in a continuous path within the electrical circuit. This mechanism is supported by the relatively recent discovery of electrical communication between biological systems and electrodes. Biological nanowires have been identified to enable efficient electron conductance between inorganic substrates and organic or biological entities. Pili-based nanowires have been identified in *Geobacter sulfurreducens* and *Shewanella oneidensis*, which are capable of electron transfer from microbes to an anode.[2,3] Direct interfacing of electron producers and electron sinks has given rise to this high degree of efficiency evidenced in microbial fuel cells. Similarly, MECs also have high efficiency, shown by the generation of hydrogen from acetate using microbes at a Coulombic efficiency above 90% and an overall energy efficiency as high as 82%.[4]



Type of BES	Cathode substrate	Product
MFC	Oxygen	Electricity
MEC	Protons	Hydrogen
BES	Acetate	Ethanol
BES	Oxygen	Hydrogen peroxide
BES	Carbon dioxide	Electro-fuels

Fig. 1. *Schematic of bioelectrochemical systems including MFCs and MECs.*

Relevance to Energy Production in the 21st Century

The field of BES has given rise to an increasing number of opportunities for collaborations between electrochemists, biologists, and engineers. This has brought together a unique opportunity for these three communities to work together and contribute to the advancement of the field. MFCs originated as a potential solution to wastewater treatment a decade ago. Water has become an increasingly scarce commodity during the last decade. Zero-energy wastewater treatment is one vision for the scientists working in the area of BES development. This is one of the many components of the water-energy nexus issues that the USA is currently facing. Synergy of BES with biorefineries has also been identified, with potential improvement in the efficiency of conversion of biomass to energy.[5] Hydrogen production has been pursued from various renewable sources including solar, wind power, and biomass, etc. Economically competitive production of renewable hydrogen, however, has been a challenge. MECs offer a new, energy-efficient method for hydrogen production from biomass and waste. The ability to produce hydrogen from waste and biomass hydrolysis products, namely sugars and organic acids has been demonstrated.[6] Conversion of lignin-degradation products, phenolic compounds, and furan aldehydes at the bioanode has also been demonstrated.[7] This opens the door to the possible conversion of essentially all components of biomass to hydrogen using MECs.

Economic Considerations

Economic feasibility of BES can come from one of three ways. While the primary function of these systems is energy production, worthwhile benefits can be realized from their contribution to reduction in waste and/or production of clean water (Fig. 2). A current

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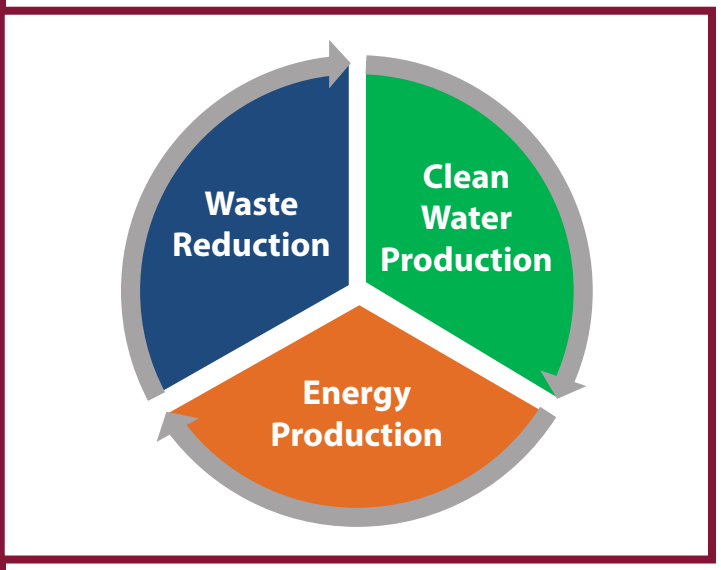

Fig. 2. *Three potential benefits of BES technology contributing to economic feasibility.*

density of 25 A/m^2 has been suggested as a threshold for economic feasibility of MFCs,[8] possible with reduction in internal electrical resistance below 40 mΩ m^2. Electricity as a product from MFCs may not by itself justify the costs of implementing these systems, however, removal of key contaminants or production/recycle of water at zero energy cost would warrant use of these systems.

Microbial electrolyzers, on the other hand, generate renewable hydrogen that is valued higher than electricity and thus have a greater potential to reach economic feasibility. A comparison of MEC technology against other existing technologies for hydrogen production is shown in Table I.

Among the renewable energy technologies included in Table 1, MECs are observed to be a relatively cost competitive alternative, however this technology is nascent and significantly more effort is required to reduce the costs down to the \$2/kg H_2 set by the U.S. Department of Energy (DOE) (not including hydrogen storage and delivery costs). Specific cost reduction goals set by the DOE Fuel Cell Technology Office (FCTO) include reduction in cathode costs to \$50/m^2 and a target rate of hydrogen production equal to 4 L-H_2/L-reactor-day by 2020. The current densities necessary for MECs to be economically feasible have been reported to be on the order of 20 A/m^2.[8] A few studies have shown this to be achievable,[13] although not in long-term studies.

Scaling-up BES

While the results from laboratory scale studies of BES have been encouraging, the demonstration of their potential for practical application has been lagging. A few investigations targeting pilot-scale studies of MFCs and MECs have shown significantly lower performance compared to laboratory-scale systems. This is due to poor understanding of the scale-up parameters. The lack of identification of electrochemical losses during scale-up is one factor contributing to the poor understanding of MECs and concomitant poor performance of these systems at scale. A number of electrochemical methods have been employed to investigate these losses; however, insufficient work has been done to date to identify which scale-up parameters matter the most and how they should be controlled as the scale of operation increases. Further collaborative work between electrochemists, microbiologists, material scientists, and chemical engineers is needed to advance this field towards commercial consideration.

Table I. Comparison of cost of hydrogen production.[9,11]
The costs reported in last column are based on 2003 \$, except for MEC.

\$/kg H_2	EERE[9,10]		Literature[8,11]
	2011 Status	2015 Target	
Wind + Electrolysis	4.10	3.00	6.64
PV-Electrolysis			6.18[a]
Biomass gasification	2.20	2.10	4.63
Biomass pyrolysis			3.80
Solar thermal	NA	14.80	
Photoelectrochemical cell	NA	17.30	
Photobiological	NA	9.20 (2020 Target)	
Nuclear thermal splitting of water			1.63
Natural gas reforming	2.00	2.10	1.03
Coal gasification			0.96
Microbial electrolysis	NA	12.43[b]	5.40[c]
Reforming of bio-derived liquids[d]			
1. Ethanol	6.60	5.90	
2. Bio-oil aqueous phase[12]	31.84	3.00[e] (2017 Target)	

[a]*Based on projected future technology.*
[b]*Derived from [10]. A cost of \$5.18 was deduced from the reported hydrogen production cost of \$12.43, which was for production of substrate via fermentation. The reported cost of electrodes for MEC (\$300/m^2, 2015 target set in the multi-year program plan developed by the FCTO),[9] however, does not give estimated cost of hydrogen production. It assumes a hydrogen production rate of 1 L-H_2/L-reactor-day (2015 Target).*
[c]*Derived from [8]. This is a projected cost using reduced cost of electrode materials in the future.*
[d]*For conversion of bio-derived liquids to hydrogen via steam reforming.*

Electrochemical Methods to Study BES

Techniques such as cyclic voltammetry and impedance spectroscopy have been employed to characterize the current generation and electrochemical parameters of BES. The application of electrochemical methods to biological systems warrants development of new ways of analysis and interpretation. While the techniques are well understood by electrochemists, the significance of resulting parameters is better understood by researchers with a background in biology. Many such collaborative teams have originated and reported findings from these systems, however much more work is needed to address the scale-up issues.

Cyclic voltammetry ▸ The use of cyclic voltammetry for studying MFCs/MECs has resulted in identification of the midpoint redox potential at which the bioanodes generate current.[14] This varies depending on the nature of the biocatalyst, which can be a single species such as *Geobacter sulfurreducens* or mixed consortium of species. For the former, the midpoint potential at which catalytic current arises has been reported to be about -0.15 V vs. a Standard Hydrogen Electrode (SHE).[15] In both cases, multiple peaks responsible for catalytic current have been commonly observed.[16] Since bioanodes are living systems, these peaks can change with time and are further influenced by process conditions. This leads to complex characteristics requiring a collaborative effort between microbiologists and electrochemists to delineate the electrochemical changes and relate them to the biology or process conditions. Multiple proteins, including cytochromes and other electron transfer agents present in outer-membrane, have been implicated in the electron transfer process. Pili proteins have been

reported to be responsible for efficient extracellular electron transfer to electrodes, leading to high current densities.[17] Two mechanisms have been reported to explain the process, namely electron super-exchange via cytochromes[18,19] and metal-like conductivity via pili nanowires,[20] both of which may be active in different microbial species or under different process conditions. The electroactive properties of proteins and biofilms create a whole new dimension of applications and their robust and diverse nature can potentially enable industrial applications even beyond MFCs and MECs. The sensitivity of the microbial systems to environmental and growth conditions results in challenges for comparison of the results from multiple laboratories, often requiring careful documentation of conditions and reproduction of data at multiple locations to provide meaningful evaluations during the developmental stage.

Electrochemical impedance spectroscopy (EIS) ▸ EIS is another tool which has been increasingly used to characterize BES and in determining the internal resistance of bioelectrochemical cells and the impedances characteristic of the electrodes and their living components. These analyses have revealed that there are major differences between the impedances of conventional fuel cells and bioelectrochemical cells.[21] First, due to the operation of the BES cell at neutral pH, the cathode charge transfer resistance can be several orders of magnitude higher than, say the PEM fuel cell. Secondly, the impedance of a bioanode harboring a microbial catalyst decreases with time as the density of active sites increases resulting from microbial growth. Additionally, the impedance of the bioelectrodes is a function of the potential, therefore, potentiostatic EIS is more appropriate for studying these systems than EIS at open-circuit conditions. The examination of the BES as full cells operating under closed-circuit conditions vs. half cells poised at specific potentials can provide complementary information and such insights can help to improve systems design.[22,23] The electrochemical parameters obtained via EIS, such as charge transfer resistance, diffusion resistance, double layer capacitance, etc., via equivalent circuit modeling (ECM) correspond to terms that can be obtained via biochemical reaction kinetic analysis and mass transfer process modeling (though appropriate model discrimination and parameter estimation is essential with the ECM approach). The exchange current obtained from measurement of bioanode charge transfer resistance can potentially be related to k_{cat} for electron donor utilization at the anode. Similarly, mass transfer of substrate and products within the biofilms is likely to be related to the diffusion resistance obtained via ECM analysis. These synergistic representations between electrochemistry and biology provide the groundwork for the newly emerging field of bioelectrochemical engineering, which can be envisioned as an exciting opportunity for academicians as well as application engineers who aim to contribute to the BES development and consequently to the 21st century bioeconomy.

Power management and energy harvesting ▸ MFCs produce relatively low voltage for direct powering of devices. Use of stacked cells and larger volume systems have been investigated, however, such configurations result in voltage reversal and inefficient energy harvesting. Use of power management systems (PMS) is therefore necessary to harvest energy efficiently. Such systems have been investigated, however, significant power loss still exists.[24] This is because the components used have not been developed for MFC/BES, but imported from solar, wind power, and other systems, which operate at different electrical outputs. Typical components used in power management systems include capacitors, charge pumps, rechargeable batteries, and boost converters. In addition, continuous energy harvesting of the low power has to be coupled to discontinuous power usage or discharge for powering sensors and other devices. This requires separate, autonomous systems for on-off control, which can themselves consume power. Thus, efficiency of these power management systems has to be high to get net power from MFCs.

The voltage output from BES changes with time and different applications require different modes of energy harvesting. For example, MECs that are used to produce hydrogen have to be operated at maximum current to maximize the hydrogen production rate, while MFCs that are primarily used to produce power have to be operated at intermediate current densities at which maximum power is realized. This requires identification of the maximum power point to harvest energy from MFCs. The energy harvesting regimes and operating voltages can influence the microbial communities and selection of extracellular electron transfer proteins and/or alter the dominant microbes in the communities. Thus, for similar feed conditions, the composition of the bioanode communities can be quite different, for example, in MFCs, where maximum power is tracked, compared to MECs, where maximum current may be of interest. Various combinations of energy storage components have been investigated, however, the efficiency of harvesting is still limited. Three main types of circuits that have been employed include capacitor-based systems, charge-pump based systems and boost converter-based systems. Optimization of energy production from BES requires significantly more work for developing integrated circuits combining multiple electronic components depending on the application needs and type of devices to enable commercial consideration.

Applications and Future Directions

Besides electricity and hydrogen production, a number of avenues have been investigated based on the bioelectrochemical approach (Fig. 3). Recovery of nutrients, such as nitrogen and phosphorous, has been demonstrated in BES systems. Production of ammonia gas at the cathode from dissolved ammonium in anode solution,[25] as well as production of struvite via precipitation of the phosphorus has been shown.[26,27] The ability to transfer electrons in the reverse direction, *i.e.*, from the cathode to microbes has also been reported, leading to the potential for bioelectrosynthesis of fuels and chemicals using biocathodes.[28] Several environmental applications have also been studied including clean-up of produced water[29] and bioremediation of pollutants. The transfer of ions between electrodes as a result of electrochemical charge separation has been employed to desalinate water. This has been coupled with energy production by BES to develop synergistic processes to clean salt and organic contaminants simultaneously.[30,31] BES systems have also been investigated as an alternative method for recovering dissolved carbon from biorefinery process water,[7,32] increasing the energy efficiency of conversion of biomass to bioenergy.

The discovery of biological nanowires and capacitive storage of electroactive biofilms has created an interest into bioelectronic applications. Research into characterization of the electronic structures of the electron transfer proteins and polymers has been initiated. The novelty of the conductive biological direct electron transfer offers a way to connect hard and soft materials, enabling electronic connectivity between silicon-type materials and biological components at the micro- and nano-scale. Development of bioelectronic devices, such as supercapacitors and transistors, has been envisioned using meta-heme cytochromes, gated proteins, etc.[33] Investigations which began a decade ago in the area of MFCs haves evolved and generated an interdisciplinary field with potential to impact a wide range of issues in the water, energy, and environment sectors in the coming decades.

