The Electrochemical Society
Interface

FULL ISSUE (PDF)

Electrochemistry in Space

To cite this article: 2020 *Electrochem. Soc. Interface* **29** 1

The Electrochemical Society
INTERFACE™
VOL. 29, NO. 1, Spring 2020


Photo: NASA

ELECTROCHEMISTRY IN SPACE

FUTURE ECS MEETINGS

237th ECS Meeting

with the 18th International Meeting on Chemical Sensors (IMCS 2020)

MONTRÉAL, CANADA
May 10-14, 2020
Palais des congrès de Montréal

PRiME 2020

HONOLULU, HI
October 4-9, 2020
Hawaii Convention Center & Hilton Hawaiian Village

239th ECS Meeting

CHICAGO, IL
May 30-June 3, 2021
Hilton Chicago

240th ECS Meeting

ORLANDO, FL
October 10-14, 2021
Orange County Convention Center

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The Presents of Presence

There has been a recent resurgence in the practice of mindfulness, in which one focuses on the present moment, accepting without self-judgement one's feelings, sensations, and thoughts. Being present in the moment is another description. Research has demonstrated multiple benefits, including stress reduction, lowered emotional reactivity, and increased satisfaction in relationships. There are numerous ways to achieve and practice mindfulness, including meditation, as well as simply intentionally paying attention to one's present situation, actively ignoring thoughts about other things outside of the present. Pretty simple to do, obviously positive, no negative side effects. What idiot wouldn't do it? Spoiler alert: this idiot.

I have been described by some as a work "enthusiast." I plead guilty to the fact that I truly enjoy what I do (except for grading, which if I never have to do it again, it will still be too soon). I also get an inappropriately good feeling from crossing things off my "To Do" list. Despite all the research that shows multitasking actually reduces productivity, I still do it because, I guess, I think I am special. If I am not overcommitted, I feel like I am cheating the world or something. (Those who know me already are snickering thinking about my extolling the benefits of living in the moment.)

Just after New Year's, my family went to Snowshoe, WV to go skiing. I was a little anxious about it; I had not skied since I suffered a major knee injury in a hunting accident six years ago (it was an *Easter egg* hunting accident, but that is another story). I also was a little anxious because I knew that the cell reception on the mountain is, in a word, terrible. Although normal humans might be concerned about the potential safety issues associated with that lack of coverage, the clearly more important aspect is that I would not be able to check my email on the chairlift. I would be incommunicado for *hours*. How would the world survive? More importantly, how would I survive?

It turns out, both the world and I survived quite nicely, thank you. I am not sure about what the world experienced, but I was forced to *be* for hours at a time. Being disconnected forced me to be in the moment, not only during the skiing down the expert slopes (by "expert" I mean "beginner"—you know, for my daughter, Jenna), but also during the lift ride back up the mountain. At first, I thought that it was a chance for my brain to turn off, but I realized that instead, it was a chance for my brain to be on—on one thing. The one thing could be feeling (and seeing) my breathing in the mountain air and taking in the amazing views of the Allegheny Mountains, trees covered in fresh snow, breeze helping them shed the flakes. I felt stress melt away that I didn't even know I had. Even more impactful was when I focused on others, talking to my family on the lift or while playing board games after the day of skiing was over. Those moments made me wish that both the lift rides and nights were longer.

Of course, all Kelly family trips have some story involving our Whippets. In this case, I found myself awake at 4:30 am, walking the two knuckleheads in a refreshing 13°F (-10°C) night with 20 mph (9 m/s) winds. I was so mindful of not freezing to death, I followed their lead back. Oddly, the door was locked and my code did not seem to work. Knowing Heather obviously was breathlessly awaiting my triumphant return, I knocked until the door opened—by the man renting the house next door. He was far more understanding than I would have been, and I hope my later delivery of a bottle of wine and a mea culpa provided positive feedback for his behavior. Once I entered the right house, Heather simply shook her head.

That glitch aside, it was a fantastic break. I hope that my experience with forced mindfulness will carry over now that I have returned home. They say that making your resolutions public increases the likelihood of meeting them. As I look forward to the rest of 2020, I resolve to be more in the moment with my students, my family, and my colleagues. I reserve the right not to be during political commercials. Although it was not my plan to have an epiphany, in retrospect, I think Heather knew exactly what she was doing when she booked our ski trip where she did. She is a crafty one. Until next time, be safe and happy.

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The Electrochemical Society
INTERFACE

Published by:
The Electrochemical Society (ECS)
65 South Main Street
Pennington, NJ 08534-2839, USA
Tel 609.737.1902, Fax 609.737.2743
www.electrochem.org

Canada Post:
Publications Mail Agreement #40612608
Canada Returns to be sent to:
Pitney Bowes International, P.O. Box 25542,
London, ON N6C 6B2

ISSN : Print: 1064-8208 Online: 1944-8783

The Electrochemical Society Interface is published quarterly by The Electrochemical Society (ECS), at 65 South Main Street, Pennington, NJ 08534-2839 USA. Subscription to members as part of membership service; subscription to nonmembers is available; see the ECS website. Single copies $10.00 to members; $19.00 to nonmembers. © Copyright 2020 by The Electrochemical Society. Periodicals postage paid at Pennington, New Jersey, and at additional mailing offices. POSTMASTER: Send address changes to The Electrochemical Society, 65 South Main Street, Pennington, NJ 08534-2839.

The Electrochemical Society is an educational, nonprofit 501(c)(3) organization with more than 8,500 scientists and engineers in over 75 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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The Electrochemical Society

INTERFACE™

Vol. 29, No. 1
Spring 2020

ECS

NASA astronaut Andrew Morgan works while tethered on the Port 6 truss segment of the International Space Station to replace older hydrogen-nickel batteries with newer, more powerful lithium ion batteries. The batteries store and distribute power collected from the station's basketball court-sized solar arrays, one of which is directly behind Morgan. Image and caption courtesy of NASA.

Cover design by Dinia Agrawala.

Why We Do What We Do

Greetings and welcome to the first edition of *Interface* for 2020 and the new decade to come!

As I begin my second full year with ECS, I want to share some thoughts that illustrate why I am so grateful, and inspired, to serve as executive director of this amazing organization.

As an undergraduate student, I was fortunate to complete part of my degree at a school in Germany. When the Berlin demonstrations began in the autumn of 1989, my friends and I left school, with the full support of our professors, to join the growing, peaceful movement that ultimately led to the fall of the Berlin Wall in early November of that year. It was a profound, life-changing experience that enabled me to learn first hand how seemingly disparate people can join together to advance a common good. When I think about it now, more than 30 years hence, I still feel a deep connection to that time in Berlin because ECS and learned societies like it have successfully worked toward that same common good for centuries.

ECS Director Jannuzzi *on the Berlin Wall all those years ago.*

Despite the fact that I am not a scientist, engineer, or researcher, through our work with ECS, the rest of the professional staff and I support the world's leading minds in the electrochemical and solid state fields as they work to not only advance our technical understanding, but to divine solutions to the grand challenges facing humanity today. For me, being part of the global ECS community and sharing in our commitment to encourage research, discussion, critical assessment, and dissemination of knowledge, provides strength and hope in a troubled time.

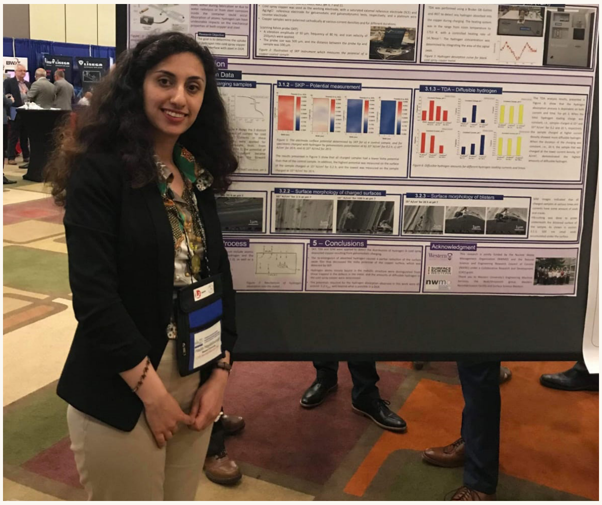
And now is certainly a troubled time. We recently received devastating news about a promising student member of the ECS community who was tragically taken from her family, friends, and colleagues. Her name is Hadis Hayatdavoudi and she was among the nearly 200 passengers and crew aboard Ukraine International Airlines Flight 752 downed on January 8.

We learned Hadis was on Flight 752 when Jamie Noël, Chair of the ECS Education Committee and her PhD advisor at Western University in Canada, wrote to ask if he would be able to present her paper, *Hydrogen Absorption By Copper Coated Steel Used Nuclear Fuel Container Materials Under Deep Geological Repository (DGR) Conditions*, slated for the 237th ECS Meeting taking place in Montréal this coming May. When we read Jamie's email, a pall fell over the office as we processed what Jamie was asking, and why he was asking it.

Our sadness deepened as we learned more about Hadis. Said Jamie in a piece on the Western University website (www.uwo.ca) about the first time he met her, "There she is, this young woman coming from halfway around the world, on her own, to a completely different culture and a completely different language, smiling and saying, 'Here I am, your student.' "

Hadis's passing is a senseless, unfathomable loss on both a human and scientific level, but heartbreaking as it is, let it remind us of why we do what we do. Teachers, students, and colleagues, reaching out across borders, across ideologies, across anything that would otherwise serve to divide us. We work together to make the world a better place for all. That is why Hadis and Jamie did it, that is why countless others in the ECS and scientific community as a whole have done it, and that is why the world needs all us to keep doing it now.

To the family, friends, and loved ones of Hadis Hayatdavoudi, and all those affected by the tragedy of Flight 752, we extend our deepest condolences and sympathies.



Hadis Hayatdavoudi *proudly presents her poster, Hydrogen Absorption by Cold Spray Deposited Copper.*

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NOBEL LAUREATES AT ECS MEETINGS – PART 1

by John Lewis

The Electrochemical Society had the honor of hosting a keynote talk at our October biannual meeting by M. Stanley Whittingham, exactly one week after he was awarded the 2019 Nobel Prize in Chemistry (with John Goodenough, and Akira Yoshino) for his work on lithium ion batteries. His presence at the fall meeting in Atlanta, GA, added a level of excitement not seen since Rudolph Marcus learned of his 1992 Nobel award while at an ECS meeting. After the meeting, we investigated connections between Society meetings and the Nobel Prize, and discovered them woven together through every decade of ECS's existence.

Indeed, ECS has been privileged over its 118-year history to have 30 Nobel Laureates (representing 14 Chemistry and eight Physics Nobel Prizes) participate at Society meetings. Their involvement ranges from giving plenary, keynote, and invited talks, to serving on panels, addressing ECS leadership groups, co-authoring innumerable presentations, and giving tours of their labs. Even more notable is that many of these distinguished minds shared their research with ECS *before* they won, illustrating the importance of the electrochemical and solid state sciences to the scientific community over the past 100 plus years.