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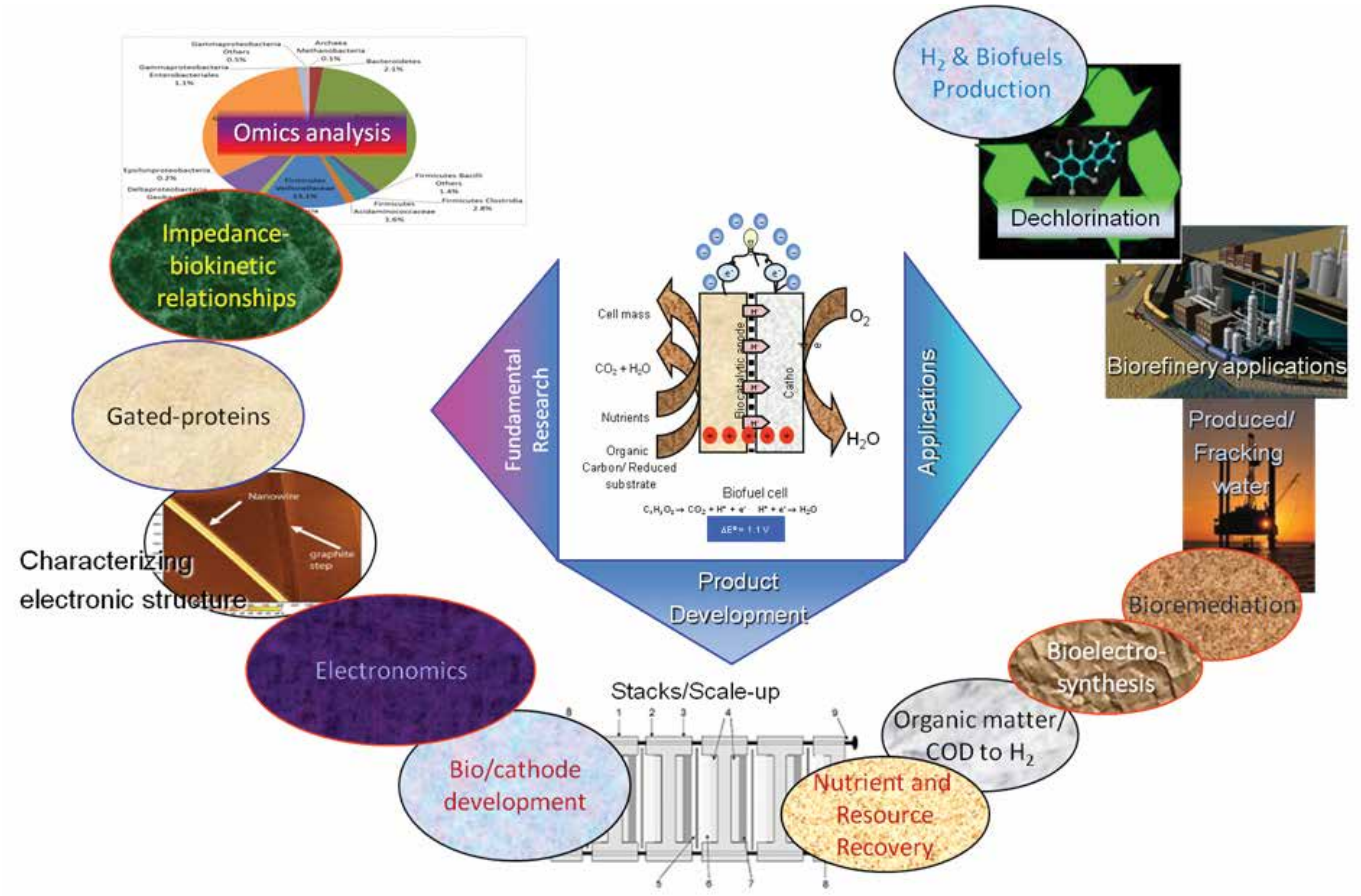

Fig. 3. *Potential directions for bioelectrochemical R&D and applications.*

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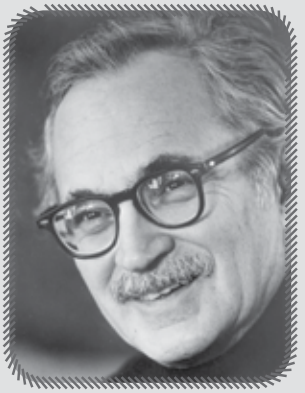

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1D Models for Enzymatic Biological Fuel Cells

by Scott Calabrese Barton

Enzyme electrocatalysts offer an intriguing approach to the design of fuel cell systems by broadening the range of fuel and oxidants available and by introducing potentially low cost organic and transition metal catalysts that are literally highly evolved.[1] Increased understanding of redox enzymes will further our ability to design catalyst active sites and possibly lead to breakthroughs in electrocatalytic technology.

Enzymes are proteins that catalyze chemical reactions. Oxidoreductase enzymes specifically catalyze oxidation-reduction reactions.[2] These enzymes can be implemented in biological fuel cells to convert chemical energy from fuels such as glucose, ethanol, or hydrogen to electrical energy. One enzyme, such as glucose oxidase, might oxidize a sugar molecule such as glucose to produce electrons and protons at an anode.[3] The free electron might then flow through an external circuit to a cathode, thereby producing electrical current. At the cathode, the electron can used to reduce oxygen, a reaction that can be catalyzed by an additional enzyme such as laccase.[4] The reduced oxygen can combine with the proton to form water, completing the electrical circuit.

The design and analysis of bioelectrocatalytic systems, not only for fuel cells but also for biosensor and bioconversion applications, requires detailed quantitative understanding of the physicochemical phenomena controlling such systems. A qualitative understanding alone can only go so far in terms of predicting performance, and is a very weak approach to teasing apart the thermodynamic, kinetic, and transport phenomena that can potentially control reaction rates. For example, one may wish to compare the kinetic aspects of two enzymes in an electrochemical system in which significant mass transport limitations are present. It may be possible in some rare circumstances to eliminate the mass transport control by manipulation of the experiment. But in most cases, such mass transport limitations can only be minimized, and quantified in terms of rigorous models. To get at the kinetics aspects, an analysis is performed to estimate and subtract off the driving force that is devoted to transport, such that the relation between driving force and kinetic rate can be estimated. This process requires not only a model for transport in the system, but also a model for the kinetics, in terms of the relationship between driving force and the kinetically-controlled rate.

Similarly, the desire to build real-world systems with bioelectrocatalysts requires engineering approaches to predict real-world performance, including the effect of length scales on device performance. These effects might include changes in efficiency or temperature due to increased limitations of heat and mass transport at large length scales. Temperature effects may be particularly important for enzymatic systems, where the activity and durability of the biocatalysts is usually maximized within a very tight temperature range.

This article describes some simple modeling approaches for enzymatic fuel cells that are applicable to many other systems, including biosensors and bioreactors. These topics are taken from a broad swath of literature, with some emphasis on recent advances. We discuss basic thin film 1D models and their analytical and numerical solutions, and then introduce the treatment of porous bioelectrodes, which covers the vast majority of practical devices. Finally we describe one type of complete cell model.

Simplifying assumptions ▸ Any approach to analyzing a system as complex as an enzymatic electrode requires simplification. We begin by addressing only one-dimensional, constant-temperature, steady state systems. Proton transport has a significant impact on enzyme kinetics, but we will roll that dependence into the kinetics by treating all rate constants as pH dependent. We will also ignore potential fields and the resulting migration losses, by assuming the low current densities associated with enzyme reactions. Similarly, convection will be ignored within the electrode in favor of diffusion, and thermodynamic partitioning of species into various phases will similarly be ignored.

Electron transport ▸ Two basic mechanisms for enzyme electrocatalysis are considered in the literature: Direct Electron Transfer (DET) and Mediated Electron Transfer (MET).[5] In DET, the enzyme is immobilized directly on an electrode surface, presumably with the active center of the enzyme within 1 nm or so of the electrode surface.

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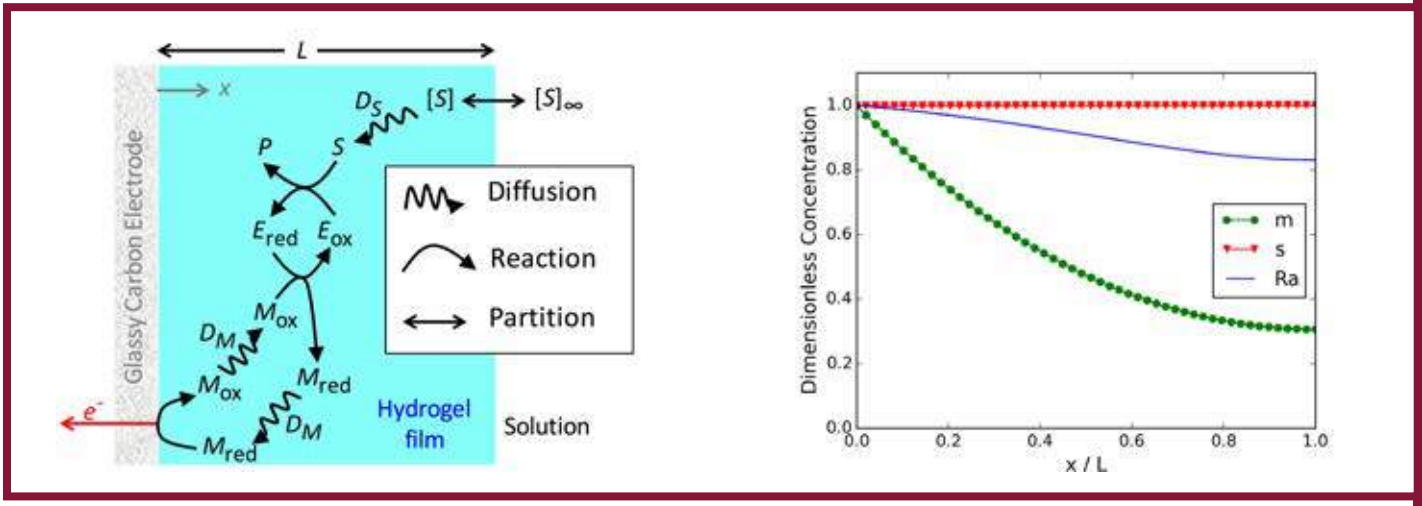

Fig. 1. *1D mediated bioelectrode model. (a) Schematic of a 1D model of a mediated glucose-oxidizing electrode, modified from Ref. 2. (b) Normalized concentration profiles for mediator,* m, *substrate* s, *and normalized reaction rate,* Ra. *For this case, the substrate concentration is uniform, and mass transfer limitations exist only for the mediator. The reaction rate varies nonlinearly with mediator concentration.*

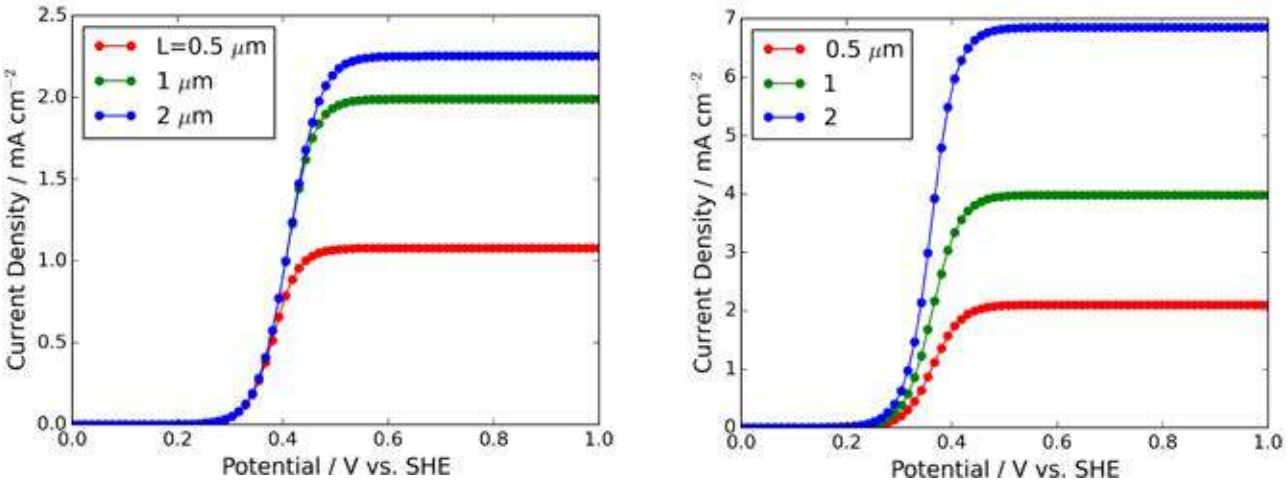

Fig. 2. *Numerically calculated polarization of a 1D bioelectrode at various film thicknesses,* L. *(a) Planar film showing reduced utilization as loading increases. (b) Porous electrode showing improved, but not perfect, utilization.*

Under these conditions, electrons are able to tunnel directly from the solid electrode phase into the enzyme, and vice versa. Combined with electron transfer to the substrate, this electron transfer current density therefore obeys a Butler-Volmer like dependence on potential:

$$i = i_0 \{\exp((V-U)/b) - \exp(-(V-U)/b\} \quad (1)$$

Here, i is current density, i_0 the exchange current density, V the electrode potential, U is reversible potential (where $i = 0$) and b is the Tafel slope.

Thin Film Model

In contrast, MET involves an additional molecular species, the mediator, that shuttles electrons between the electrode surface and an enzyme site that might be multiple microns away. This introduces issues of electron transfer between the electrode and mediator, transport of electrons by the mediator, and electron transfer between the mediator and the enzyme, shown schematically in Fig. 1a. Ideally, these processes occur with a thin film (the blue region of thickness L in Fig. 1a) where the enzyme and mediator are entrapped.