The Early Years

"I believe it is very important that a Society should form the common ground for the electrochemical interests in the United States, where, favored by natural resources and fostered by broad-minded and indefatigable chemists, a wonderful development of electrochemistry has been accomplished. I want to express the heartiest wishes for the further success of your work…"[1]

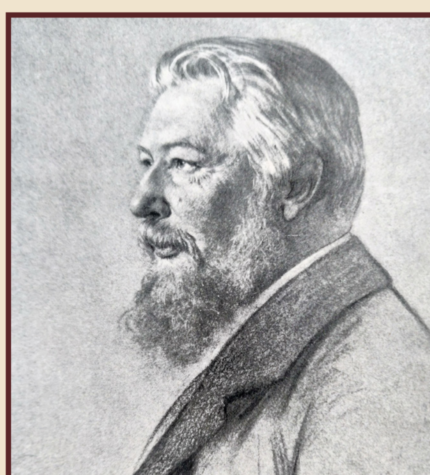
With these words, Fritz Haber began his technical presentation to the attendees of the American Electrochemical Society (AES) in Niagara Falls, NY, on September 17, 1902. Though only the second AES meeting —AES would become ECS in 1930[2]—this marked the first time that a Nobel Laureate would give a presentation at an AES/ECS meeting (*see Appendix*).

A chemist by trade, Haber won the Nobel Prize in 1918 for his role in creating the Haber–Bosch process, a method used in industry to synthesize ammonia from nitrogen gas and hydrogen gas. Though his work had a significant effect on the large scale synthesis of fertilizers to assist with global food production, it also was used by Germany to manufacture explosives in World War I, something that engulfed Haber in controversy over his personal role in the war efforts.

In 1903, Walther Hermann Nernst gave the opening talk at the fall meeting in New York City. He was awarded the 1920 Chemistry Nobel for his work on the Nernst heat theorem used in the development of the third law of thermodynamics. During his keynote on vapor densities in an electric furnace, he passed around an apparatus used in his experiments. Based on the proceedings paper, this was most likely an iridium bulb manufactured by Heraeus, which resulted in his "relatively simple and certain method for determining molecular weights up to about 2,200 degrees."[3]

The 1904 fall meeting in St. Louis, MO (the sixth overall) featured papers by not one or two, but three future Nobel winners for Chemistry: Haber (again), Theodore William Richards, and Wilhelm Ostwald. In recognition of his work determining the atomic weight of many chemical elements, Richards won in 1914, while Ostwald was honored in 1909 for his work on catalysis, chemical equilibria, and rates of reaction. To put this in perspective, only 15 papers in total were contributed to the St. Louis meeting, and 20 percent were from future Nobel Laureates.

As impressive as this may be, none of these Laureates attended the meeting in person. Their talks were presented by colleagues. Given the many challenges faced at today's meetings with author attendance (funding, visas, schedules, travel issues, etc.), it was consoling to discover that this problem is not new for scientific conferences. Though Haber and Ostwald did not attend further meetings, Richards went on to contribute and present a paper in person at the 1912 fall meeting in New York City. An interesting footnote is that Richards received one vote for Society vice president during the spring 1905 meeting in Boston, MA.[4]



A pastel portrait of **Wilhelm Ostwald**. *Published in* Transactions of the American Electrochemical Society, *Vol. VIII, 1905*.

> *The Electric Insulation Division of The Electrochemical Society acknowledges its indebtedness to P. Debye without whose imagination, vision, and inspiration many advances in dielectrics would not have been possible.*[8]
>
> —Scroll presented to P. Debye at 1953 New York City meeting.

After his talk in the fall of 1910, Robert Andrews Millikan, a local resident, invited lucky attendees at the Chicago, IL, meeting on a personal tour of his University of Chicago lab. There they saw his famous oil-drop apparatus which measured the elementary electric charge of a single electron, one of the experiments that contributed to Millikan's winning the 1923 Nobel Prize in Physics. Also notably, at the end of Millikan's talk, he briefly discussed Felix Ehrenhaft's work, an early reference to what became a longstanding dispute between the two scientists over their research.

Millikan returned to the 1912 spring meeting in Boston, MA, with a talk updating the research he reported in 1910. He also participated in a discussion on electric conduction with Owen Willans Richardson, who won the 1928 Physics prize for his work on thermionic emission. Richardson had developed his eponymous law by 1912 and treated the attendees to a talk on metallic conductors. Millikan and Richardson are noted as two of the speakers at an informal attendee "dinner at which interesting speeches were made,"[5] leaving one to wonder exactly what was discussed that evening.

Irving Langmuir presented three times at ECS meetings; the first at the fall 1911 meeting in Toronto, Canada, then in spring 1913 in Atlantic City, NJ, and spring 1916 in Washington, DC. The lead author on the first paper presented at the fall 1913 Denver, CO, meeting, Langmuir could not attend to present it himself. In his spring 1913 address on the convection and radiation of heat, Willis R. Whitney (a founder of the General Electric Research Laboratory) described Langmuir's work as "what the Germans call *bahn brechend,*"[6] or "groundbreaking." Whitney might have been predicting Langmuir's 1932 win in Chemistry. During the 1916 meeting in DC, Langmuir also received one vote for vice president in the Society elections.[7]

Prior to 1942, all of the winners who gave talks at ECS meetings had yet to receive their Nobel prizes. Peter Debye spoke at four Society meetings. He gave his first talk at the 1927 spring meeting in Philadelphia, PA before receiving the 1936 Chemistry prize for his work on the study of molecular structure. In 1942, at the fall meeting in Philadelphia, Debye then became the first speaker to address an ECS audience as a Nobel Laureate. He returned to the 1953 meeting in New York City.

Debye's final talk at an ECS meeting was the keynote speech at the Theoretical Division luncheon at the 1957 Washington, DC, meeting. He also participated informally in a symposium at this meeting on the structure of electrolytic solutions (see *The Age of Electronics*).

Jaroslav Heyrovský, who received the 1959 Chemistry prize for his work in polarography, addressed the spring 1931 meeting in Birmingham, AL. He later contributed discussion comments to a paper being presented at the spring 1938 meeting in Savannah, GA. Heyrovský took issue with the authors' paper, which was based on his own research on the cathode ray oscillograph as applied to the dropping mercury electrode. The authors considered theirs an improvement on Heyrovský's method. In his comments and response to the authors, Heyrovský made clear his opinion that their work was neither useful nor an improvement.

The Age of Electronics

ECS was in the thick of things as the scientific world began focusing attention on the research and applications of electronics in the 1950s. At the 1953 New York City meeting where Peter Debye was honored, William Shockley, co-winner of the 1956 Physics prize, addressed the general attendees and gave the Joseph Richards Memorial Lecture. Shockley received the prize for his work on semiconductors and discovery of the transistor effect. He was also an amateur magician. As an added bonus, he performed magic tricks for meeting attendees. The Richards Lecture (now called the ECS Lecture) was given sporadically between 1932 and 1958, with Shockley's being the penultimate one.

Henry Taube spoke at the spring 1954 meeting in Chicago. When he received the 1983 Chemistry prize for his work on electron transfer reactions, the Nobel committee cited the research done at the time of his Society presentation.[9] Of further interest, at the time of his award, Taube was the first inorganic chemist to win the prize since 1913.

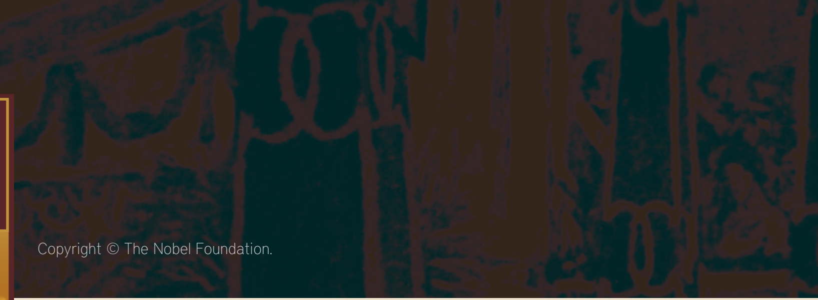
History does not confirm whether Walter Houser Brattain, a 1956 co-winner with Shockley, presented his talk at the 1954 Chicago, IL meeting. He co-authored four other papers between 1955 and 1964.

(continued on next page)

Peter J. Debye *speaks at the luncheon meeting of the Electric Insulation Division on Wednesday. Published in* Journal of The Electrochemical Society*, Vol. 100, No. 6, June 1953, p. 161C.*

William Shockley*, of Bell Telephone Laboratories, delivers the Richards Memorial Lecture on Wednesday afternoon. Published in* Journal of The Electrochemical Society*, Vol. 100, No. 6, June 1953, p. 161C.*

APPENDIX[12]



- Wilhelm Ostwald wrote a paper for the 1904 St. Louis, MO meeting on "Electrolysis and Catalysis." He was later recognized with the 1909 Nobel Prize in Chemistry *"in recognition of his work on catalysis and for his investigations into the fundamental principles governing chemical equilibria and rates of reaction."*
- Theodore William Richards wrote a paper for "The Relation of the Hypothesis of Compressible Atoms to Electrochemistry" at the 1904 St. Louis, MO meeting and spoke on "The Electrochemical Behavior of Very Concentrated Thallium Amalgams" at the 1912 New York City meeting. He was awarded the 1914 Nobel Prize in Chemistry *"in recognition of his accurate determinations of the atomic weight of a large number of chemical elements."*
- Fritz Haber presented a paper on "The Phenomenon of the Formulation of Metallic Dust from Cathodes" at the 1902 Niagara Falls, NY meeting and wrote "The Carbon Cell" for the 1904 St. Louis, MO meeting. He was awarded the 1918 Nobel Prize in Chemistry, "*for the synthesis of ammonia from its elements.*"
- Walther Hermann Nernst presented a paper on "Determination of Vapor Densities in an Electric Furnace" at the 1903 meeting in New York City. He was awarded the 1920 Nobel Prize in Chemistry, *"in recognition of his work in thermochemistry."*
- Robert Andrews Millikan presented a paper on "The Unit Charge in Gaseous Ionization" at the 1910 meeting in Chicago. At the 1912 meeting in Boston, he presented a paper on "The Oil Drop Method of Studying Electrical Phenomena in Gases." He also was a participant in "Discussion on Electron Conduction." Millikan was awarded the 1923 Nobel Prize in Physics, *"for his work on the elementary charge of electricity and on the photoelectric effect."*
- Owen Willans Richardson presented a paper at the 1912 meeting in Boston, "The Electron Theory of Metallic Conduction." He also was a participant in "Discussion on Electron Conduction." Richardson was awarded the 1928 Nobel Prize in Physics, *"for his work on the thermionic phenomenon and especially for the discovery of the law named after him."*
- Irving Langmuir presented a paper at the 1911 meeting in Toronto, Canada on "Thermal Conduction and Convection in Gases at Extremely High Temperatures." In 1913, he wrote a paper for the meeting in Atlantic City, NJ on "Convection and Radiation of Heat." At the Denver, CO meeting that year, he was a lead author of "Flow of Heat thru Furnace Walls: The Shape Factor." In 1916, Langmuir presented a paper on "The Relation Between Contact Potentials and Electrochemical Action" at the meeting in Washington, DC. He was awarded the 1932 Nobel Prize in Chemistry, *"for his discoveries and investigations in surface chemistry."*
- Peter Debye presented a paper on "The Dielectric Constant of Electrolyte Solutions" at the 1927 meeting in Philadelphia. At the 1942 meeting in Detroit, MI, he presented "Reaction Rates in Ionic Solutions." In 1953, he presented "Historical Interpretations of the Concept of Molecular Change" at the New York City meeting. Debye also spoke at the 1957 meeting in Washington, DC at the Theoretical Division Luncheon. He was awarded the 1936 Nobel Prize in Chemistry, *"for his contributions to our knowledge of molecular structure through his investigations on dipole moments and on the diffraction of X-rays and electrons in gases."*

Rudolph A. Marcus *gets the call from the Royal Swedish Academy of Sciences. Published in* Interface*, Winter 1992, Vol. 1, No. 1.*

It is not known if he presented these either, however, it is likely that he attended some of these meetings. Brattain was at the 1959 fall meeting in Columbus, OH, where he gave an introductory talk on the physics and chemistry of surfaces.

Rounding out the trio of 1956 winners, John Bardeen gave a talk on the surface states of semiconductors at the 1956 spring meeting in San Francisco, CA, only months before winning the Physics prize. As if his work with Shockley and Brattain was not enough for one lifetime, Bardeen went on to win the Nobel Prize again in 1972, being the only person to receive the Physics prize twice, and the fourth person overall to receive two Nobel Prizes.

The spring 1957 meeting in Washington, DC, featured a special symposium on the *Structure of Electrolytic Solutions* (*electrolytes*). Manfred Eigen, winner of the 1967 Chemistry prize for his study of extremely fast chemical reactions, was a speaker. Not only did this event (which was financially supported by the National Science Foundation) feature an abundance of high-level speakers, but the symposium discussion also featured Peter Debye and Lars Onsager.[10] A one-time assistant of Debye, Onsager won the 1968 Nobel Prize in Chemistry for the development of the Onsager reciprocal relations utilized in thermodynamics. While Onsager does not appear to have formally presented at an ECS meeting, it is possible that he attended other ECS meetings.

Rudolph Arthur Marcus began his association with ECS meetings at the spring 1959 meeting in Philadelphia. There his talk titled "A Theory of Electron Transfer Processes at Electrodes" was supported by the Office of Naval Research, and subsequently published in the proceedings. Over 30 years later, Marcus was an invited speaker at the fall 1992 meeting in Toronto, Canada. In between his talks at that meeting, he received the call from the Royal Swedish Academy of Sciences notifying him that he had won the Nobel Prize in Chemistry for his work on the theory of electron transfer reactions. ECS was working on the first issue of *Interface* at the time and shouted, "Stop the presses!" in time to put Marcus on the inaugural cover, along with an excellent article describing the event.[11]

Between 1959 and 1992, Marcus spoke at a handful of ECS meetings. He served as a panelist at the spring 1966 meeting in Columbus, OH; gave talks at the spring 1979 meeting in Boston, MA, and spring 1983 in San Francisco, CA; and delivered the ECS Lecture to the full audience of the fall 1979 meeting in Los Angeles, CA. Finally, he brought it all home when he gave the ECS Lecture for a second time to the attendees of the spring 1996 meeting in Los Angeles, stepping up to the podium as a Nobel Laureate.

 DOI: 10.1149/2.F01201IF.

About the Series

*The second part of this article, picking up with the fall 1970 meeting in Atlantic City, NJ, and M. Stanley Whittingham's first presentation at an ECS meeting, will appear in the summer 2019 issue of Interface***.**

About the Author

John Lewis is Director of Meetings at ECS and has been with the Society since 2005. Readers who would like to comment on this article, share their recollections of a Nobel Laureate at an ECS meeting, or fund the digitization of our meeting archives, are welcome to email him at john.lewis@electrochem.org.

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11. P. Kohl, *Electrochem. Soc. Interface*, **1**(1), 20 (1992).
12. Details regarding ECS meeting appearances were obtained from the following publications; *Transactions of the American Electrochemical Society*, *Transactions of the Electrochemical Society*, *Extended Abstracts*, *Meeting Abstracts*, *ECS Proceedings Volumes*, *ECS Transactions*, and printed meeting programs.

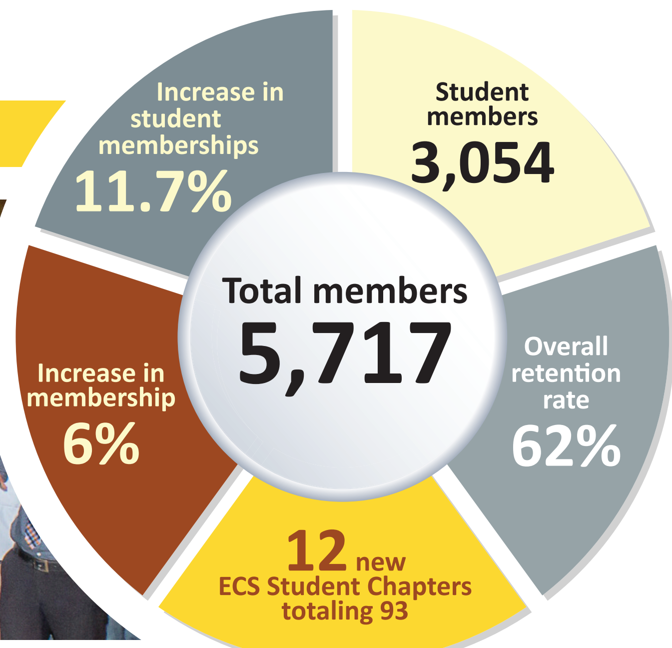
APPENDIX[12]

- William Shockley presented a paper at the 1953 New York City meeting on "Transistor Physics" at the Plenary/Joseph Richards Memorial Lecture. Shockley was awarded the 1956 Nobel Prize in Physics, "*for research on semiconductors and the discovery of the transistor effect.*"
- John Bardeen presented a paper on "Surface States of Semiconductors" for the 1956 meeting in San Francisco. Bardeen was awarded two Nobels. In 1956, he was awarded the Nobel Prize in Physics, *"for research on semiconductors and the discovery of the transistor effect."* Then, in 1972, he was awarded the Nobel Prize in Physics, for "*for (a) jointly developed theory of superconductivity, usually called the BCS-theory.*"
- Walter Houser Brattain wrote a paper on "Introduction to the Physics and Chemistry of Surfaces" for the 1959 meeting in Columbus, OH. Between 1954 and 1963, he co-authored five other presentations. Brattain was awarded the 1956 Nobel Prize in Physics, *"for research on semiconductors and the discovery of the transistor effect."*
- Jaroslav Heyrovský presented a paper on "Analysis of Petroleum and its Distillates" at the 1931 meeting in Birmingham, AL. At the 1938 meeting in Savannah, GA, he was part of the discussion on "The Cathode Ray Oscillograph Applied to the Dropping Mercury Electrode." Heyrovský was awarded the 1959 Nobel Prize in Chemistry, "*for his discovery and development of the polarographic methods of analysis.*"
- Manfred Eigen presented a paper on "Hydrogen Bond Structures, Hydration of Protons, and Proton Transfer in Aqueous Solutions" at the 1957 meeting in Washington, DC. He was awarded the 1967 Nobel Prize in Chemistry, "*for studies of extremely fast chemical reactions, effected by disturbing the equilibrium by means of very short pulses of energy.*"
- Henry Taube presented a paper on "Use of Isotopes in the Study of Ionic Hydration" at the 1954 meeting in Chicago. He was awarded the 1983 Nobel Prize in Chemistry, "*for his work on the mechanisms of electron transfer reactions, especially in metal complexes.*"
- Rudolph Arthur Marcus has a list of ECS Meetings accomplishments. In 1959, he presented a paper on "A Theory of Electron Transfer Processes at Electrodes" at the Philadelphia meeting. He was a panelist on "Panel Discussion on Electrode Photocurrents" at the 1966 meeting in Cleveland, OH. At the 1979 meeting in Boston, Marcus presented a paper on "Similarities and Differences between Electron and Proton Transfers at Electrodes and In Solution." In 1979, in Los Angeles, CA, he was the speaker at the Plenary/ECS Lecture, "Theory of Electron and Proton Transfer at Electrodes." In 1983, Marcus presented a paper on "Strong and Weak Overlap Reactions: Similarities and Differences" at the San Francisco meeting. In 1992, he presented a paper on "Electron Transfer across Interfaces" at the meeting in Toronto, Canada. In 1996, Marcus presented the Plenary/ECS Lecture, "Electron Transfers in Electrochemistry, Chemistry, and Biology," in Los Angeles, CA. He also was credited with being the co-author on one other presentation in 1960. Marcus was awarded the 1992 Nobel Prize in Chemistry, "*for his contributions to the theory of electron transfer reactions in chemical systems.*"

2019 Year in Review

The Electrochemical Society is proud to announce that 2019 was a year of achievement and growth. We kept on track with our stellar performance in relation to education, meetings, and scholarly publications. Our strong programs supported the Society's mission in 2019, and enabled ECS to further advance electrochemical and solid state science and technology. In the following *2019 Year in Review*, we present ECS milestones in membership, meetings, and publications.

Membership



Fellowships and Awards

- ECS Toyota Young Investigator Fellowship: $250,000 awarded to 5 recipients
- Travel grants:
  - 235th ECS Meeting: $37,525 awarded to 91 recipients
  - 236th ECS Meeting: $35,180 awarded to 64 recipients
- 14 ECS Fellows named at the 236th ECS Meeting
- ECS Summer Fellowships: 2 students each awarded $5,000
- $78,000 in Society, Section, and Division prizes awarded

Meetings

235th ECS Meeting
May 26-30, 2019
Dallas, TX, US

2,195 attendees

47 symposia

2,285 abstracts

28 exhibitors

60 countries represented

Symposium speaker funding:
- $6,675 in registration waivers
- $40,651 in travel reimbursement

Special Events

- ECS Data Science Hack Week, May 26-29, 2019
- Z03: Nanoscale Electrochemical Imaging and Detection, sponsored by the International Society of Electrochemistry (ISE), May 27, 2019

236th ECS Meeting
October 13-17, 2019
Atlanta, GA, US

2,526 attendees

52 symposia

2,521 abstracts

31 exhibitors

52 countries represented

Symposium speaker funding:
- $ 37,578 in registration waivers
- $ 59,535 in travel reimbursement

Special Events

- ECS Data Science Showcase, October 4, 2019
- 40 Years After: A Symposium on Diversity, October 16, 2019
- Electrochemical Energy Summit (E2S): Electrochemistry in Space, October 14-16, 2019
- M. Stanley Whittingham, 2019 Nobel Prize in Chemistry Laureate, delivers keynote address at "Symposium in Honor of Bob Huggins: Fast Iconic Conductors – Principles and Applications," October 16, 2019

Other Meetings

Electrochemical Conference on Energy and the Environment: Bioelectrochemistry and Energy Storage (ECEE 2019),

Glasgow, Scotland,
July 21-26, 2019
(ECS satellite meeting)

International Battery Association (IBA) 2019

La Jolla, California
March 3-8, 2019
(ECS sponsored meeting)

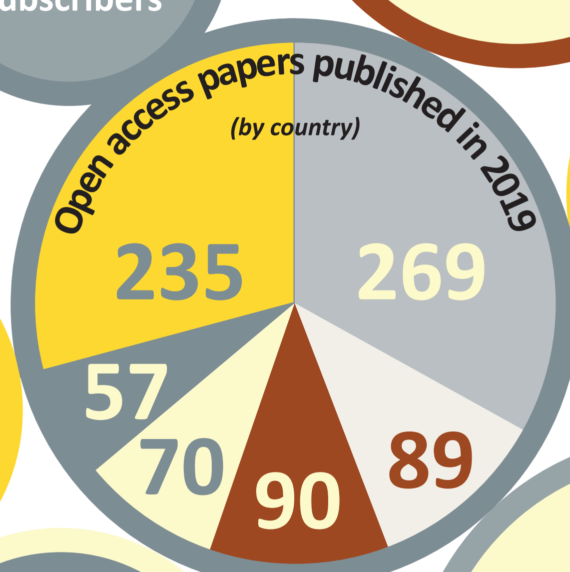
2019 Year in Review

(continued)

Publications

1,209 subscribing institutions publish open access at no cost

2,000 institutional subscribers



3.5M articles and abstracts downloaded from the ECS Digital Library

Over **37%** of all journal content published since 2014 is open access

Over **41%** of articles published in 2019 were open access

1,955 journal articles published in the 2019 volume year

ECS Announces the 2019 Class of Highly Cited Researchers

The Electrochemical Society is proud to announce the Society's most distinguished members recognized as 2019 Highly Cited Researchers. The prestigious list, published by the Web of Science Group at Clarivate Analytics, identifies scientists and social scientists who produced multiple papers ranking in the top 1% by citations for their field and year of publication, demonstrating significant research influence among their peers.