Surface-mediator electron transfer can be thought to follow Butler-Volmer kinetics, similar to DET. These kinetics are typically sufficiently fast to assume that the reactions are in equilibrium. In this case one can assume that the reduced and oxidized mediator concentrations (M_{ox} and M_{red} respectively) exist at the electrode surface in a ratio related to the electrode potential, V and redox potential of the mediator, U, by the Nernst Equation:

$$V = U + \frac{nF}{RT}\log\frac{M_{ox}}{M_{red}} = U + \frac{nF}{RT}\log\frac{M_{ox}}{M_{tot} - M_{ox}} \quad (2)$$

where F is Faraday's constant, R is the gas constant, T is temperature, and n is the number of electrons transferred between M_{ox} and M_{red} (typically $n = 1$). Here we have used the fact that the total mediator concentration, M_{tot}, is the sum of M_{ox} and M_{red}.

Transport of reactants occurs primarily by diffusion in electrolyte of sufficient ionic conductivity. The Nernst equation therefore describes the one-dimensional flux, N, of all species:

$$N_M = -D_M\frac{dM}{dx} \;;\; N_S = -D_S\frac{dS}{dx} \quad (3)$$

Here, D_M and D_S represent the diffusivity of mediator and substrate, respectively, M and S are concentration, and x is spatial position. The species in question are typically the mediator and substrate (Fig. 1a) but the concept of diffusivity is complicated when applied to the mediator. The mediator may be either a freely diffusing molecule, such as quinone, or an immobilized redox complex such as a redox polymer. For a redox polymer, the diffusivity D_i refers to the apparent diffusion of electrons through the polymer, because the redox moieties themselves do not move.[6] Additionally, if conductivity is low, migration effects due to potential gradients must be considered.[7]

Kinetics at the enzyme involve the simultaneous oxidation of mediator combined with reduction of the oxidant (at a cathode) or mediator reduction/fuel oxidation (anode). The kinetics can be quite complex, involving reactant-enzyme binding, reversibility, inhibition, and cooperativity in multi-site enzymes. Full-blown kinetics may include some dozens of parameters, and simplifications are usually required. For example, if only one form of the mediator exists in significant quantity, irreversible kinetics may be assumed. The simplest enzyme rate expression that accounts for mediator and substrate binding is the ping-pong expression:[8]

$$r = \frac{k_{cat}EMS}{K_M S + K_S M + MS} \quad (4)$$

where k_{cat}, K_M, and K_S are rate constants. This expression is not applicable to all enzymes, however, and more generalized approaches that account for reversibility and other kinetic mechanisms are available. Examples include the Hanekom and Liebermaster generalized rate laws.[9]

In 1D at steady-state and neglecting migration, the rate of change of diffusive flux of both mediator and substrate is related directly to the enzymatic reaction, leading to two second-order differential equations:[10-12]

$$-\frac{dN_M}{dx} = D_M\frac{d^2M}{dx^2} = \frac{\nu_S k_{cat}EMS}{K_M S + K_S M + MS} \quad (5)$$

$$-\frac{dN_S}{dx} = D_S\frac{d^2M}{dx^2} = \frac{\nu_S k_{cat}EMS}{K_M S + K_S M + MS} \quad (6)$$

Boundary conditions depend strongly on the physical system of interest. For example, the solid electrode is impermeable to the substrate, so the flux of substrate, N_S, is zero there. Similarly, the mediator may be retained in the electrode film, so the flux of mediator at the electrolyte film, N_M, is zero. Lastly, the Nernst equation (Eq. 2) can be used to relate the mediator concentration at the electrode to the

potential, and the bulk concentration at the electrolyte interface may be assumed. To summarize the boundary conditions:

$$\begin{aligned} &\text{at } x = 0 \;:\; V = U + \frac{nF}{RT}\log\frac{M_{ox}}{M_{tot} = M_{ox}} \;;\; \frac{dS}{dx} = 0 \\ &\text{at } x = L \;:\; \frac{dM}{dx} = 0 \;;\; S = S_0 \end{aligned} \tag{7}$$

The above equations represent a nonlinear set of coupled differential equations, whose solution can only be found numerically. Numerical solutions abound in the literature.[10-12] If simplifying assumptions are made, however, analytical solutions may be found. Bartlett et al. explore analytical solutions for simplified cases of these equations in detail.[10] More recently, Rajendran has reported an analytical solution for the case where the electrode is saturated in substrate, $S \gg K_S$.[13] Figure 1b shows a plot of mediator and substrate concentrations as well as the enzyme reaction rate as a function of position, calculated numerically for some typical conditions. Python code for this numerical solution is available online.[14]

Because this is an electrode, we are primarily interested in the current generated. We can calculate the current density from the mediator flux at the electrode surface according to Fick's law:

$$i = -nFD\left.\frac{dM}{dx}\right|_{x=0} \tag{8}$$

Figure 2a shows a polarization plot of current density vs. electrode potential for a range of electrode thicknesses, L. We see that the plateau current approximately doubles from L = 0.5 to 1 μm, but increases only a small amount at L = 2 μm, due to mediator mass transport limitations that lead to reduced enzyme utilization.

Porous Electrode Model

Practical electrodes require high surface area to achieve relevant current densities. In the case of biological fuel cells, this is most often achieved by immobilizing a thin film of the enzyme catalyst (plus mediator) on the surface of a high-surface area solid conductor such as carbon. There is some risk of immobilizing the enzyme directly on the carbon surface due to the possibility of denaturation.[15] In the case of hydrogel bioelectrodes, the risk is mitigated by the stabilization effect of the hydrogel as well as the reduced amount of enzyme directly contacting the surface.

Using a macrohomogeneous approach, the above thin film model can be applied to a porous electrode. The main new parameters to be introduced are the conductor surface area per volume, a, the porosity, ε, and the porous electrode thickness L_P. The thin film model is used to calculate the local consumption rate, R_p, within the porous structure, assuming some effective film thickness. For example, assuming a roughness factor aL_P, the film thickness of the porous electrode would be $L/(aL_P)$ where ^{L} is the film thickness for the planar case. The resulting material balance on the substrate becomes:

$$-\frac{dN_S}{dy} = D_S^e\frac{d^2M}{dy^2} = aR_pS \tag{9}$$

where is the effective diffusivity of substrate in the porous electrode, and y is the position within the porous electrode. Here we continue to neglect migration and convection terms. Using similar boundary conditions as the thin film model,

$$\text{at } y = 0 \;:\; \frac{dS}{dx} = 0 \;;\; \text{at } y = L_P \;:\; S = S_0 \tag{10}$$

We may solve this system numerically for the substrate concentration profile within the electrode, and calculate the current density as it relates to the substrate gradient concentration at the electrode-electrolyte interface

$$i = nFD_S^e\left.\frac{dS}{dY}\right|_{L_P} \tag{11}$$

As an example, Fig. 2b shows polarization curves for a glucose-oxidizing electrode using Toray paper as a substrate, for varying loading, L. Here the surface roughness was calculated by electrochemical capacitance measurements.[16] Utilization of the enzyme is improved, as the plateau current is approximately linearly dependent on L. However, the plateau does not reach the expected 8 mA cm^{-2} for L = 2 μm because substrate transport becomes rate limiting. Python code for this numerical solution is also provided online.[14] We have previously extended this approach to gas diffusion electrodes.[17]

Complete Cell Model

The above approaches can be combined to obtain a complete cell model. In this case, one typically wishes to prepare two electrode models that have matching current density, coupled via a common electrolyte. This common electrolyte might also contain substrates for each electrode- for example glucose for the anode and oxygen for the cathode. It is important to consider the effect of the each reactant at each electrode- for example oxygen is a natural substrate of glucose oxidase but glucose does not affect the activity of laccase at a laccase-catalyzed oxygen electrode.

To match current densities, one may choose to change the boundary conditions in Eq. 7, or just iterate the model over a range of potentials until the current densities at each electrode match a desired value. The latter approach is shown in Fig. 3, where the polarization of individual laccase and glucose oxidase electrodes are shown alongside the overall cell potential.

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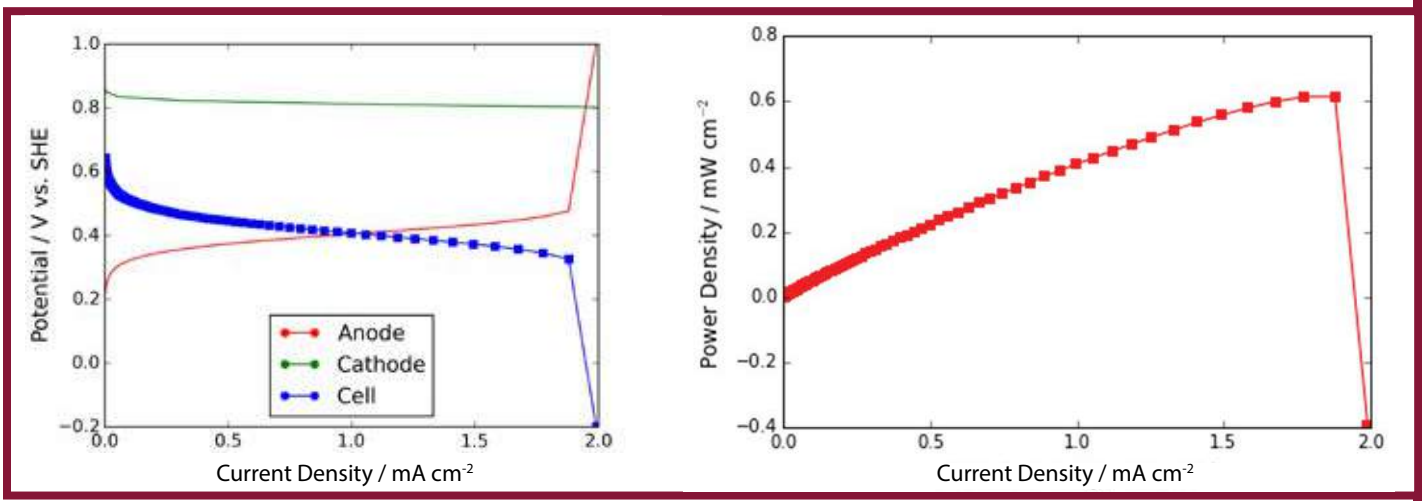

Fig. 3. *Complete cell polarization by taking the difference between anode and cathode polarization curves. (a) Cell polarization. (b) Cell power density. Details of the calculation are available online.*[14]

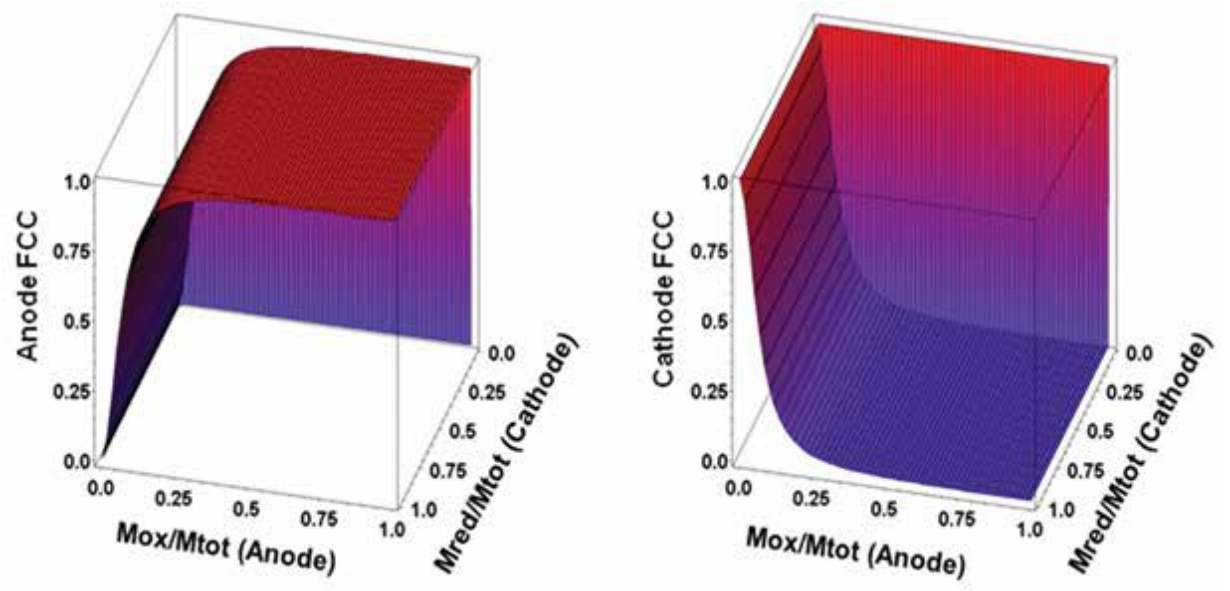

Fig. 4. *Flux control coefficients (FCCs) for a mediated glucose anode (left) and oxygen cathode (right) as a function of mediator redox state (Mox/Mtot for the anode and Mred/Mtot for the cathode) at ambient oxygen concentration (0.28 mM) and a total mediator concentration of 500 mM on each electrode.*[18]

Assuming that transport limitations can be ignored and that enzyme kinetics control overall biofuel cell performance, metabolic control analysis (MCA) can be applied to determine the degree of control of each electrode reaction over the fuel cell performance. For example, Glykys et al. have constructed a detailed MCA model for the glucose-oxygen fuel cell, and considered the degree of control by each electrode in terms of a flux control coefficient (FCC).[18] This model allowed a determination of the extent to which each electrode controlled cell current density and power at any potential, glucose concentration, or oxygen concentration (Fig. 4).

Parameterization

A challenging aspect of modeling bioelectrodes is determination of parameters. In particular, enzyme loadings and concentrations may be quite difficult to determine, and may change with time due to denaturation and de-immobilization. Often, nominal loading values are assumed, which do not account for these losses. In some cases, actual catalyst loadings may be determined analytically, for example using fluorescence approaches.[19,20] This remains an ongoing challenge in this research area.