This year's list includes some of the "world's most influential scientific minds." Among those on the top of the list is 2019 Nobel Laureate (Chemistry) and ECS Fellow **John B. Goodenough**. For 2019, Goodenough was selected for the field of chemistry. Back in 2001, the first year the Highly Cited Researchers list was issued, he was selected for the field of materials science. ECS Fellow **Yi Cui** was recognized for three fields—chemistry, engineering, and materials science. ECS Life Member **Michael Graetzel** received accolades for the fields of chemistry, materials science, and physics. Nine additional ECS Fellows were considered Highly Cited Researchers—**Khalil Amine**, **Hubert Gasteiger**, **Yury Gogotsi**, **Prashant Kamat**, **Meilin Liu**, **Yang-Kook Sun**, **Joseph Wang**, **Yang Shao-Horn**, and **Jun Liu**.

Below is a list of ECS members whose research on electrochemistry and solid state science and technology is shaping the scientific discourse. (F denotes ECS Fellow.) Did we miss your name? Let us know and we will broadcast your achievements online.

Congratulations to all!


Khalil Amine (F)


Peter Bruce


Gerbrand Ceder


YongSheng Chen


Jaephil Cho


Yi Cui (F)


Hubert Gasteiger (F)


Yury Gogotsi (F)


John B. Goodenough (F)

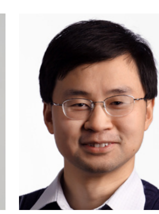

Michael Graetzel


Mark Hersam


Yang Shao-Horn (F)


Joseph Hupp
Photo: Northwestern University


Ali Javey


Song Jin


Prashant Kamat (F)
Photo: University of Notre Dame


Marc Koper


Yuehe Lin

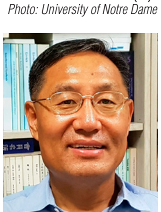

Jun Liu (F)


Meilin Liu (F)


Chad Mirkin


Jens Norskov


Peter Strasser

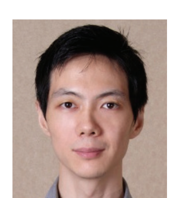

Yang-Kook Sun (F)


Chunsheng Wang


Joseph Wang (F)


Gang Wu


Jie Xiao


Qingyu Yan


JiuJun Zhang


Qiang Zhang

Jan Talbot Collection Reached Milestone

Through generous donations from friends, colleagues, and members of the scientific community, the Jan Talbot Collection officially reached a fundraising milestone of $30,000, ensuring free, permanent access to her legacy of ECS-published works.

Jan Talbot is a longtime ECS member, serving as board vice president (1998-2001), president (2001-2002), and editor of *Interface* from 1995-1998. She was inducted as Fellow of The Electrochemical Society in 2004. Talbot's career was equally impressive outside of ECS. She was the Chair of the University of California San Diego Academic Senate from 2003-2004. In 2010, she was awarded a UCSD Distinguished Teaching Award. Since 2000, Talbot has been the Director of the Jacobs School's Chemical Engineering Program. From 2014-2016, she was Associate Dean of the Jacobs School of Engineering. From 1975-1981, she worked as a development engineer at Oak Ridge National Laboratory in Tennessee.

Talbot's collection includes 42 *Journal of The Electrochemical Society* papers and six *ECS Journal of Solid State Science and Technology* papers. Her body of work is focused on electrophoretic deposition, electrodeposition, chemical mechanical polishing, display screen processing, solid state lightning materials, materials science, and electrochemical transport phenomena and engineering.

"It amazes me that ECS, its journals, and its meetings were the main venue for my research interests over 30 years, which has spanned applications of corrosion, magnetic recording, semiconductor processing, and solid state lighting," Talbot reflects. "It has truly been my professional home."

Talbot retired on July 1, 2018 and as a celebration of her body of work, a sponsored collection was created in the ECS Digital Library. This collection was created through a donation of $10,000 from Talbot. An additional goal of $20,000 to free the collection was met in December 2019.

Thank you to the following individuals, ECS divisions, and and organizations for their generous contributions to help free this collection.

Anonymous Donor
William M. Ayers
Madonna H. Bentz
Stanko R. Brankovic
Mandy Bratton
Pamela C. Cosman
Beth Craanen
Lili Deligianni
Detlef Diesing
Nikolay G. Dimitrov
Joseph P. Drago
Electrodeposition Division
Ronnie-Gail Emden
Yasuhiro Fukunaka
Tim Gamberzky
Judy Gaukel
Olivia Graeve
Vicki Grassian
Jinkyu Han
Takayuki Homma
Qiang Huang
Simi Hundal
Industrial Electrochemistry and Electrochemical Engineering Division
Karen Kavanagh
Robert G. Kelly
Darshan Kundaliya
Roya Maboudian
Joanna McKittrick
Jose Antonio Medina
Shirley Meng
Kailash C. Mishra
Thomas Polk Moffat
Rangachary Mukundan
Matthew Murbach
Paul M. Natishan
Mercedes Teresita Oropeza Guzman
Nestor Perea Lopez
Daniel T. Schwartz
Michael J. Shane
Carolyn Sheehan
Ellen Speert
Kathy Spencer
Jack Spiegelberg
James H. Spreen
Gery R. Stafford
Daniel Steingart
Venkat R. Subramanian
Kevin Shing Sung
Alice H. Suroviec
Wendi Sweet
Jay A. Switzer
Jan B. Talbot
E. Jennings Taylor
Charles W. Tu
University of California San Diego
Natasa R. Vasiljevic
Gomathi Venkat
Gabriele Wienhausen

Visit and read the Jan Talbot Collection at www.electrochem.org/talbotcollection.

ECS sponsored collections are generously supported by the family, friends, students, and colleagues of ECS authors. Compiling all of an author's articles published in ECS journals and other publications, these collections honor the author's significant contributions to their particular field, the Society, and the wider scientific community by aiming to make their research freely accessible.

If you are interested discussing the opportunity to develop your own sponsored collection or be named on a leadership collection, please contact Beth Craanen at beth.craanen@electrochem.org.

ECS Journals – Current and Upcoming Focus Issues

The following issues have recently been completed and are available to read online in the ECS Digital Library.

- **JSS: Recent Advances in Wide Bandgap III-Nitride Devices and Solid State Lighting: A Tribute to Isamu Akasaki**
  Kailash Mishra, JSS technical editor
  Hiroshi Amano, John Collins, Jung Han, Won Bin Im, Michael Kneissl, Tae-Yeon Seong, Anant Setlur, Tadek Suski, and Eugeniusz Zych, guest editors
- **JES: Mathematical Modeling of Electrochemical Systems at Multiple Scales in Honor of Richard Alkire**
  John Harb, JES technical editor
  Venkat Subramanian, former JES technical editor and lead guest editor; John Weidner, Perla Balbuena, Adam Weber, Venkat Srinivasan, guest editors
- **JES: Sensor Reviews**
  Ajit Khosla, JES technical editor
  Nick Wu, Peter Hesketh, Muthukumaram Packirisamy, Praveen Kumar Sekhar, Aicheng Chen, Shekhar Bhansali, Jessica Koehne, Larry Nagahara, Thomas Thundat, Netz Arroyo, Kumkum Ahmed, Trisha Andrew, Rangachary Mukundan, and Jeffrey Halpern, guest editors

The following issues are currently in production with many papers published online in the ECS Digital Library.

- **JES: Heterogeneous Functional Materials for Energy Conversion and Storage**
  Thomas Fuller, former JES technical editor, Doron Aurbach, David Cliffel, JES technical editors
  Wilson Chiu, Vito Di Noto, Srikanth Gopalan, Nian Liu, and Alice Suroviec, guest editors
- **JES: Challenges in Novel Electrolytes, Organic Materials, and Innovative Chemistries for Batteries in Honor of Michel Armand**
  Doron Aurbach, JES technical editor
  Brett Lucht, JES associate editor and guest editor
  Dominique Guyomard, lead guest editor
  Vito Di Noto, Maria Forsyth, Philippe Poizot, Teofilo Rojo, and Karim Zaghib, guest editors
- **JES: Battery Reliability and Safety, Design, and Mitigation**
  Doron Aurbach, JES technical editor
  Bor Yann Liaw and Thomas Barrera, guest editors
- **JSS: Gallium Oxide Based Materials and Devices II**
  Fan Ren, JSS technical editor
  Steve Pearton, Jihyun Kim, Alexander Polyakov, Holger von Wenckstern, Rajendra Singh, and Xing Lu, guest editors

The following focus issues are open for submissions. Manuscripts may be submitted at www.electrochem.org/submit:

- **JES & JSS: 2D Layered Materials: From Fundamental Science to Applications**
  David Cliffel, JES technical editor, and Peter Mascher, JSS technical editor
  Wolfram Jaegermann, Zia Karim, Yaw Obeng, and Colm O'Dwyer, guest editors
  Submission deadline is May 13, 2020.
- **JSS: Porphyrins, Phthalocyanines, and Supramolecular Assemblies in Honor of Karl M. Kadish**
  Francis D'Souza, JSS technical editor
  Dirk Guldi, Robert Paolesse, and Tomas Torres, guest editors
  Submission deadline is May 31, 2020.