In the case of hydrogel bioelectrodes, the film thickness resulting from formation of the hydrogel introduces significant uncertainty. This thickness can be nonuniform and range from nanometer to millimeter scales. Film thicknesses have been determined using a variety of techniques, including confocal microscopy,[21] profilometry,[11] and ellipsometry.[22] Hydrogel film thickness is also dependent on the degree of hydration of the film, making ex-situ measurements challenging. The results of film thickness measurements have direct impact on estimates of enzyme, mediator concentrations as well as mediator effective diffusivity measurements.[11] Therefore, good estimates of these parameters are essential for determination of kinetic parameters from performance data using the present models.

Multi-Enzyme Cascades

The above models are simplistic for many reasons, one of which is the fact that only one enzyme is utilized in each electrode. Examples of multi-enzyme systems have be extensively reported recently, primarily for deep oxidation of complex fuels such as methanol, glucose, and ethylene glycol.[23-25] Models of such systems have been reported, and include the enzyme kinetics for each individual step.[26,27] For example, Osman et al. report a complete, transient model for a glucose-oxygen biological fuel cell utilizing both glucose dehydrogenase mediated diaphorase at the glucose anode (Fig. 5).[27] Kinetic parameters, primarily drawn from the literature, are sufficient to closely predict the performance of each half-cell and the resulting overall cell.

A significant challenge is to account for transport of intermediates between each reactant step, and to consider the reversibility of the enzyme kinetics. For sufficiently large polarization, this reversibility can be neglected because a key product (such as a reduced mediator or cofactor) may be assumed to be absent. At intermediate potentials, however, this assumption may not be appropriate and reversible rate expressions are required. Regarding intermediate transport, loss of intermediates from the electrode is a significant factor that must be accounted for in the model. This is particularly important because the turnover rates of adjacent reaction steps may vary widely.

Summary

The above discussion reflects a simplified approach to modelling of biological electrodes applicable to biological fuel cells, sensors, and bioreactors. These models are useful for describing the relationship between individual physical properties and overall electrochemical performance, and can be used to for determination of unknown parameters and prediction of performance. Nonetheless, significant challenges arise in applying such models due to uncertainties in parameter estimation, and in the complex nonlinear kinetics and transport associated with enzymatic reactions. Such complexity increases with the number of biocatalysts included in a given electrode, and hence biological electrode modeling remains an area of significant research interest, with immense potential for further advances.

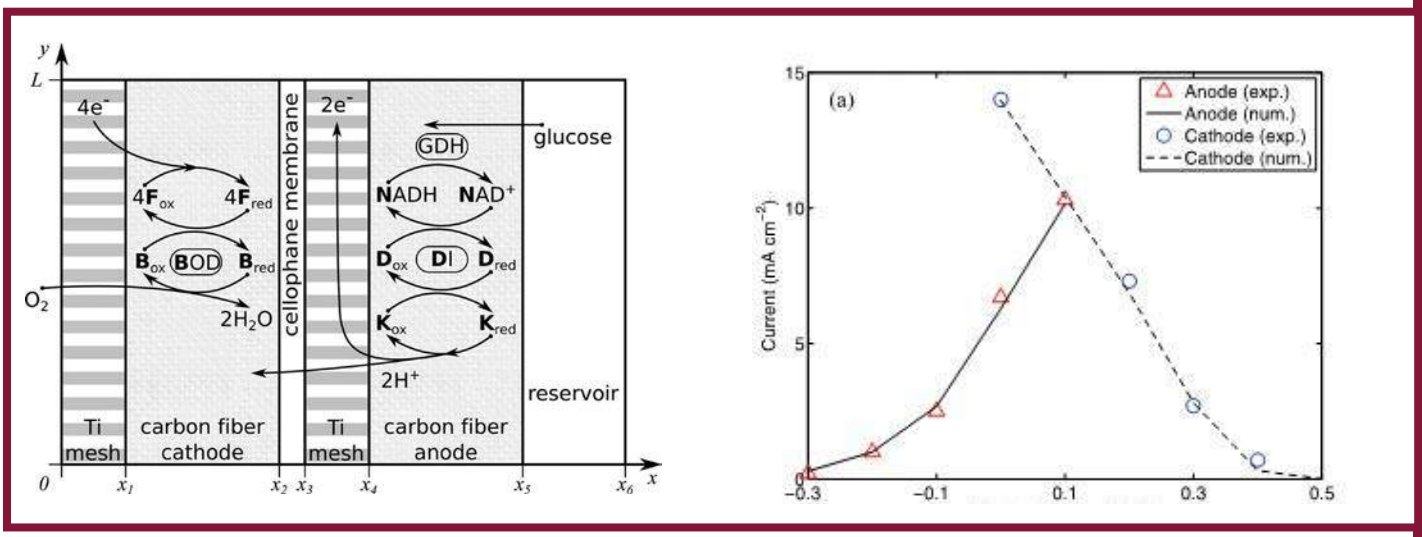

Fig. 5. *Complete model of a Glucose-oxygen fuel cell utilizing glucose dehydrogenase and diaphorase at the anode.[27] (a) Model schematic. (b) Model results for each half-cell closely match experiment.*

About the Author

Scott Calabrese Barton is an Associate Professor of Chemical Engineering at Michigan State University, where his research focuses on engineering and materials issues in low-temperature fuel cells, particularly transport processes in porous electrodes. His doctoral work in direct methanol fuel cells and zinc-air batteries at Columbia University led to postdoctoral studies of novel biofuel cell electrodes at the University of Texas at Austin. He is the recipient of a CAREER award from the National Science Foundation and a Petroleum Research Fund award from the American Chemical Society. He currently serves as Chair of the Energy Technology Division of ECS. He may be reached at scb@msu.edu.

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Photosynthetic Energy Conversion: Recent Advances and Future Perspective

by Narendran Sekar and Ramaraja P. Ramasamy

Photosynthesis is the most important natural process on earth, which transformed the once lifeless planet into a living world. While primitive photosynthetic bacteria such as purple sulfur bacteria and green sulfur bacteria carry out anoxygenic photosynthesis, producing elemental sulfur from hydrogen sulfide with the help of sunlight, cyanobacteria, algae and plants carry out oxygenic photosynthesis to convert water and carbon dioxide to sugars with the help of sunlight and release oxygen as a byproduct. The conversion of solar energy to chemical energy via photosynthesis with the release of oxygen has an evolutionary significance on life as we know it today. In fact, photosynthesis is the only natural process known on earth to form oxygen from water. Further, fossil fuels such as coal, petroleum and natural gas are formed from the remains of the dead plants by exposure to heat and pressure in the earth's crust over millions of years. With increasing energy crisis and environmental issues lately, now is the time to revisit photosynthesis in order to address these issues. In this context, a great deal of ongoing research is focused on utilizing photosynthetic energy conversion as a renewable, self-sustainable and environment friendly source of energy. When compared to the finite reserve of fossil fuels, sunlight, the energy source for photosynthesis, is abundant around the planet and is inexhaustible.

The earth receives solar energy at the rate of about 120,000 TW, which far exceeds our current global demand of ~16 TW.[1] However the only major technology available for solar energy conversion is photovoltaics (PV). PV devices such as solar panels generate electrical power by converting solar radiation into direct current electricity using semiconductors. Solar cells include first generation conventional wafer-based cells made up of crystalline silicon (Fig. 1a), second generation thin film solar cells (Fig. 1b) made up

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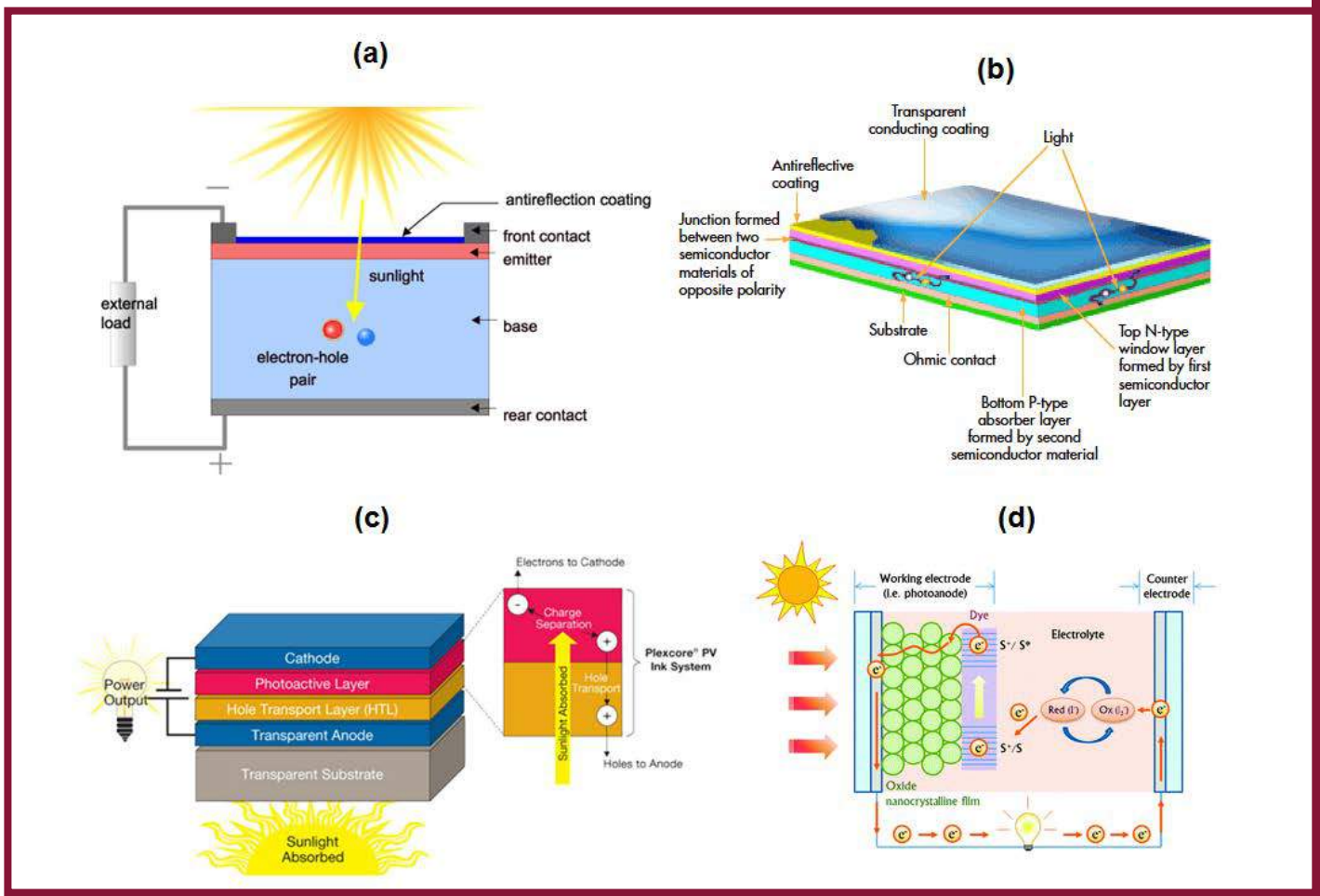

Fig. 1. *Schematic showing different photovoltaic technologies: (a) crystalline silicon solar cell; (b) thin film solar cell; (c) organic solar cell; and (d) dye sensitized solar cell.*

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of amorphous silicon, cadmium telluride, and copper indium gallium selenide, and third generation emerging solar cells such as organic solar cells (Fig. 1c), dye sensitized solar cells (DSSC) (Fig. 1d), and quantum dots solar cells, each with their own efficiency limits, advantages and disadvantages. Compared to the single junction solar cells (maximum efficiency of ~27% for crystalline Si cell with concentrator), gallium arsenide based multiple junction solar cells can reach efficiencies as high as 44%. However the PV-based technologies (some of which remain expensive today) are not suited for pushing the efficiency limits higher. This is main reason why alternate solar capture technologies based on natural photosynthesis are being explored. The internal quantum efficiency of the charge separation step in natural photosynthesis is ~100%. Further the charge carrier recombination time is much lower for photosynthesis-based light capture (>10^{-1} for PSII stacked membrane converter), compared to PV technologies (<10^{-3} for Si PV and <10^{-6} for organic PV) as shown in Table 1. Another remarkable feature that separates photosynthesis from traditional PV technologies is that photosynthesis contributes to global CO_2 sequestration (via the dark reaction), which can never be accomplished by any of the PV systems designed so far.

Table I. Performance comparison of natural photosynthesis versus different photovoltaic technologies (DSSC: dye sensitized solar cells; PV: photovoltaics; adopted from Pace 2005[58]).

Solar energy technology	Internal Quantum Efficiency	Theoretical Maximum Efficiency	Present Efficiency Range	Charge Recombination Duration
Silicon PV	~ 55 %	~ 25 %	18-24 %	≤ 10^{-3} s
Organic PV	10-30 %	-	2-6 %	≤ 10^{-6} s
DSSC	~ 90 %	~ 33 %	10-12 %	~ 10^{-1} s
Natural photosynthesis	~ 100 %	> 40 %	-	≥ 10^{-1} s

Mechanism of Photosynthesis

In higher plants, photosynthesis takes place in compartmentalized organelles called chloroplasts (Fig. 2). The inner matrix of chloroplast is called the stroma, in which thylakoids are organized into a structure similar to a stack of coins called granum (plural: grana) (Fig. 2). Photosynthesis consists of two reactions: (1) a light dependent reaction called the light reaction that takes place inside thylakoids (lumen); and (2) a light independent reaction called the dark reaction (Calvin cycle) that takes place in the stroma. During the light reaction, with the help of sunlight, water is oxidized to protons, electrons, and oxygen. The sequential steps of transferring the electrons from water to $NADP^+$ to generate NADPH are collectively called the photosynthetic electron transport chain (P-ETC) as shown in Fig. 3. P-ETC encompasses various protein complexes such as photosystem II (PSII), cytochrome b_6f, photosystem I (PSI) and ATP synthase, soluble proteins such as plastocyanin, ferredoxin and NADP reductase and plastoquinone that are embedded in the thylakoid membrane (Fig. 2). Both the photosystem complexes, namely PSI and PSII, contain chlorophylls at their core reaction center, where the actual charge separation happens upon light absorption thereby generating the excited electrons. When these photo-excited high energy electrons transfer down the energy gradient, the energy drop is harnessed to pump protons outside the thylakoid membrane. This generates the proton motive force necessary to generate ATP by ATP synthase. The NADPH and ATP generated in the light reactions are used in the dark reactions, during which the absorbed CO_2 is reduced to metabolites that subsequently form sugar (Fig. 4). The net reaction of photosynthesis is the synthesis of sugar using sunlight, water, and CO_2 while oxygen is released as a byproduct.