Upcoming focus issues include:

- **JSS: Solid-State Materials and Devices for Biological and Medical Applications**
  Fan Ren, JSS technical editor
  Yu-Lin Wang, Toshiya Sakata, Zong-Hong Lin, and Wenzhuo Wu, guest editors
  Accepting submissions on April 2, 2020.
  Submission deadline is July 1, 2020.
- **JES: Organic and Inorganic Molecular Electrochemistry**
  Janine Mauzeroll, JES technical editor
  John-Paul Lumb, Song Lin, John Harb, and Matthew Graaf, guest editors
  Accepting submissions on April 9, 2020.
  Submission deadline is July 8, 2020.
- **JES: International Meeting on Chemical Sensors (IMCS) 2020**
  Ajit Khosla, JES technical editor
  Peter Hesketh, Steve Semancik, Udo Weimar, Yasuhiro Shimizu, Joseph Stetter, Gary Hunter, Joseph Wang, Xiangqun Zeng, Sheikh Akbar, Muthukumaran Packirisamy, and Rudra Pratap, guest editors
  Accepting submissions on May 4, 2020.
  Submission deadline is August 12, 2020.
- **JSS: Photovoltaics for the 21st Century**
  Fan Ren, JSS technical editor
  Meng Tao, JSS associate editor and guest editor
  Hiroki Hamada, Thad Druffel, and Jae-Joon Lee, guest editors
  Accepting submissions on July 16, 2020.
  Submission deadline is October 14, 2020.
- **JES: International Meeting on Lithium Batteries (IMLB) 2020**
  Doron Aurbach, JES technical editor
  Accepting submissions summer 2020.
  Anticipated submission deadline is October 14, 2020.
- **JES: Molten Salts and Ionic Liquids II**
  David Cliffel, JES technical editor
  David P. Durkin, Paul C. Trulove, Robert A. Mantz, guest editors
  Accepting submissions on October 15, 2020.
  Submission deadline is January 13, 2021.
- **JES: Recent Advances in Chemical and Biological Sensors & Micro-Nanofabricated Sensors and Systems**
  Ajit Khosla JES technical editor
  Michael Adachi, Thomas Thundat and Netz Arayyo, JES associate editors
  Accepting submissions on November 19, 2020.
  Submission deadline is February 17, 2021.

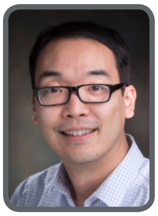
To see the calls for papers for upcoming focus issues, for links to the published issues, or if you would like to propose a future focus issue, visit **www.electrochem.org/focusissues**.

Editorial Board Appointments for ECS Journals

Journal of The Electrochemical Society
Technical Editor

Xiao-Dong Zhou recently has been appointed technical editor for the *Journal of The Electrochemical Society*. Zhou handles manuscripts submitted to the subject area of fuel cells, electrolyzers, and energy conversion. He is a professor and the executive director of the Institute for Materials Research and Innovation at the University of Louisiana at Lafayette. His lab researches the durability of materials and interfaces of electrochemical systems. Zhou's three-year appointment is from January 1, 2020 through December 31, 2022.

Journal of The Electrochemical Society
Associate Editor



Michael Adachi recently has been appointed as an associate editor of the *Journal of The Electrochemical Society*. Adachi handles manuscripts submitted to the sensors topical interest area. He is an assistant professor in the School of Engineering Science at Simon Fraser University. Adachi's research interests include solar cells, nanodevice fabrication, and 2D materials and devices. His one-year appointment is from November 15, 2019 through November 14, 2020.

Netz Arroyo recently has been appointed as an associate editor in the area of sensors for the *Journal of The Electrochemistry Society*. Arroyo is an assistant professor of pharmacology and molecular sciences at Johns Hopkins University School of Medicine. The Netz Lab at Johns Hopkins University studies the mechanisms of drug transport within the body in real time. His one-year appointment is from November 15, 2019 through November 14, 2020.

Thomas Thundat recently has been appointed as an associate editor of the *Journal of The Electrochemical Society*. Thundat will be handling manuscripts related to the area of sensors. He is an Empire Innovation Professor at the University of Buffalo, Department of Chemical and Biological Engineering. His research currently is focused on novel physical, chemical, and biological detection using micro and nano mechanical sensors and electrical power delivery using the single wire concept. Thundat's one-year appointment is from November 15, 2019 through November 14, 2020.

UPCOMING ECS SPONSORED MEETINGS

In addition to the 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 partial list of upcoming sponsored meetings. Please visit the ECS website (www.electrochem.org/upcoming-meetings) for a list of all sponsored meetings.

2020

- **The 20th IEEE International Conference on Nanotechnology**
  July 29-31, 2020 – Montréal, Canada
  Hotel Bonaventure
  (https://2020.ieeenano.org)

- **11th International Frumkin Symposium**
  October 19-23, 2020 – Moscow, Russia
  Russian Academy of Sciences
  (http://frumkinsymp.ru)

2021

- **Solid Oxide Fuel Cells 17 (SOFC-XVII)**
  July 18-23, 2021 – Stockholm, Sweden
  The Brewery Conference Center

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.

Division News

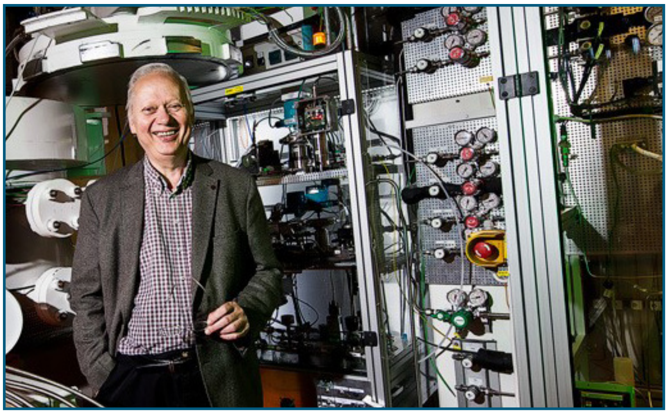
H-TEMP Celebration

The High-Temperature Energy, Materials, and Processes Division is proud to announce that the celebration of Mogens Mogensen's career will be part of sessions at the *Electrosynthesis of Fuels 6* symposium held during the 237th ECS Meeting in Montréal, May 10-14, 2020.

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.

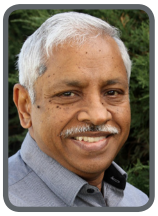
He has co-authored more than 350 scientific papers, of which over 200 were published in international refereed journals. He has participated in a large number of international conferences and given more than 40 invited talks, some of which were keynote and plenary talks.

Through his career in academia, he has supervised over 10 Master students, more than 20 PhD students, and around 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.



The distinguished career of **Mogens Mogensen** *will be part of the Electrosynthesis of Fuels 6 symposium held during the 237th ECS Meeting in Montréal, May 10-14, 2020.*

The First Cell to Mars



H-TEMP member S. Elango Elangovan will be sending the first high-temperature electrochemical cell to Mars to convert CO_2 to O_2. According to H-TEMP Chair Paul Gannon, the stack is made by OxEon and integrated by MIT and JPL into the nuclear powered *Mars 2020 Rover*. This exciting news has made its way to major news outlets in the last few months. Elangovan is Vice President-Research at OxEon Energy. He is responsible for solid oxide device development. Elangovan also contributes to the feature *Electrochemical Approaches to "Living off the Land" in Space* found in this issue of *Interface*.

ECS Thanks 2019 Reviewers

The Electrochemical Society relies upon the technical expertise and judgement of the many individuals who, as reviewers, help to maintain the high standards characteristic of the Society's peer-reviewed journals.

In 2019, 3,693 individuals supported the Society's long-standing commitment to ensuring both the technical quality of the works published, as well as the integrity and validity of the peer review the community provides.

ECS greatly appreciates the time and effort put forth by these individuals, and the Society would like to express a sincere thank-you for their hard work and support.

For a complete list of the 2019 reviewers, visit www.electrochem.org/ecs-blog/ecs-thanks-2019-reviewers.

New Division Officer Slates

New division officers for the spring 2020–fall 2022 term have been nominated for the following divisions. All election results will be reported in the summer 2020 issue of *Interface*.

Dielectric Science and Technology

Chair
Peter Mascher, McMaster University
Vice Chair
Uros Cvelbar, Jozef Stefan Institute
Secretary
Sreeram Vaddiraju, Texas A&M University
Treasurer
Zhi David Chen, University of Electronic Science and Technology of China

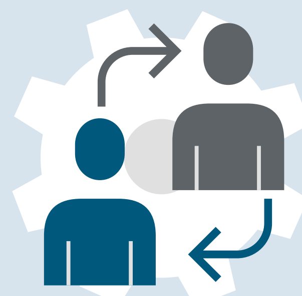
Industrial Electrochemistry and Electrochemical Engineering

Chair
Shrisudersan Jayaraman, Corning Incorporated
Vice Chair
Maria Inman, Faraday Technology, Inc.
Secretary/Treasurer
Chockkalingam Karuppaiah, Vetri Labs
Hui Xu, Giner Inc.
Paul Kenis, University of Illinois at Urbana-Champaign

Nanocarbons

Chair
Hiroshi Imahori, Kyoto University
Vice Chair
Jeffrey Blackburn, National Renewable Energy Laboratory
Secretary
Ardemis Boghossian, Ecole Polytechnique Federale de Lausanne
Treasurer
Slava Rotkin, Pennsylvania State University

Institutional Membership Program



Institutional membership provides organizations the opportunity to support and advance the dissemination of electrochemical and solid state science research. Member organizations save 15-20% in spending through discounts on ECS subscriptions, meeting registrations, marketing opportunities, and are able to provide ECS membership benefits to their employees.

Contact **Anna.Olsen@electrochem.org** to learn more about institutional membership benefits.

Publisher's Note

In the winter 2019 issue of *Interface*, on page 33, the Battery Division contact listing contained an error. This error was listed as such since the winter 2018 issue of *Interface*. It should be correctly stated that the Vice Chair is Y. Shirley Meng.

In the winter 2019 online issue of *Interface*, under Article Information for the feature *Social Media Platforms for Electrochemistry*, there were errors in two email addresses. It should read that Edwin Khoo can be emailed at edwinksl@gmail.com. It also should be noted that Steven C. DeCaluwe's email address is decaluwe@mines.edu.

In the winter 2018 issue of *Interface*, on page 24, the Sensor Division contact listing contained an error. It should be correctly stated that the Journals Editorial Board Representative is Rangachary Mukundan.

ECS regrets these errors.

ECS Division Contacts

Battery

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Lawrence Berkeley National Laboratory
mmdoeff@lbl.gov • 510.486.5821 (US)

Y. Shirley Meng, Vice Chair   Brett Lucht, Secretary
Jie Xiao, Treasurer
Doron Aurbach, Journals Editorial Board Representative

Corrosion

Masayuki Itagaki, Chair
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itagaki@rs.noda.tus.ac.jp • 471229492 (JP)

James Noël, Vice Chair
Dev Chidambaram, Secretary/Treasurer
Gerald Frankel, Journals Editorial Board Representative

Dielectric Science and Technology

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Peter Mascher, Vice Chair   Uros Cvelbar, Secretary
Zhi David Chen, Treasurer
Peter Mascher, Journals Editorial Board Representative

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Natasa R.Vasiljevic, Vice Chair   Luca Magagnin, Secretary
Andreas Bund, Treasurer
Takayuki Homma, Journals Editorial Board Representative

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Junichi Murota, Chair
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Yu-Lin Wang, Vice Chair   Jennifer Hite, 2nd Vice Chair
Qiliang Li, Secretary   Robert Lynch, Treasurer
Fan Ren, Journals Editorial Board Representative
Jennifer Bardwell, Journals Editorial Board Representative

Energy Technology

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William Mustain, Vice Chair
Katherine Ayers, Secretary   Minhua Shao, Treasurer
Xiao-Dong Zhou, Journals Editorial Board Representative

High-Temperature Energy, Materials, & Processes

Paul Gannon, Chair
Montana State University
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Sean Bishop, Jr., Sr. Vice Chair   Cortney Kreller, Jr. Vice Chair
Xingbo Liu, Secretary/Treasurer
Raymond Gorte, Journals Editorial Board Representative

Industrial Electrochemistry and Electrochemical Engineering

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Shrisudersan Jayaraman, Vice Chair
Maria Inman, Secretary/Treasurer
John Harb, Journals Editorial Board Representative

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Rong-Jun Xie, Vice Chair
Eugeniusz Zych, Secretary/Treasurer
Kailash Mishra, Journals Editorial Board Representative

Nanocarbons

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Pennsylvania State University
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Hiroshi Imahori, Vice Chair   Olga Boltalina, Secretary
R. Bruce Weisman, Treasurer
Francis D'Souza, Journals Editorial Board Representative

Organic and Biological Electrochemistry

Diane Smith, Chair
San Diego State University
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Sadagopan Krishnan, Vice Chair
Song Lin, Secretary/Treasurer
Janine Mauzeroll, Journals Editorial Board Representative

Physical and Analytical Electrochemistry

Petr Vanýsek, Chair
Northern Illinois University
pvanysek@gmail.com • 815.753.1131 (US)

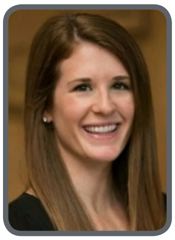
Andrew Hillier, Vice Chair   Stephen Paddison, Secretary
Anne Co, Treasurer
David Cliffel, Journals Editorial Board Representative

Sensor

Ajit Khosla, Chair
Yamagata University
khosla@gmail.com • 080.907.44765 (JP)

Jessica Koehne, Vice Chair   Larry Nagahara, Secretary
Praveen Sekhar, Treasurer
Ajit Khosla, Journals Editorial Board Representative

Staff News



Casey Annunziata celebrated five years with The Electrochemical Society on January 12. She started with a focus on the meeting logistics, such as food and beverage planning, overseeing the hotel blocks, collateral production, and staff travel. During her time at ECS, her role has evolved to touch almost all aspects of the meetings, including the exhibit and sponsorship programs, symposium funding, producing the satellite meetings, and most recently, taking on the department's marketing efforts.

Since joining ECS, Casey has been promoted twice, earned her Certified Meeting Planner (CMP) certificate, and became an active member of Professional Convention Management Association (PCMA). On a personal level, she has gotten married and welcomed two children, making these last five years a time of significant growth.

The unique format of the ECS meetings and how they continuously change locations makes this a dynamic role. Casey explained, "Each meeting feels like a blank slate with an entirely new set of obstacles to overcome, and opportunities to take advantage of. Changing locations forces us to continuously reevaluate how we do things and enables us to constantly evolve and progress in order to better meet the needs of our community. It has been an honor to help create the setting for these scientists to come together and discuss projects that influence the entire world."

John Lewis, Director of Meetings, said, "One of the best things about Casey is the energy and enthusiasm that she brings to the ECS meetings department. You will see her smiling face everywhere at the events, always keeping a keen eye on the endless details, and constantly looking for ways to improve the meeting experience for the attendees. She is smart and hardworking, with skills and talents that have been of great value to the Society over the past five years. It is a pleasure to congratulate her on this anniversary!"

In the NEXT issue of INTERFACE

- The summer 2020 issue of *Interface* will have features by the Physical and Analytical Electrochemistry Division. The focus topic will be Electrocatalysis. The issue will be guest edited by Alice Suroviec, Associate Editor of the PAE Division for the *Journal of the Electrochemical Society*. Summer 2020 *Interface* is tentatively scheduled to have articles by such ECS leaders as John A. Keith (University of Pittsburgh) and Pawel Kulesza (University of Warsaw).
- **From the President**. In this column, the newly elected ECS president will share some thoughts and wisdom about the Society and its enduring impact on its members and constituents.
- **Highlights from Montréal, Canada**. Don't miss the exclusive news coverage from the 237th ECS Meeting in Montréal.
- **Results of the 2019 Election**. Discover the results of the 2019 election of officers, along with the slate of officers for 2020.

Beth Craanen celebrated her five-year anniversary with ECS in December 2019. Beth joined the Society staff as the associate director of development & membership services in December 2014. She was promoted to the director of membership services in September 2015 and was named director of publications in September 2016.

"Beth has been, and continues to be, a tremendous asset to ECS. She did an amazing job leading the effort to overhaul ECS's publications operations and launch our new digital library on IOPscience," says Chris Jannuzzi, ECS Executive Director. "Congratulations to Beth on a very successful five years and here's wishing her many happy returns."

Prior to ECS, Beth served as the director for student affairs and community engagement in the School of Pharmacy at Fairleigh Dickinson University. As a founding team member, she was instrumental in building resources critical to student success. Beth holds a Bachelor of Science degree from Johnson & Wales University and a Master of Science degree from West Chester University of Pennsylvania.

Genevieve Goldy joined ECS in January as the Society's Board Relations Specialist. In this role, Gen, as she likes to be called, will serve as the primary support staff and point-of-contact for the Board of Directors and Division leadership. In addition, she will oversee ECS elections and the Society's robust Honors and Awards program.

"I am so pleased Gen joined our team," says Chris Jannuzzi, ECS Executive Director. "Gen comes to us from the legal world, having had a successful career as a paralegal supporting attorneys dealing with complex litigation. As such, she brings a keen eye for detail and understands the value of clear, precise communications. Gen also is a pleasure to work with, so this is a great way to start the New Year!"

Gen brings an international flare to the staff, having lived abroad for many years. She remains an avid traveler in her free time and enjoys seeking new, diverse cultural experiences.

Please join us in welcoming Gen to the ECS family!

Anna Olsen joined ECS in the fall of 2010. Anna's tenure with ECS has been a personal growth for herself and of her knowledge of the Society. She smoothly made the transition from constituent and membership services associate to senior content associate and library liaison to recently taking the position of corporate programs manager. Anna, a nine-year employee at ECS, has not only accepted these new challenges, but has embraced the opportunity of learning new things at ECS. Anna's background, with a BA in Education, comes into play especially at our ECS biannual meetings. Anna said, "My favorite part of going to ECS meetings is meeting the attendees and working with our student volunteers." If you have not noticed, Anna usually has a group of student attendees working along with her at our ECS exhibit booth and she would encourage you all to come and meet them!

Anna shares the Society's vision of advancing science and technology (www.electrochem.org/mission), which fosters a community of scientists, engineers, cooperates, and other organizations to promote science and technology in the public interest.

APP CORNER

Suggested for you by Alice Suroviec.

Slack

Devices: Web, Android, iPhone/iPad compatible
Cost: Free

Slack is a collaboration app. This works much like text messaging; however, it is multiplatform and you can hold conversations in different channels to keep the conversation focused. *Slack* integrates with other apps (*Google Drive*, *Dropbox*, *Trello*) to keep everyone in the loop on a project.

iCircuit

Devices: iPhone/iPad compatible
Cost: $9.99

The ***iCircuit*** app can be used for designing and experimenting with circuits and Arduinos. This app can be used to design both analog and digital circuits and features real-time always-on analysis. It is similar to CAD programs, however the app is continuously simulating.

Engineering Cookbook

Devices: Android, iPhone/iPad compatible
Cost: Free

This app is a convenient reference guide for mechanical designers. The ***Engineering Cookbook*** provides quick access to frequently needed information. The app includes details on heating and cooling load estimation, as well as design formulas and conversion factors.

NASA App

Devices: Android, iPhone/iPad compatible
Cost: Free

The ***NASA*** app contains a large variety of resources, including images, videos on-demand, satellite tracking, and *ISS* sighting opportunities. This app is the perfect one to follow up on the *Electrochemistry in Space* symposium that was held at the 236th ECS Meeting in Atlanta, GA.

(Please note that certain apps might not be available depending on the end user's region or country. The features of some apps also can vary.)

About the Author

Alice Suroviec is professor of bioanalytical chemistry and chair of the Department of Chemistry and Biochemistry at Berry College. She earned a BS in chemistry from Allegheny College in 2000. She received her PhD from Virginia Tech in 2005 under the direction of Dr. Mark R. Anderson. Her research focuses on enzymatically modified electrodes for use as biosensors. She is currently associate editor of the PAE Technical Division for the *Journal of The Electrochemical Society.* She can be reached at asuroviec@berry.edu and is always looking for new app suggestions.

https://orcid.org/0000-0002-9252-2468

Join us at this international conference as scientists, engineers, and researchers from academia, industry, and government laboratories come together to share results and discuss issues on related topics through oral presentations, poster sessions, panel discussions, tutorial sessions, short courses, professional development workshops, a career expo, exhibits, and more. The unique blend of electrochemical and solid state science and technology at an ECS meeting provides you with an opportunity to absorb and exchange information on the latest scientific developments across a variety of interdisciplinary areas in a forum of your peers.

This year's spring meeting will be held in Montréal, a striking union of European charm and North American attitude that captivates visitors with a harmonious pairing of the historic and the new, from exquisite architecture to fine dining. With more than four million inhabitants and no less than 120 different nationalities, Montréal boasts a rich and vibrant cultural fabric. A world leader in such industries as aeronautics, information technology, and biotechnology, the city has also made significant innovations in medicine, multimedia, the arts, and urban planning. Come with us this May and experience the joie de vivre and creativity of Montréal!

GET THE ECS APP!
Search "ECS mobile" in your app store

- Five days of technical programming across 52 symposia, including the 18th International Meeting on Chemical Sensors (IMCS)
- Over 2,900 abstracts
- Nearly 2,300 oral presentations, with almost 650 invited talks from the world's leading experts
- Over 600 posters during three evenings of poster sessions
- 14 hours of exhibit hall time over three days
- Daily morning and afternoon coffee breaks
- Complimentary WiFi in meeting rooms
- Special program for nontechnical registrants

The ECS Lecture

Monday, May 11

"New Directions for Energy from Sunlight"
Harry Atwater, *California Institute of Technology*

Harry Atwater is the Howard Hughes Professor of Applied Physics and Materials Science at the California Institute of Technology. Atwater's scientific interests span nanophotonic light-matter interactions and solar energy conversion. Atwater was an early pioneer in nanophotonics and plasmonics; he gave the name to the field of plasmonics in 2001. He has also created new high efficiency solar cell designs and has pioneered principles for light management in solar cells and solar fuels. He currently serves as Director of the Joint Center for Artificial Photosynthesis, a DOE Hub. Atwater is a member of U.S. National Academy of Engineering and is also a fellow of the APS, MRS, SPIE, and the National Academy of Inventors. He is the founding editor-in-chief of the journal *ACS Photonics* and chair of the LightSail Committee for the Breakthrough Starshot program. In his plenary lecture at ECS, Atwater will review advances over the last decade in artificial photosynthesis and will give an outlook for advances in solar-driven photocatalytic generation of liquid fuels.

Award-Winning Speakers

(Check the meeting app for times.)