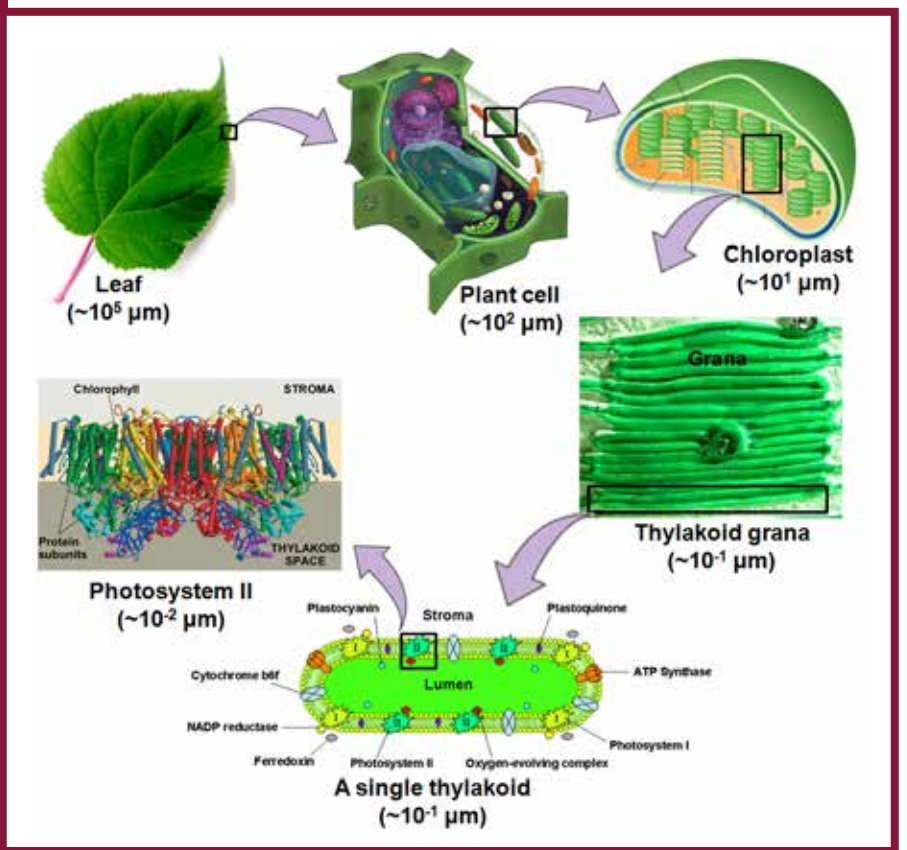

Fig. 2. *Hierarchical organization of photosynthetic machinery in thylakoids inside the chloroplast of plant cell (with relative dimensions mentioned in micrometers).*

Light energy can be harnessed in many ways using photosynthesis for either direct generation of electricity or the production of energy rich fuels like ethanol, propanol, butanol or hydrogen (Fig. 4).[2] For electricity and hydrogen generation, the light reaction is of the most concern; however, for the production of energy-rich carbon-based fuels, the dark reaction is exploited. Figure 5 shows different schemes of electricity generation in photo-bioelectrochemical cells (PBEC). The PBEC is made up of an anode containing a biocatalyst such as photosystem II (Fig. 5a), thylakoid membrane (Fig. 5b), or whole cell microorganism such as cyanobacteria (Fig. 5c) coupled with an enzymatic cathode. With the help of light, the biocatalyst on the anode transfers the electron generated from oxidation of water. On the cathode, enzymes such as laccase or bilirubin oxidase are employed that catalyze the reduction of oxygen to water. When such anodes are coupled with cathodes containing enzymes such as hydrogenase or nitrogenase, the system generates hydrogen (Fig. 5d). In either case, water and light are the only raw materials used to generate electricity and hydrogen, thereby making the system sustainable, economic, and environment friendly. On the other hand, the pathways in the Calvin cycle and the central carbon metabolism are manipulated to produce carbon based biofuels like ethanol, propanol, and butanol.

Electricity Generation

Direct conversion of light to electricity can be achieved in a photo-bioelectrochemical cell (PBEC) using natural photosynthetic machines as biocatalysts. The photosynthetic machines

include bacterial photosynthetic reaction center (RC), photosystem I and II (PSI and PSII) complexes, organelles such as thylakoids that are isolated from algae and plants, and whole cell photosynthetic microorganisms such as cyanobacteria and microalgae. When the biocatalyst used is a photosynthetic microorganism, the system is also called as photosynthetic microbial fuel cell (PMFC).[3] The PBEC systems based on the various biocatalysts (Fig. 6a) are discussed below.

Thylakoids, PSI, PSII ▸ Like any other bio-electrochemical system, the primary challenge in getting the photosynthetic machines to work on the electrode relies on the electrical communication between the biocatalyst and the electrode. The electrical communication is heavily dependent on the effectiveness of the attachment between the electrode and the biocatalyst and therefore the type of biocatalyst immobilization is of prime importance. The immobilization method determines how effectively the biocatalysts (thylakoids, PSI and PSII complexes) are tethered onto the electrode. An effective immobilization confers structural stability and retains biocatalyst activity.

Various attempts have been made to immobilize the isolated thylakoids onto different support matrices such as albumin-glutaraldehyde cross-linked matrix,[4] multi-walled carbon nanotubes,[5] encapsulating the thylakoid membrane vesicles onto conductive nanofibers by electrospinning,[6] and vapor deposition of thin layer of silica onto the thylakoid layer.[7] PSI complexes have been immobilized using several different strategies such as gold nanoparticle (GNP) modified electrode,[8] functionalized nano-porous gold leaf electrodes,[9] PSI-GNP hybrid electrode modified with 3-mercapto-1-propanesulfonic acid,[10] and via self-assembly onto zinc oxide nanomaterials.[11] The immobilization strategy is instrumental in dictating the orientation of biocatalyst on the surface as well as its proximity to the electrode. These two factors are very important for electrochemical reactions because the electron transport pathway inside the huge PSI and PSII complexes is strictly vectorial. A poly-histidine (His) tag and Ni(II)-nitrilotriacetic acid (Ni-NTA) system has been found to be profoundly useful in immobilizing PSII for its efficient photo-electrochemistry.[12-16]. Other significant improvements are witnessed by immobilizing PSII in osmium-containing redox polymer based on poly(1-vinylimidazole)[17] and a matrix of 2-mercapto-1,4-benzoquinone (MBQ), electro-polymerized on the gold surface.[18] Further, a lot of effort has been taken to maintain the activity of the isolated thylakoids and photosystems by mimicking the natural environment on the electrode[11,13] or by preventing the loss of activity through catalytic quenching of reactive oxygen species which otherwise reduces the activity of the photosynthetic machines.[19]

Photosynthetic Microorganism ▸ While relatively higher power densities were achieved using isolated photosynthetic machines such as RC, PSI, PSII or thylakoids, they are not practical for energy conversion systems due to: (1) requirement of laborious, skillful isolation procedures; (2) requirement of specific environmental conditions (pH, temperature, ionic concentration of surrounding media etc.,); (3) instability caused by photo damage; and (4) inability to self-repair upon photo damage, since they are present in an artificial environment devoid of their natural counterparts. All the above caveats can be overcome by employing the whole cell photosynthetic microorganisms in PBEC/PMFC. The whole cells retain all their native biological functions and therefore possess superior stability upon immobilization on electrode surfaces. Cyanobacteria such as *Synechococcus elongatus*,[20] *Synechocystis* sp.,[21,22] *Nostoc* sp.,[23] *Anabaena variabilis*,[24] and *Spirulina platensis*[25] and green algae such as *Chlamydomonas reinhardtii*,[26] *Chlorella vulgaris*,[27] and *Ulva lactuca*[27]are employed in the PMFC for light induced electric current generation. Compared to growing the culture of cyanobacteria in PMFCs with bare untreated electrodes,[22] growing cyanobacterial biofilm or immobilizing the cyanobacterial cells onto electrodes modified with nanostructure based support matrix such as polyaniline,[28] polypyrrole,[29] multi-walled carbon nanotubes,[23] and electrodes modified with osmium redox polymer,[30] indium tin oxide[31] have been shown to significantly improve the power density. When such an anode is combined with an oxygen reducing cathode, the oxygen evolved in photosynthesis would be subsequently reduced at the cathode and the entire system would be completely sustainable, environment friendly and requires only water and light for the generation of electricity.[23] However, the extracellular electron transport flux from P-ETC of the photosynthetic microorganisms to the electrode is fairly low compared to the extracellular electron transport flux of dissimilatory metal reducing bacteria (DMRB) such as *Geobacter* and *Shewanella* in microbial fuel cells (MFC).[32,33]. One way to address this is through the use of redox mediators such as 1,4-benzoquinone,[23,34] 2,6-dimethyl-1,4-benzoquinone,[34,35] 2-hydroxy-

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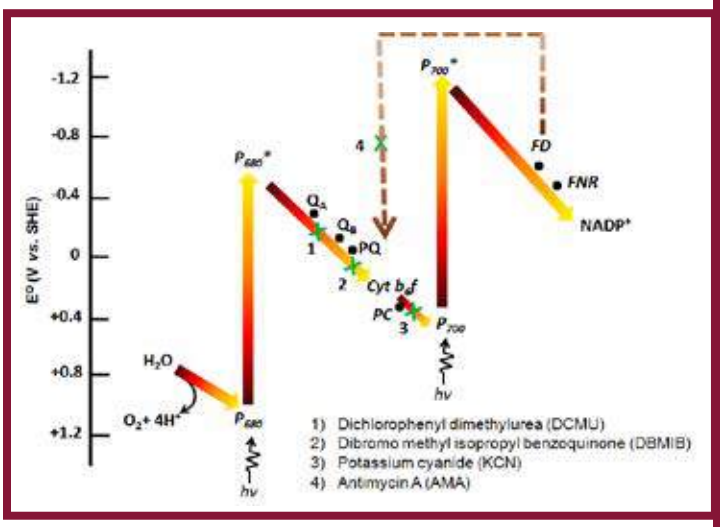

Fig. 3. *Z- scheme of linear photosynthetic electron transport chain (solid arrow) and cyclic electron transport chain around PSI (broken arrow) with all the components expressed along the redox potential scale; the green cross marks (1-4) represent the specific sites inhibited by the photosynthesis inhibitors such as DCMU, DBMIB, KCN and AMA. (P_{680}: photosystem II; P_{680}*: excited photosystem II; Q_A: Q_A site of photosystem II; Q_B: Q_B site of photosystem II; PQ: plastoquinone; Cyt b_6f: cytochrome b_6f complex; PC: plastocyanin; P_{700}: photosystem I; P_{700}*: excited photosystem I; FD: ferredoxin; FNR: ferredoxin NADPH reductase; NADP+: oxidised form of NADPH; Adopted from Sekar et al. 2015[2]).*

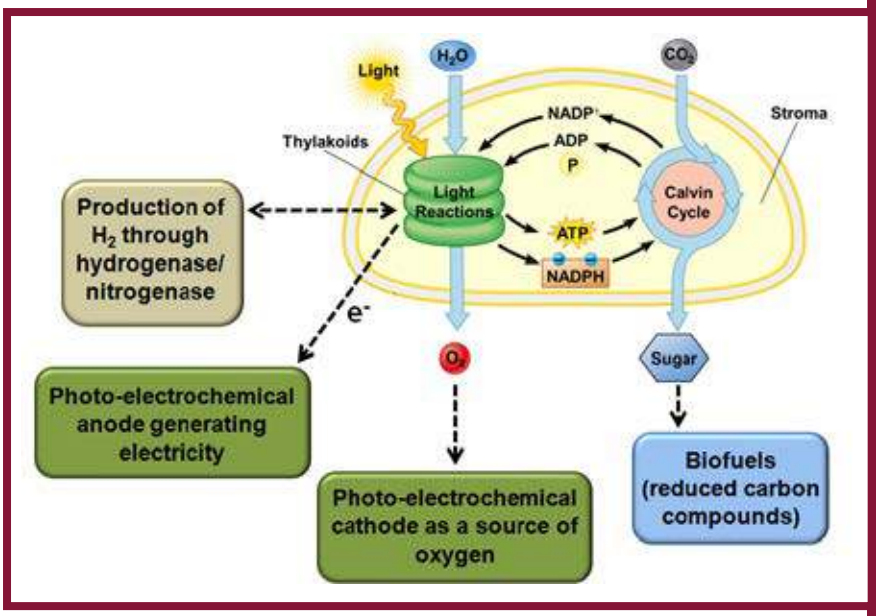

Fig. 4. *Chloroplast showing light reaction in thylakoid and dark reaction in stroma and utilization of these reactions for various applications such as generation of electricity, hydrogen and carbon based biofuels.*

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1,4-napthaquinone,[20] or phenazine methosulfate[36] that are permeable through the outer membrane of the living cell and greatly enhance the power density. However, from an energy conversion standpoint, the use of redox mediators decreases the overall cell voltage and therefore is not attractive. Moreover, mediators must be regenerated constantly, which introduces additional complexity to the system and hence is not attractive from a design standpoint. High power density can also be achieved by engineering a novel miniaturized systems such as microfluidic bio-photovoltaic devices[37] and micro-sized bio-solar cells,[38] however these systems are only suited for ultra-low power applications.