SOCIETY AWARD WINNING SPEAKERS

Arumugam Manthiram, University of Texas at Austin
Henry B. Linford Award for Distinguished Teaching

Hubert Gasteiger, Technical University of Munich
Vittorio de Nora Award

DIVISION AWARD WINNING SPEAKERS

Andrew Steckl, University of Cincinnati
Electronics and Photonics Division Award

Paul Kenis, University of Illinois at Urbana-Champaign
Energy Technology Division Research Award

Christopher Hahn, Stanford University
Energy Technology Division Supramaniam Srinivasan Young Investigator Award

Lisa Housel, Stony Brook University
Energy Technology Division Graduate Student Award sponsored by Bio-Logic

Saket Bhargava, University of Illinois
Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Award

Zhongyang Wang, Washington University in St. Louis
Industrial Electrochemistry and Electrochemical Engineering Division H. H. Dow Memorial Student Achievement Award

Andreas Hirsch, Friedrich-Alexander-Universität Erlangen-Nürnberg
Nanocarbons Division Robert C. Haddon Research Award

Markita Landry, University of California at Berkeley
Nanocarbons Division SES Young Investigator Award

Siegfried R. Waldvogel, Johannes Gutenberg University Mainz
Organic and Biological Electrochemistry Division Manuel M. Baizer Award

Read more about these award winners in this issue starting on page 75.

Short Courses

Sunday, May 10

ECS short courses are all-day classes designed to provide students or seasoned professionals with an in-depth education on a wide range of topics. Taught by academic and industry experts, the small classes make for an excellent opportunity for personalized instruction, helping both novices and experts advance their technical expertise and knowledge.

Basic Impedance Spectroscopy
Mark Orazem, *Instructor*

Fundamentals of Electrochemistry: Basic Theory and Thermodynamic Methods
James Noël, *Instructor*

Electrochemical Biosensors
Joseph Wang, *Instructor*

Introduction to Micro/Nanofabrication, C-MEMS, and Applications of Chemical Gas Sensors
Marc Madou, Peter Hesketh, Gary Hunter, *Instructors*

AC Electrical Measurements and Modelling of Gas Sensors
Sheikh Akbar, *Instructor*

Professional Development Workshops

(Check the meeting app for times.)

Offered at every biannual Society meeting, the professional development workshops help to serve our attendees' career needs. These workshops are available to you whether you are a student looking for some help with your resume or a mid-career researcher looking for a refresher on team management.

- **Running an Effective Meeting**
- **Managing and Leading Teams**
- **Win Funding: How to Write a Competitive Proposal**
- **Essential Elements for Employment Success**
- **Resume Review**
- **U.S. Immigration & Visa Options for International Researchers**

ECS Data Sciences Data Hack Week

The ECS Data Sciences Hack Week is part of the Society's continuing work toward building an electrochemical data sciences and open source community. All electrochemical engineers, whether experimentally or theoretically focused, can benefit from this workshop program by learning how to create, share, use, and improve open source software tools and public datasets to accelerate research progress in our field. Apply now to join us for this weeklong event!
Application Deadline: *April 4, 2020*

Special Events

(Check the meeting app for times.)

Opening Reception
Come join us for an evening of fun, as we kick off what is sure to be a great week. This is an excellent opportunity to meet old and new friends, so make sure to stop by for some food, drinks, and great conversation!

Student Mixer
The student mixer is one of the most popular events at an ECS meeting. Students and early career professionals are provided an opportunity to network without the hustle and bustle of technical or poster sessions. Attend and meet your future co-workers in the fields of electrochemistry!

Annual Society Business Meeting and Luncheon
Join us as we celebrate the many successes of 2019 and look forward to an even brighter future! This luncheon will feature a special talk titled, "Critical Materials for Emerging Energy Technologies: What are the Main Risks and Challenges?" by Dr. Luisa Moreno, Managing Director of Tahuti Global Inc.

General and Student Poster Sessions
With hundreds of posters to explore, you won't want to miss a single minute of these sessions. Wander the aisles, review the presentations, talk to the authors, share some laughs…these sessions are a great way to end the day!

Business Meetings for Industrial Electrochemistry and Electrochemical Engineering, Energy Technology, Organic and Biological Electrochemistry, and Physical and Analytical Electrochemistry Divisions
Know your division—come down to network and get involved with future activities!

18th International Meeting on Chemical Sensors (IMCS)
We are pleased to have the 18th IMCS meeting co-locate with us here in Montréal! As a special bonus, registrants of the ECS and IMCS meetings will be able to attend the sessions for both meetings. See page 28 for more information on IMCS.

For more information, visit
www.electrochem.org/237

SYMPOSIUM TOPICS AND DEADLINES

A— Batteries and Energy Storage

A01—Battery and Energy Technology Joint General Session
M. Manivannan, T. Barrera, S. Narayanan, H. Xu
Energy Technology, Battery

A02—Lithium Ion Batteries and Beyond
F. Lin, M. Dollé, Y. Mo, H. Chen, Y. S. Jung, I. Zenyuk, J. Rodriguez-Lopez, W. Xu
Battery, Physical and Analytical Electrochemistry

A03—Large Scale Energy Storage 11
T. Nguyen, D. Steingart, B. Li
Energy Technology, Battery, Industrial Electrochemistry and Electrochemical Engineering, Organic and Biological Electrochemistry

A04—Student Battery Slam 4
X. Meng, K. Harrison, H. Zhou, X. Wang
Battery

B— Carbon Nanostructures and Devices

B01—Carbon Nanostructures for Energy Conversion and Storage
J. Blackburn, V. Di Noto, P. Atanassov, M.-K. Song, M. Arnold, S. Doorn, D. Cliffel, C. Bock, X. Ji
Nanocarbons, Battery, Energy Technology, Physical and Analytical Electrochemistry

B02—Carbon Nanostructures in Medicine and Biology
D. Heller, A. Boghossian, M. Bayachou, J. Burgess, L. Nagahara, T. DaRos, F. Papadimitrakopoulos
Nanocarbons, Organic and Biological Electrochemistry, Sensor

B03—Carbon Nanotubes - From Fundamentals to Devices
M. Zheng, Y. Gogotsi, P. Kulesza, S. Doorn, S. Rotkin, R. Bruce Weisman, S. Maruyama, B. Flavel, Y. Li
Nanocarbons, Physical and Analytical Electrochemistry

B04—NANO in La Francophonie
R. Martel, T. Szkopek, L. Cognet, A. Boghossian, C. Voisin, J.-F. Nierengarten, A. Loiseau, J.-C. Charlier, S. V. Rotkin, D. Bouilly
Nanocarbons, Dielectric Science and Technology, Sensor

B05—Fullerenes - Endohedral Fullerenes and Molecular Carbon
S. Yang, A. Balch, F. D'Souza, L. Echegoyen, D. Guldi, N. Martin, S. Stevenson
Nanocarbons

B06—2D Layered Materials from Fundamental Science to Applications
M. Arnold, S. De Gendt, Z. Karim, C. O'Dwyer, S. Rotkin, V. Di Noto, Y. Obeng
Nanocarbons, Dielectric Science and Technology, Electronics and Photonics, Energy Technology, Interdisciplinary Science and Technology Subcommittee

B07—Light Energy Conversion with Metal Halide Perovskites, Semiconductor Nanostructures, and Inorganic/Organic Hybrid Materials
H. Imahori, P. Kamat, K. Murakoshi, T. Torimoto, V. Di Noto
Nanocarbons, Energy Technology

B08—Porphyrins, Phthalocyanines, and Supramolecular Assemblies
K. Kadish, R. Paolesse, T. Torres, N. Solladie, D. Smith, N. Jux
Nanocarbons, Organic and Biological Electrochemistry

B09—Nano for Industry
S. Rotkin, L. Haverhals, F. D'Souza, O. Leonte, E. J. Taylor
Nanocarbons, Dielectric Science and Technology, Industrial Electrochemistry and Electrochemical Engineering, Physical and Analytical Electrochemistry, Sensor, Interdisciplinary Science and Technology Subcommittee

C— Corrosion Science and Technology

C01— Corrosion General Session
M. Itagaki, J. Noel
Corrosion

D— Dielectric Science and Materials

D01—Dielectrics for Nanosystems 8: Materials Science, Processing, Reliability, and Manufacturing
D. Misra, Z. Chen, D.-K. Ko, Y. Obeng, D. Bauza, T. Chikyow
Dielectric Science and Technology

D02—Nanoscale Luminescent Materials 6
P. Mascher, F. Rosei, D. Lockwood
Dielectric Science and Technology, Luminescence and Display Materials

D04—Plasma Electrochemistry and Catalysis
R. M. Sankaran, M. Sunkara, U. Cvelbar, D. Mariotti
Dielectric Science and Technology

E— Electrochemical/Electroless Deposition

E01—Surfactant and Additive Effects on Thin Film Deposition, Dissolution, and Particle Growth 2
T. Moffat, P. Broekmann, R. Akolkar, J.-G. Zhang, B. Wiley
Electrodeposition

E02—Nucleation and Growth Processes Enabling Energy Conversion and Storage
Y. Fukunaka, T. Moffat, J. Ustarroz, Y. Meng
Electrodeposition, Battery

E03—Electrodeposition of Alloys, Intermetallic Compounds, and Eutectics
A. Radisic, T. Hall, D. Davis
Electrodeposition

F— Electrochemical Engineering

F01—Advances in Industrial Electrochemistry and Electrochemical Engineering
D. Riemer, J. Staser, S.-K. Kim
Industrial Electrochemistry and Electrochemical Engineering

G— Electronic Materials and Processing

G01—Silicon Compatible Emerging Materials, Processes, and Technologies for Advanced CMOS and Post-CMOS Applications 10
H. Jagannathan, K. Kakushima, P. Timans, E. Gusev, Z. Karim, S. De Gendt, D. Misra, Y. Obeng, F. Roozeboom
Electronics and Photonics, Dielectric Science and Technology

H— Electronic and Photonic Devices and Systems

H01—Wide-Bandgap Semiconductor Materials and Devices 21
J. Hite, S. Kilgore, M. Tadjer, V. Chakrapani, J. Zavada, T. Anderson
Electronics and Photonics

H02—Advanced CMOS-Compatible Semiconductor Devices 19
J. Martino, B.-Y. Nguyen, F. Gamiz, H. Ishii, S. Selberherr, E. Simoen
Electronics and Photonics, Dielectric Science and Technology

H03—Solid-State Electronics and Photonics in Biology and Medicine 7
Y.-L. Wang, Z. Aguilar, W. Wu, Z.-H. Lin, A. Hoff, C.-T. Lin, L. Marsal, M. Jamal Deen, T. Sakata
Electronics and Photonics, Sensor

I— Fuel Cells, Electrolyzers, and Energy Conversion

I01—Electrosynthesis of Fuels 6: In Honor of Mogens Mogensen
X.-D. Zhou, P. Kenis, O. Marina, H. Xu, D. Ding, T. Gur, G. Brisard, J. Staser, W. Mustain, J. Flake, M. Mogensen
High-Temperature Energy, Materials, & Processes, Energy Technology, Industrial Electrochemistry and Electrochemical Engineering, Physical and Analytical Electrochemistry

I02—Hydrogen or Oxygen Evolution Catalysis for Water Electrolysis 6
H. Xu, J. Spurgeon, E. Podlaha, E. Biddinger
Energy Technology, Electrodeposition, Industrial Electrochemistry and Electrochemical Engineering