Genetic Engineering ▸ Regardless of the mode of extracellular electron transport (direct or mediated), the PMFC generally suffers from low electron flux because the electrons must be diverted from their native routes to alternate pathways to reach the electrode. These alternate electron-harvesting pathway are very difficult to achieve. A robust approach to efficiently collect more electrons from the P-ETC without using the redox mediators would be a welcome strategy to improve the performance of PMFC on par with that of MFC.[1,39] The photosynthetic microorganisms such as cyanobacteria have been performing photosynthesis for over 3.5 billion years. However they have not evolved for extracellular electron transport. Nonetheless, with the advancement of genetic engineering and molecular biology, these smart microorganisms can be made smarter to benefit our needs to generate more electricity. Analyses of electron transfer pathways from the P-ETC to the electrode leading to photocurrent generation on the PMFC anode would greatly help in understanding the mechanism of extracellular electron transfer as well as other bottlenecks which facilitates further optimization for enhancing photocurrent. This can be accomplished with the help of site-specific photosynthesis inhibitors that block a specific pathway in P-ETC as shown in Fig. 3. Using these inhibitors both individually as well in certain combinations, more precise source of photocurrent can be ascertained[5,23,40,41] and is very useful to engineer appropriate strategy to improve the photocurrent. For example, diverting electrons from earlier steps in P-ETC, say from PSII complex, contributes to more photocurrent and the conversion efficiency can be further increased (Table 1). Accordingly various efforts have been undertaken to collect more electrons from PSII.[42]

Certain genetic engineering approaches have been used to redirect the electrons from the photosystem complexes, thereby manipulating P-ETC for generating higher photocurrent. Electrons from Q_A^- in PSII were redirected to engineered collection sites approximately 13 Å away on the stromal side of the thylakoid membrane.[42] The positively charged amino acid lysine (Lys, K) at position 238 of D1 protein in PSII is important for the insulation of the PSII electron flow from external oxidation by soluble species and is also highly conserved in PSII of higher plants and algae. Modification of this lysine to glutamate (Glu, E), i.e., K238E resulted in alternative electron transfer pathway to soluble electron acceptor protein (cytochrome c) near the Q_A^- site.[42] This redirection along with the addition of an herbicide that blocks the electron flow at Q_B site resulted in decreased oxidative damage. In another attempt, cationic redox-active metal complexes

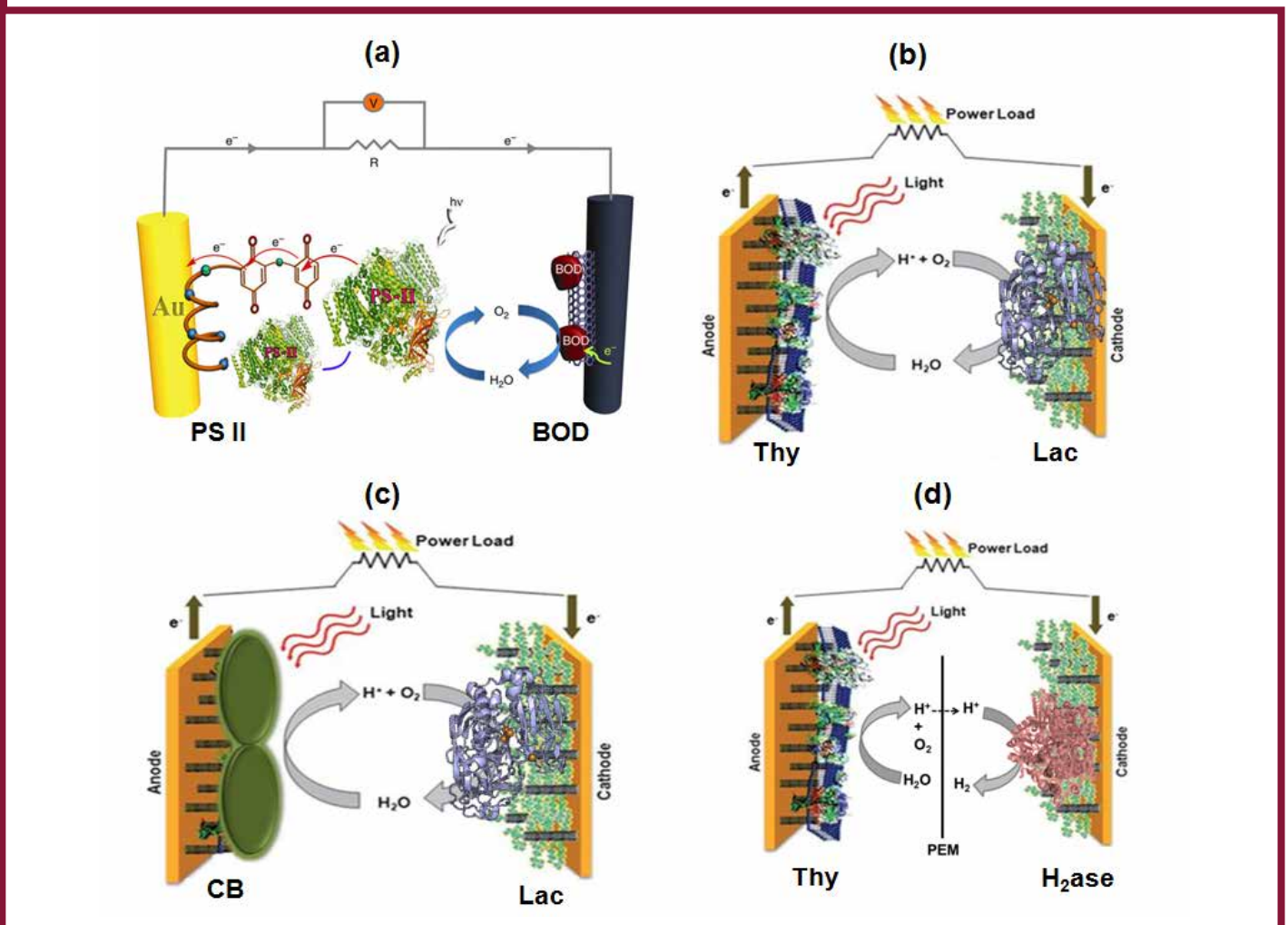

Fig. 5. *Schematic showing different photo-bioelectrochemical cell architectures for photosynthesis based electricity generation using biocatalysts such as (a) photosystem II (PSII);[18] (b) thylakoid (Thy);[5] (c) whole cell photosynthetic microorganisms like cyanobacteria (CB)[2] on the anode and enzymatic cathode employing laccase (Lac) and bilirubin oxidase (BOD); (d) hydrogen generation using thylakoid (Thy) on the anode and hydrogenase (H_2ase) on the cathode (PEM: proton exchange membrane).*

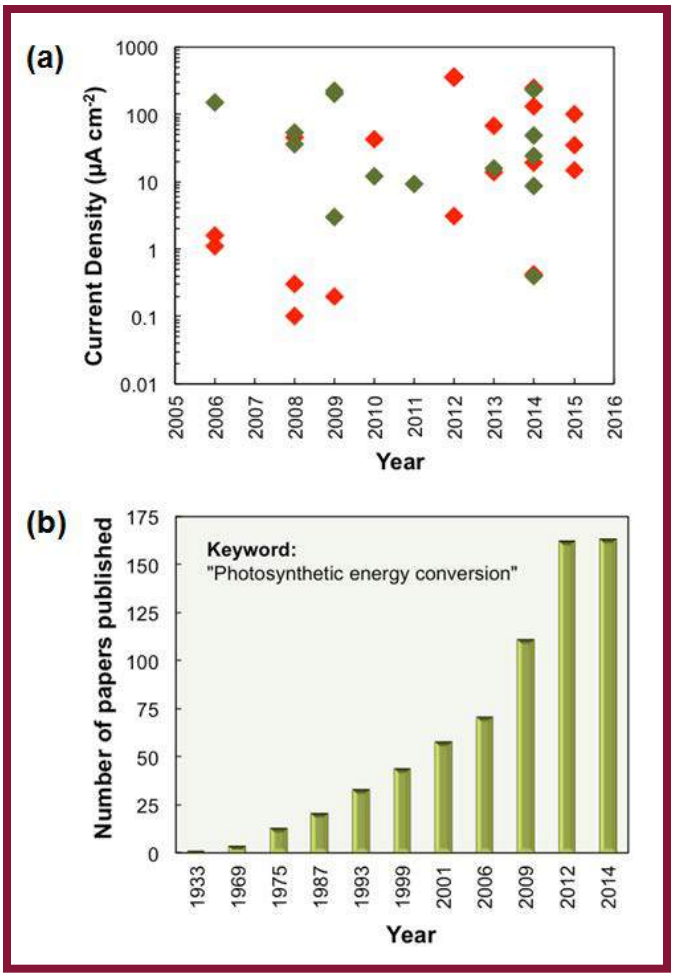

Fig. 6. *(a) Current density achieved in photo-bioelectrochemical cells in the last decade using thylakoids or photosystems (red filled marker) and whole cell microorganisms such as cyanobacteria or microalgae (green filled marker) as a biocatalyst on the anode; (b) Number of papers published in the research area of photosynthetic energy conversion (data collected from Web of Science database using the keyword "photosynthetic energy conversion").*

like Co^{III} complexes, small enough to fit in a 5 Å diameter negatively charged patch along the stromal side of the membrane were also used to redirect electrons from Q_A^- site.[43]

Cyanobacteria, algae and green plants contain chlorophyll-a (Chl-a) as the primary photosynthetic pigment in their PSI and PSII complexes. Chl-a strongly absorbs only blue (430 nm) and red (670-680 nm) lights. Light harvesting complexes in algae and green plants and phycobilins in cyanobacteria contain accessory pigments that absorb visible light in the range of wavelengths neglected by the Chl-a, thereby increasing the action spectrum of photosynthesis. In any case, they cannot absorb light beyond the red end of visible spectrum. However, another class of photosynthetic bacteria such as green bacteria and purple bacteria contain bacteriochlorophylls (BChl) that absorb strongly in near infrared region spectrum (705–1040 nm range). Further, Chl-a present in both PSI and PSII compete for the same light which theoretically reduces the efficiency by half. Replacing one of these Chl-a in the photosystems with BChl could effectively enhance the existing efficiency by a factor of two, similar to the multi-junction solar cell with different bandgaps and greatly broadens the action spectrum of photosynthesis to the near infra-red region.[1] Besides the recommendation and discussion of the prospects this genetic modification could bring, no attempts have been made yet in this pursuit.

An interesting feature unique to cyanobacteria is that both P-ETC and R-ETC are functional in their thylakoid membrane. The photosynthesis and respiration reactions share certain components such as plastoquinone pool, cytochrome b_6f complex and cytochrome c_6 or plastocyanin.[44] This peculiar organization in cyanobacteria is the primary reason for its capability to generate electricity under both light and dark conditions[23] unlike PBEC based on isolated thylakoids, PSI and PSII, which can generate electricity only in light. The light-induced generation of electrons in P-ETC can be used up by either quinol oxidase or cytochrome oxidase in R-ETC and vice versa. Indeed the overlapping of photosynthesis and respiration is a protective mechanism evolved to handle excess electrons.[40,45] The photocurrent generated by live cyanobacteria can be attributed to the overflow of the excess electrons from the P-ETC on excessive light absorption.[40] From a PMFC perspective, the R-ETC can be considered as a competitive pathway for electron transport that decreases the electron flux to the electrode thereby decreasing the photocurrent generation. Some or all of the competing oxidases in R-ETC were knocked out of cyanobacteria through genetic manipulations that resulted in more electrons being available for photocurrent generation.[46] Further, the superior electron transfer ability of DMRB such as *Geobacter* and *Shewanella* can be predominantly attributed to the cytochromes present in their outer membrane collectively called as outer membrane cytochromes (OMC). Imparting these efficient extracellular electron transfer ability of DMRB to cyanobacteria through genetic manipulations can be a ground breaking and remarkable milestone in cyanobacterial photosynthetic energy conversion. Recently, one such novel and innovative manipulation has been successfully carried out by our group.[47]

Hydrogen and Other Biofuels

Hydrogen is one of the most attractive alternate energy carriers that are expected to replace fossil fuels for transportation applications. Currently, the production of hydrogen is carried out through conventional steam reforming, electrolysis and thermolysis. All these three methods are expensive and operate at high temperatures and pressures. Steam reforming uses hydrocarbons, which are non-sustainable, and generates CO_2 as byproduct. On the contrary, photosynthesis based hydrogen production is carried out at ambient temperature using photosynthetic microorganisms which generates hydrogen as part of their metabolism by simultaneously sequestering CO_2 in a photobioreactor.[48] Further, cyanobacteria such as *Synechocystis* are employed in bio-photoelectrolysis cells[49] for generating hydrogen. In vivo, hydrogen is produced with the help of metallo-enzyme complex called hydrogenases, which catalyze the reversible oxidation of hydrogen to protons and electrons. Hydrogen is also produced as a by-product during nitrogen fixation by other enzyme complexes called nitrogenases in nitrogen fixing cyanobacteria such as *Cyanothece* and *Anabaena*. The ferredoxin in the P-ETC is the electron donor for both nitrogenases and hydrogenases. In vitro, the photosynthetic route for hydrogen production would involve an electrochemical full cell with photosynthetic machinery such as PSII as biocatalyst on the anode and enzyme that can catalyze the reduction of protons such as hydrogenase on the cathode as shown in Fig. 7. To date, the highest production rate was achieved by Melnicki et al. (2012), who witnessed sustained H_2 production by a unicellular cyanobacterium *Cyanothece* through photosynthetic process in an electrochemical cell. Under continuous illumination and a nitrogen-deprived environment, cyanobacteria cells in the photo-bioreactor generated H_2 at the rate of 400 μmol/mgChl/h.[50] Though the production of H_2 through photosynthetic means is quite inspiring and challenging, a huge leap in productivity is required for this technology to supersede the conventional production of H_2. With the advancement of metabolic engineering and synthetic biology, attempts are being carried out in cyanobacteria namely *Synechococcus elongatus* PCC 7942 and *Synechocystis* sp. PCC 6803 to synthesize complex biofuels and biofuel precursors such as ethanol,[51,52] 1,2-propanediol,[53] 1-butanol,[54] 2-methyl-1-butanol,[55] isobutyraldehyde and isobutanol.[56] More literature for biofuel production in cyanobacteria has been found in reviews such as those by Machado and Atsumi (2012).[57]

(continued on next page)

Concluding Remarks

Photosynthetic energy conversion is a sustainable, renewable, clean and environment-friendly process. It has an enormous potential to be an alternative energy technology that could effectively replace the finite fossil energy. The field of research has already witnessed major breakthroughs towards generating electricity, hydrogen and other chemical fuels (Fig. 6b). However the technology is still primitive and the performance parameters such as power density, biocatalyst stability, and output require huge improvements before the technology can be considered for any practical application. Modern genetic engineering tools offer prospects for engineering the biology towards enhanced energy conversion. There have been a few endeavors towards this outlook, but more interdisciplinary research work encompassing molecular biology, protein engineering and metabolic engineering along with electrochemistry is required to reach a paradigm shift towards realizing a true biological solar cell based on natural photosynthesis as an alternative power source.

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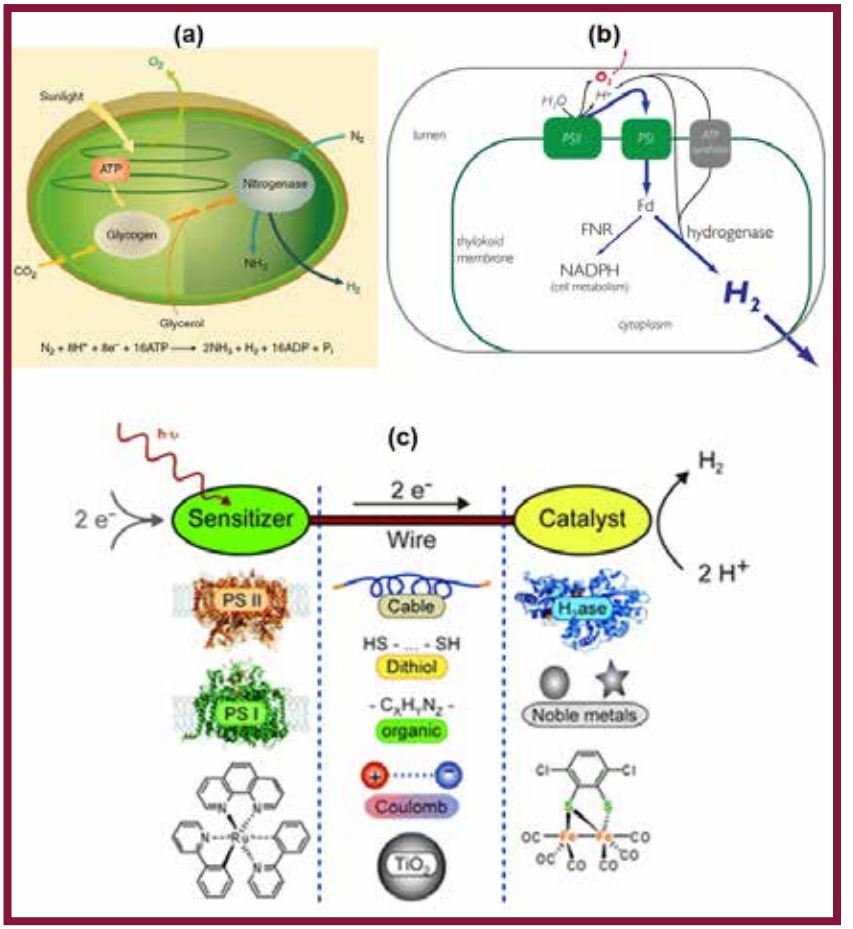

Fig. 7. *Photosynthesis based hydrogen generation in vivo using (a) nitrogenase; (b) hydrogenase; and (c) in vitro by combining photosystem (PSII/PSI) and hydrogenase (H_2ase).*[59]

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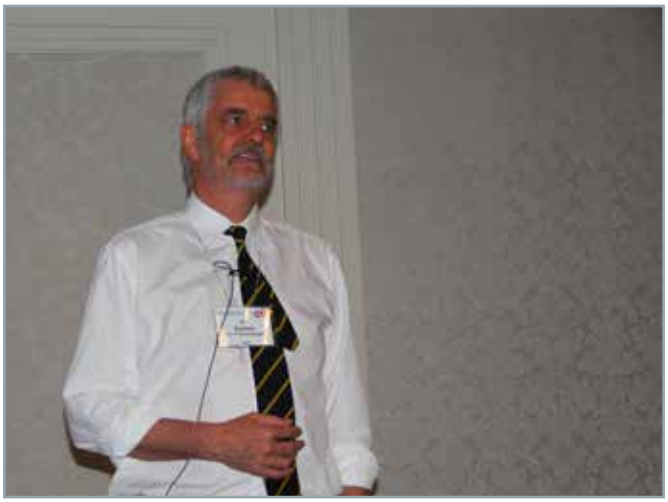

Philip Bartlett, *the 2014 winner of the Europe Section Alessandro Volta Medal.*

The **Europe Section** membership bridges most countries of Europe, which would make it seem impossible for the members to meet regularly. However, the Section membership traditionally meets twice a year — at each ECS biannual meeting. The meeting is usually held on Sunday evening at 6 PM. This year, at the May 2015 meeting in Chicago, Enrico Traversa, the new Section chair, took the helm from Noel Buckley, who guided the Section for a number of years.

While it is the norm for the members to meet for a wine and cheese reception, seldom is a photographer available to take a group picture. The Chicago meeting was a happy exception.

The Section also participates through appropriate symposia at which the winners of the Section awards are recognized and give their award presentations. The 2014 winner of the Europe Section Alessandro Volta Medal was Philip Bartlett, University of Southampton, who gave his presentation at the May 2015 meeting. The winner of the 2015 Europe Section Heinz Gerischer Award is Adam Heller (University of Texas at Austin). He is scheduled to receive his award and give a presentation in Phoenix, at the fall 2015 ECS meeting.

A group photo from the reception of the Europe Section.

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ECS Awards

Fellow of The Electrochemical Society was established in 1989 as the Society's highest honor in recognition of advanced individual technological contributions in the field of electrochemical and solid-state science and technology, and active ECS membership. The award consists of an appropriately worded scroll and lapel pin.

Go to www.electrochem.org/society to start the nomination process.
Materials are due by February 1, 2016

The **Allen J. Bard Award** was established in 2013 to recognize distinguished contributions to electrochemical science and exceptionally creative experimental or theoretical studies that have opened new directions in electroanalytical chemistry or electrocatalysis. The award consists of a plaque, the sum of $7,500, complimentary meeting registration, a dinner held in recipient's honor during the designated meeting, and Life Membership in the Society.

Go to www.electrochem.org/society to start the nomination process.
Materials are due by April 15, 2016.

The **Gordon E. Moore Medal** was established in 1971 for distinguished contributions to the field of solid state science and technology. The award consists of a silver medal, a plaque, the sum of $7,500, complimentary meeting registration, a dinner held in recipient's honor during the designated meeting, and Life Membership in the Society.

Go to www.electrochem.org/society to start the nomination process.
Materials are due by April 15, 2016

ECS Division Awards

The **Corrosion Division Herbert H. Uhlig Award** was established in 1972 to recognize excellence in corrosion research and outstanding technical contributions to the field of corrosion science and technology. The Award will consist of $1,500 and an appropriately worded scroll and the recipient may receive (if required) financial assistance from the Corrosion Division toward travel expenses to the Society meeting at which the award is presented.

Go to www.electrochem.org/division to start the nomination process.
Materials are due by December 15, 2015.

The **High Temperature Materials Division Outstanding Achievement Award** was established in 1984 to recognize excellence in high temperature materials research and outstanding technical contributions to the field of high temperature materials science. The award consists of an appropriately worded scroll and the sum of $1,000. The recipient may receive (if required) complimentary registration and up to $1,000 in financial assistance from the High Temperature Materials Division toward travel expenses to the Society meeting at which the award is made.

Go to www.electrochem.org/division to start the nomination process.
Materials are due by January 1, 2016.

The **Luminescence and Display Materials Divisions Centennial Outstanding Achievement Award** was established in 2002 to encourage excellence in luminescence and display materials research and outstanding contributions to the field of luminescence and display materials science. The award consists of a certificate and the sum of $1,000.

Go to www.electrochem.org/division to start the nomination process.
Materials are due by January 1, 2016.

The **Sensor Division Outstanding Achievement Award** was established in 1989 to recognize outstanding achievement in the science and/or technology of sensors and to encourage excellence of work in the field. The award will consist of an appropriately worded scroll and the sum of $1,000. The recipient is required to attend the Society meeting to receive the award and to give a lecture on topics for which the award is made.

Go to www.electrochem.org/division to start the nomination process.

Materials are due by March 1, 2016

The **Battery Division Research Award** was established in 1958 to recognize excellence in battery and fuel cell research, and encourage publication in ECS outlets. The award recognizes outstanding contributions to the science of primary and secondary cells, batteries and fuel cells. The award consists of a certificate and the sum of $2,000.

Go to www.electrochem.org/division to start the nomination process.

Materials are due by March 15, 2016.

The Battery Division Technology Award was established in 1993 to encourage the development of battery and fuel cell technology, and to recognize significant achievements in this area. The award is given to those individuals who have made outstanding contributions to the technology of primary and secondary cells, batteries, and/or fuel cells. The award consists of a certificate and the sum of $2,000.

Go to www.electrochem.org/division to start the nomination process.

Materials are due by March 15, 2016.

The **Electrodeposition Division Research Award** recognizes outstanding research contributions to the field of electrodeposition and encourages the publication of high quality papers in this field in the Journal of The Electrochemical Society. The award shall be based on recent outstanding achievement in, or contribution to, the field of electrodeposition and will be given to an author or co-author of a paper that must have appeared in the Journal or another ECS publication. The award consists of a certificate and the sum of $2,000.

Go to www.electrochem.org/division to start the nomination process.

Materials are due by April 1, 2016.

ECS Student Awards

The **Corrosion Division Morris Cohen Graduate Student Award** was established in 1991 to recognize and reward outstanding graduate research in the field of corrosion science and/or engineering. The award consists of a certificate and the sum of $1,000. The award, for outstanding Masters or PhD work, is open to graduate students who have successfully completed all the requirements for their degrees as testified to by the student's advisor, within a period of two years prior to the nomination submission deadline.

Go to www.electrochem.org/student to start the nomination process.

Materials are due by December 15, 2015.

The **Battery Division Student Research Award** recognizes promising young engineers and scientists in the field of electrochemical power sources. The award is intended to encourage the recipients to initiate or continue careers in the field. Eligible candidates must be enrolled in a college or university at the time of the nomination deadline. The award consists of a certificate and the sum of $1,000.

Go to www.electrochem.org/student to start the nomination process.

Materials are due by March 15, 2016.

The **ECS Outstanding Student Chapter Award** was established in 2012 to recognize distinguished student chapters that demonstrate active participation in The Electrochemical Society's technical activities, establish community and outreach activities in the areas of electrochemical and solid state science and engineering education, and create and maintain a robust membership base.

Please visit the student awards page at www.electrochem.org/awards for complete rules and nomination requirements. Nominations are being accepted for the 2016 award, which will be presented at the ECS fall meeting in Honolulu, HI, October 2-7, 2016. For questions or additional information, please contact awards@electrochem.org.

Materials are due by March 31, 2016.

Travel Grants

Several of the Society's Divisions offer travel assistance to students, postdoctoral researchers, and young professionals presenting papers at ECS meetings. For details about travel grants for upcoming ECS biannual meetings and to apply, visit the ECS website at www.electrochem.org/travel_grants. Please be sure to review travel grant requirements for each Division. Formal abstract submission is required for the respective meeting you wish to attend in order to apply for a travel grant. For questions or additional information, please contact travelgrant@electrochem.org.

Submission deadlines for upcoming ECS biannual meetings:

- **229th ECS Meeting, San Diego, CA – February 12, 2016**
- **PRiME 2016, Honolulu, HI – June 10, 2016**

Fellowships

The **ECS Toyota Young Investigator Fellowship** was establish in 2014 to support young professors and scholars with a research focus in green energy technology. The Fellowship begins September 1, 2016 and will be awarded to a minimum of one candidate. To qualify, candidates must be under 40 years of age and working in North America. The winner(s) will receive a restricted grant of no less than $50,000 to conduct research outlined in their proposal.

Visit www.electrochem.org/awards for more information. For questions, please contact awards@electrochem.org.

Materials are due by January 31, 2016.

Discover Your Community

Your ECS membership defines you as a leader in your field – as someone who believes in:

- Disseminating scientific research in the most accessible ways
- Advancing the science by bridging the gaps between academia, industry, and government
- Mentoring young people through networking and by providing quality training and education
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"I just like to disseminate my results. To share what I've done with others and help grow the field. That's why I'm a member."
– Researcher and 12-year ECS member

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- **The ECS Member Article Pack—$3,300 VALUE—**100 free downloads from all ECS journals giving you access to full-text articles in the ECS Digital Library, including the top publications in solid state and electrochemical science and technology:
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Yuhua Xia, London, UK
Yingying Xie, Shanghai, P.R. China
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Yunjie Xu, Chicago, IL, USA
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Zhenpeng Yao, Evanston, IL, USA
Nanami Yokota, Canterbury, UK
Dian Yu, Los Angeles, CA, USA
Shankaracharya Zance, Karaikudi, Tamilnadu, India
Guangtong Zeng, Los Angeles, CA, USA
Fan Zhang, Chicago, IL, USA
Yunzhu Zhang, Chicago, IL, USA
Shuai Zhao, Mansfield Center, CT, USA
Fabio Zheng, Colorno, Italy
Yihao Zhou Durham, NC, USA

ECS 2015 Summer Fellowship Winners

Each year ECS awards Summer Fellowships to assist students in continuing their graduate work during the summer months in a field of interest to the Society. Congratulations to the following five Summer Fellowship recipients in 2015. The reports of the 2015 Summer Fellows will appear in the winter issue of *Interface*.

Gen Chen is the recipient of the 2015 ECS Edward G. Weston Summer Fellowship. He is currently a PhD candidate in the Department of Chemical and Materials Engineering at New Mexico State University, working with Hongmei Luo on the nanoscale engineering of heterostructured composites for energy conversion and storage. He received my BE (2009) and MS (2012) in materials science from the Central South University, China. He has published more than 20 papers in peer-reviewed journals, given many presentations, and been serving as a reviewer for many electrochemical energy storage-related journals. In 2014, he and his colleagues developed a synthetic strategy of "solvothermal route based in situ carbonization to transition metal compounds with carbon,", which can be extensively applied for the acquiring of electrode materials with good electrochemical performances. During his academic program, he has also been awarded the merit-based Enhancement Award and Outstanding Graduate Award by New Mexico State University many times. In the future he pictures himself to be a researcher with a strong desire to make novel nanomaterials and nanostructures widely applied in the electrochemical energy storage field.

Hadi Khani is the recipient of the 2015 ECS Colin Garfield Fink Summer Fellowship. He received his BS degree in Chemistry from the University of Aark, Iran, in 2007. He then joined Tarbiat Moallem University (now Kharazmi University) and was awarded his MSc in Analytical Chemistry under the supervision of M. H. Mashhadizadeh. For his MSc research, he worked on ion-selective electrodes and electrochemical sensors. After his MSc graduation in 2009, he joined the Iranian Research & Development Center for Chemical Industries where he worked on multidisciplinary industrial research projects. In 2012 he began his PhD study in the Department of Chemistry at Mississippi State University (MSU) under the supervision of David Wipf. At MSU, he has undertaken a research program that not only includes work in chemistry but also research activity to support a minor degree in mathematics and statistics. His PhD research is mostly focused on scanning electrochemical microscopy (SECM) and supercapacitors. For his summer fellowship, he has proposed a high-resolution SECM imaging based on nanometric size pH electrodes to study the "crystal structure orientation-electrocatalytic activity" relationship of Pt and Ir oxide surfaces for water-splitting, ORR, and HOR reactions.

Mohammad Mahdi Hasani-Sadrabadi is currently a graduate researcher studying bioengineering at Georgia Tech. Aside from his current studies, Hasani-Sadrabadi spent time at the Swiss Federal Institute of Technology in Lausanne, where he developed microfluidic platforms for controlled synthesis of polymeric nanoparticles. In 2007, he began his research on fuel cells while at Amirkabir University of Technology. He continued to establish the Biologically-Inspired Developing Advanced Research (BiDAR) group as an international collaborative research time. His main research area of interest is the development of bio-inspired nanomaterials for energy and biomedical applications which the results of his researches are published as more than 40 peer-reviewed papers with average impact factor of about 5.3 in different journals with total citation of about 750 and his h-index is 17. Among his many awards are the ACS CELL Student division award (2015), ECS Joseph W. Richards Summer Fellowship (2015), ECS Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Awards (2015), POOIA Student Scholarship, (2015), and Grand Prize Winner of Dr. Baker Award for Fuel Cell Research (2012).

Raphaële Clément is the recipient of the 2015 ECS F.M. Becket Summer Fellowship. Raphaële obtained her BA and MSc in Natural Sciences (Chemistry) at the University of Cambridge. She spent her third year of undergraduate studies at the Massachusetts Institute of Technology (MIT), as part of the Cambridge-MIT Exchange (CME), and worked in the research group of Daniel Nocera on the CoPi water oxidation catalyst. While working on her Masters, she spent time at the European Nuclear Magnetic Resonance facility (CRMN) in Lyon, France, working under the co-supervision of Clare Grey, Lyndon Emsley, and Guido Pintacuda on the study of the $LiFe_xMn_{1-x}PO_4$ lithium-ion battery cathode using paramagnetic solid-state Nuclear Magnetic Resonance. Raphaële is currently a PhD candidate in the Department of Chemistry of the University of Cambridge, under the supervision of Clare Grey. Her thesis research focuses on layered sodium transition metal oxides for sodium-ion battery cathode applications, investigated using a combination of ab initio Density Functional Theory calculations and solid state Nuclear Magnetic Resonance. Her collaborations with the research groups of Shirley Meng (UCSD), Peter Bruce (Oxford), and Teofilo Rojo (CIC EnergiGUNE), have been very successful and have lead to publications in high-impact journals. In September 2014, she co-organized an international conference and workshop on the "New Developments in Experimental and Theoretical Nuclear Magnetic Resonance Techniques for the Study of Paramagnetic Materials" in Cambridge, UK.

Alexander J. Pak is the recipient of the 2015 ECS H. H. Uhlig Summer Fellowship Award. In 2010, he received his BS in Chemical Engineering from the Massachusetts Institute of Technology. Here, he developed a passion for solving global challenges such as energy conversion and storage, water purification, and affordable medical care and diagnosis. Alex is currently a PhD candidate in Chemical Engineering at the University of Texas at Austin under the guidance of Gyeong S. Hwang. His thesis research is focused on understanding fundamental charge storage mechanisms at the interface of graphene-based materials, with a specific emphasis on supercapacitor applications, by utilizing a combined density functional theory and classical molecular dynamics computational approach. He has co-authored 11 peer-reviewed journal publications, presented his research at numerous national society conferences, and is a co-inventor on a patent. Outside of research, Alex enjoys mentoring middle-school and high-school students in the principles of nanotechnology and computational research. He is also actively involved as a member of the Graduate Chemical Engineering Leadership Council.

Student Award Winners

Matteo Bianchini has been named the Battery Division's 2015 Student Research Award recipient. He began his scientific career at the Polytechnic University in Milan, where he obtained his Bachelor's degree (2009) and Master of Science (2012) in Physics Engineering. During this time, Bianchini had many transformative experiences in the sciences, including a semester spent at the University of Amsterdam in 2010 as part of the Erasmus Programme.

In 2011, Bianchini gained experience in the world of large scientific instruments through and internship with ID26, where he worked on x-ray absorption and emission spectroscopy. Bianchini's PhD focused on advanced characterization of electrode materials for lithium-ion and sodium-ion batteries.

Bianchini's research focuses primarily on real-time (operando) diffraction experiments using neutrons, x-rays, and synchrotron radiation to student lithium and sodium (de) intercalation processes inside rechargeable batteries. Through collaboration with different institutes on this project, Bianchini has been able to access different domains of electrochemical and diffraction fields.

Eric Schindelholz has been named the Corrosion Division's 2015 Morris Cohen Graduate Student Award recipient. He is a senior member of technical staff at Sandia National Laboratories. He received his PhD in Materials Science at the University of Virginia (UVA) in 2014 under the direction of Professor Robert Kelly. His graduate work focused on understanding the interrelationship between the hygroscopic behavior of marine atmospheric particles and the humidity dependence of steel corrosion associated with these particles.

Prior to his studies at UVA, Schindelholz served as a conservator in both federal and private institutions, specializing in the corrosion assessment and mitigation of historic artifacts and monuments.

His present work includes electrochemical measurement and modeling of atmospheric corrosion, corrosion in supercritical fluids and advanced materials.

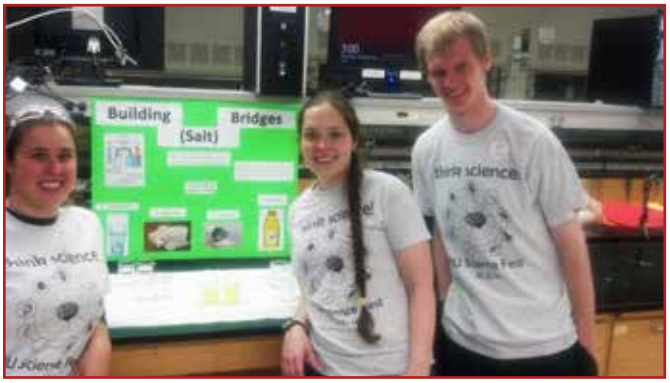
The student award winners will each be giving an award talk at the upcoming Phoenix meeting. See page 32 in this issue for more information about the time and place of these talks.

Student Chapter News

Indiana University Student Chapter

Students of Indiana University have continued to promote The Electrochemical Society this year on the Bloomington campus. In addition to regular social activities such as decorating cookies and playing friendly volleyball matches, the Chapter participated in the campus-wide Science Fest and organized a seminar speaker visit.

On October 25, 2014, our Chapter prepared a chemistry room to showcase electrochemical science at the Indiana University inaugural Science Fest (expanded from the Chemistry Open House, which was organized in previous years). In keeping with the theme of science in food, members set up a demonstration of cyclic voltammetric detection of capsaicin and used a multimeter to determine whether a popular sports drink is a good salt bridge and able to pass as much current as salt water (young scientists determined that it behaves more like sugar water). The Chapter also held a Minute-to-Win-It-like electron relay race to demonstrate changing oxidation states. The most popular activity by far, however, was the creation of "Squishy Circuits" using insulating sugar and conductive salt doughs. They encouraged visitors to get creative with their circuit-sculpture designs and showed them that, if they incorporated a light-emitting diode in the dough three-dimensional circuitry connected to a power supply, they would be able to turn on the light. This sparked a lot of great discussions about conductivity and circuitry components.



Indiana University Student Chapter members (left to right) **Lauren Strawsine**, **Erin Martin**, *and* **John Rose** *at the Science Fest.*

A third annual spring seminar was organized to host (by Chapter member vote) guest speaker, Nathan Lewis, the George L. Argyros Professor of Chemistry at the California Institute of Technology. Professor Lewis was enthusiastic about spending as much time with students as possible; immediately after his arrival in Bloomington, he met with Chapter members for a dinner and social time. Much of his visit was spent meeting with various research groups and discussing the challenges of individual student projects. Professor Lewis then was invited to present a seminar in his own charismatic style, highlighting his work with artificial photosynthesis. Following the April 8, 2015 seminar, Professor Lewis again met with students at a reception to further discuss aspects of his work with charge transfer and anode/cathode development. Our friends, electrochemistry students from the University of Illinois, drove through rough weather to join the Chapter for this seminar and were able to discuss their research with him at this time as well. He continued debating energy advances up until the moment chapter officers saw him off to the airport.

The Chapter is grateful for the opportunities that ECS provides in meeting with such accomplished and enthusiastic speakers, and is eagerly looking forward to planning next year's events.

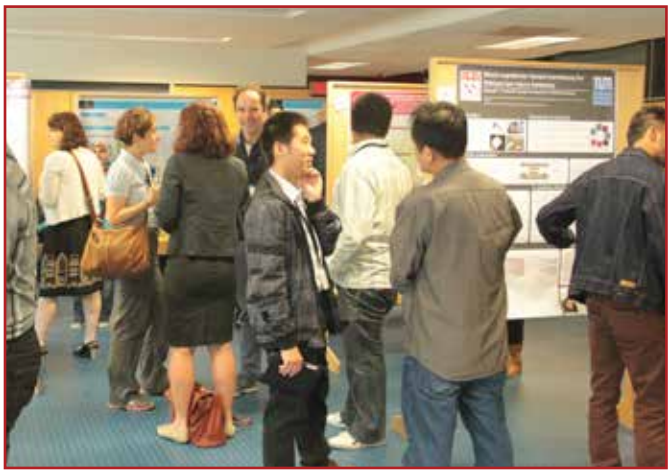
The members of the Indiana University Student Chapter with seminar speaker **Nathan Lewis** *(fourth from left).*

Montreal Student Chapter

The 5th ECS Montreal Student Symposium took place on June 5, 2015, at McGill University, Canada, sponsored by Pine Research Instrumentation, Metrohm Canada, SnowHouse Solutions, Centre québécois sur les matériaux fonctionnels (CQMF), McGill Chemistry, Association étudiante du Secteur des sciences de l'Université du Québec à Montréal, and the Post-Graduate Students' Society of McGill University. More than ninety participants took part in the annual symposium, hailing from eight universities in Montreal, Sherbrooke, Halifax, London, as well as a national research center. The attendees enjoyed 16 talks and 16 posters, including the two invited presentations of Jeff Dahn (Dalhousie University) and Dominic Rochefort (Université de Montréal). Prof. Dahn's talk entitled "Advanced Diagnostics to Learn about Li-ion Battery Failure Mechanisms" discussed novel characterization and tools to diagnose Li-ion batteries performance. Moreover, he mentioned that, starting in next July, his industrial partnership was moving with Tesla. On a related topic, Prof. Rochefort presented his recent research entitled "Electroactive Ionic Liquids in Energy Storage Devices" about future electroactive ionic liquid electrolytes for potential application in batteries.

Prizes for the best oral and best poster presentations were awarded to Mark McArthur from McGill University for his talk on "Mixed Metal Oxide / Functionalized Carbon Nanotube Composite Electrodes for Electrochemical Energy Storage," and Andrew Danis from McGill University for his poster on the "Electrogenerated Chemiluminescence (ECL) of Self-Assembled Ruthenium-Containing Nanospheres for Bioassay Applications." Further information about the ECS Montreal Student Chapter can be found at http://ecsmontreal.blogspot.com or visit us on Facebook.

The 5th ECS Montreal Student Symposium attracted more than ninety students and faculty members from Montreal, Sherbrooke, Halifax, and London universities and research centers.



Students in discussions during the poster session.

ECS Montreal Student Chapter committee.

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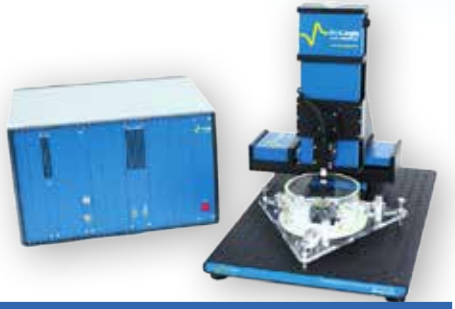

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