I03—Materials for Low Temperature Electrochemical Systems 6
M. Shao, Y.-C. Lu, John Flake, C. Xiong
Energy Technology, Battery

I04—Renewable Fuels via Artificial Photosynthesis or Heterocatalysis 5
N. Wu, Heli Wang, J.-J. Lee, F. Osterloh, B. Ohtani, P. Kulesza, E. Miller, V. Subramanian, M. Sunkara, J. Yang
Energy Technology, Sensor

I05—Mechano-Electro-Chemical Coupling in Energy Related Materials and Devices 4
N. Perry, A. Kusoglu, J. Nicholas, N. Zhao, F. Lin
High-Temperature Energy, Materials, & Processes, Battery

I06—Energy Conversion Systems Based on Nitrogen 3
G. Wu, H. Xu, S. Minteer, K. Ayers, J. Renner, L. Greenlee, C. Kreller, G. Botte
Energy Technology, High-Temperature Energy, Materials, & Processes, Industrial Electrochemistry and Electrochemical Engineering, Physical and Analytical Electrochemistry

I07—Invited Perspectives and Tutorials on Electrolysis
B. Pivovar, H. Xu, K. Ayers
Energy Technology, Battery, Industrial Electrochemistry and Electrochemical Engineering

K— Organic and Bioelectrochemistry

K01—14th Manuel M. Baizer Memorial Symposium on Organic Electrochemistry
G. Cheek, F. Maran, D. Smith
Organic and Biological Electrochemistry

K02—Electron-transfer Reactions in the Characterization of Biological Systems
D. Smith, G. Cheek, J. Rusling
Organic and Biological Electrochemistry

L—Physical and Analytical Electrochemistry, Electrocatalysis, and Photoelectrochemistry

L01—Physical and Analytical Electrochemistry, Electrocatalysis, and Photoelectrochemistry General Session
A. Suroviec, P. Vanysek
Physical and Analytical Electrochemistry

L02—Electrocatalysis 10
G. Brisard, M. Shao, P. Kulesza, V. Di Noto
Physical and Analytical Electrochemistry, Energy Technology

L03—Biological Fuel Cells 9
S. Minteer, S. Calabrese Barton, P. Atanassov, S. Krishnan
Physical and Analytical Electrochemistry, Energy Technology, Organic and Biological Electrochemistry

L04—Nanoporous Materials 2
R. Warren, N. Dimitrov, N. Vasiljevic, I. Zenyuk
Energy Technology, Electrodeposition, Physical and Analytical Electrochemistry

L05—Composite Electrodes
D. Wood, T. Zawodzinski, P. Liu, R. Borup, J. Staser
Physical and Analytical Electrochemistry, Battery, Energy Technology, Industrial Electrochemistry and Electrochemical Engineering

L06—Electronic Structure Theory and Simulations for Energy and Electronics
Y. Liu, H. Zhuang
Physical and Analytical Electrochemistry

L07—Nanostructured Functional Materials for Electrochemistry
P. Kulesza, H. Habazaki, P. Atanassov, V. Di Noto, I. Rutkowska
Physical and Analytical Electrochemistry, Energy Technology

Z—General Topics

Z01—ECS General Student Poster Session
A. Suroviec, K. Sundaram, V. Chaitanya, V. Subramanian
All Divisions

IMCS—18th International Meeting on Chemical Sensors (IMCS 2020)

IMCS 01—Artificial Intelligence, Machine Learning, Chemometrics, and Sensor Arrays
K. Johnson, L.-k. Tsui, J.-h. Jiang
Sensor

IMCS 02—Chemical and Biosensors, Medical/Health, and Wearables
N. Wu, R.-I. Stefan-van Staden, D. Cliffel, L, Nagahara, C. Z. Li, H. Susan Zhou, L. Soleymani, J. Wang, W.-H. Huang, S. Krishnan
Sensor, Organic and Biological Electrochemistry, Physical and Analytical Electrochemistry

IMCS 03—Electrochemical and Metal Oxide Sensors
S. Akbar, J. Stetter, N. Myung, H. (Lili) Deligianni, J.-H. Lee, G. Lu
Sensor, Electrodeposition

IMCS 04—Sensors for Agricultural and Environmental Applications
R. Ramasamy, B. Chin, A. Chen, X.-J. Huang, P. Chen, W. Wu
Sensor

IMCS 05—Recent Advances and Future Directions in Chemical and Bio Sensor Technology
G. Hunter, G. Xu, J. Stetter, W. Wu, J.-W. Choi
Sensor

IMCS 07—MEMS/NEMS, FET Sensors, and Resonators
P. Hesketh, P. Vanysek, T. Thundat, F. Ayazi, E. Vogel
Sensor, Physical and Analytical Electrochemistry

IMCS 08—Microfluidic Devices and Sensors
J. Koehne, S. Mitra, I. Fritsch, M. Madou
Sensor, Physical and Analytical Electrochemistry

IMCS 09—Optical Sensors, Plasmonics, Chemiluminescent, and Electrochemiluminescent Sensors
G. Xu, J. Zhao, U. Cvelbar, H.-T. Chang, Z. Ding, X. Jiang
Sensor, Dielectric Science and Technology

IMCS 10—Sensors for Breath Analysis, Biomimetic Taste, and Olfaction Sensing
P. Hesketh, D.-J. Kim, P. Gouma, H. Cui, N. Sojic
Sensor

IMCS 11—Chemical and Biosensing Materials and Sensing Interface Design
X. Zeng, X. Chen, O. Niwa
Sensor

IMPORTANT DATES AND DEADLINES

Hotel and early registration deadlines......................April 6, 2020
Anticipated release date for *ECS Transactions* issues ....May 1, 2020
237th ECS Meeting with 18th International Meeting on Chemical Sensors (IMCS 2020) ..... May 10-14, 2020

ECS Annual Business Meeting and Luncheon

237th ECS Meeting in Montréal

Tuesday, May 12, 2020

1200-1400h
Room: 524BC, Palais des congrès de Montréal

Purchase tickets when you register.

	Early (before April 6)	Regular (after April 6)	Onsite
ECS Fellow	$25	$35	$45
ECS member	$35	$45	$55
Non-member	$45	$55	$65

18th International Meeting on Chemical Sensors (IMCS 2020)

The Committees for North America, Asia, and Europe for the International Meeting on Chemical Sensors invite you to IMCS 2020, held in Montréal during May of 2020. This will be the 18th in a series of successful meetings for researchers, professionals, and business leaders to see the state of the art in sensors for gases, liquids, biologicals, for applications in health and environment, wearables and fixed infrastructure, as well as wired and wireless.

Chemical and biosensors for gases, vapors, and liquids are becoming more critical, with recent developments in changing weather patterns and the impact of greenhouse gases and their adverse effects on the environment. We anticipate sweeping changes to the application of sensors to air quality monitoring, food safety, and water quality in the near future. Sensor technology is also widely applied to human medical diagnostics and health and fitness monitoring. The demand for environment sensing and development of sensor technology to determine the effects on human and animal health are critically important. This is an opportunity to participate in the revolution that is taking place in sensor technology leading to new monitoring and sensing systems connected to the Internet of Things.

Symposium Topics

- Artificial Intelligence, Machine Learning, Chemometrics, and Sensor Arrays
- Chemical and Biosensors, Medical/Health, and Wearables
- Electrochemical and Metal Oxide Sensors
- Sensors for Agricultural and Environmental Applications
- Recent Advances and Future Directions in Chemical and Bio Sensor Technology
- MEMS/NEMS, FET Sensors, and Resonators
- Microfluidic Devices and Sensors
- Optical Sensors, Plasmonics, Chemiluminescent, and Electrochemiluminescent Sensors
- Sensors for Breath Analysis, Biomimetic Taste, and Olfaction Sensing
- Chemical and Biosensing Materials and Sensing Interface Design

Plenary Speakers

Monday, May 11

"Design Strategies for High-Performance Oxide Semiconductor Gas Sensors"
Jong-Heun Lee, *Korea University*

Photo: Jong-Heun Lee

Jong-Heun Lee has been a professor at the Department of Materials Science and Engineering, Korea University, since 2003. His research interests include semiconductor gas sensors and functional oxide nanostructures. He received his BS, MS, and PhD degrees from the Department of Inorganic Materials and Engineering, Seoul National University, Seoul, Korea, in 1987, 1989, and 1993, respectively. Between 1993 and 1999, as a senior researcher, he developed automotive air-fuel-ratio sensors at the Samsung Advanced Institute of Technology. He was a STA Fellow at the National Institute for Research in Inorganic Materials (currently NIMS, Tsukuba, Japan) from 1999 to 2000, and a research professor at Seoul National University from 2000 to 2003. He is an editor of *Sensors and Actuators B: Chemical*, a fellow member of the Korean Academy of Science and Technology, and general member of the National Academy of Engineering of Korea. In 2014, he was a Highly Cited Researcher by Thomson Reuters for ranking in the top 1% most cited papers. He has won several awards, including POSCO TJ Award (2017), Knowledge Creation Award (2014), 100 Future-Leading Technologies and Their Developers (2013), Korean Sensor Society Academic Award (2016), Korea University Special Award for Distinguished Research (2014), and Patent of Year (2001). He was co-chairman of the International Meeting on Chemical Sensors 2016, Jeju, Korea. He has published 305 peer-reviewed papers. In addition, he holds 40 domestic and international patents.

Tuesday, May 12

"Wearable Sensors for Monitoring Chemical Markers: Beyond Steps and Vitals"
Joseph Wang, *University of California, San Diego*

Photo: Joseph Wang

Joseph Wang is SAIC Endowed Chair and Distinguished Professor in the Department of Nanoengineering at University of California, San Diego (UCSD). He is also the Director of the UCSD Center of Wearable Sensors and the Founding Editor of *Electroanalysis*. He served as the Chair of the Department of Nanoengineering (2014-2019) and as the Director of Center for Bioelectronics of ASU (2004-2008). Wang has made pioneering contributions to wearable biosensors, electrochemical devices, nanomachines, and nanobioelectronics. Prof. Wang has published more than 1,060 papers and 11 books. He holds 30 patents. His publications have been cited over 107,000 times and his h-index is 160. He has been an ISI Thomson Reuters Highly Cited Researcher in both chemistry and engineering from 2014 through 2019.

Wang has received several national ACS, ECS, and SEAC Awards in instrumentation and electrochemistry, 10 honorary professors from around the globe, and three Medals of Honor from the United Kingdom, Australia, and Czech Republic. He is a fellow of the ECS, Royal Society of Chemistry (RSC), and of the American Institute of Medical and Biological Engineering (AIMBE). Over his career, Wang has guided over 300 PhD students and postdoc fellows.

Wednesday, May 13

"Electrochemical/Optical Sensors in Medicine: Meeting Needs for the 21st Century"

Mark E. Meyerhoff, ***University of Michigan***

Photo: Department of Chemistry, University of Michigan

Mark E. Meyerhoff is currently Philip J. Elving Professor of Chemistry in the Department of Chemistry at the University of Michigan, Ann Arbor. He received his PhD from the State University of New York at Buffalo in 1979, working with Prof. Garry A. Rechnitz. Following a short postdoctoral stint at the University of Delaware, he joined the faculty at Michigan as an assistant professor in the fall of 1979. Meyerhoff's primary research interests are in the field of analytical chemistry, particularly the development of new ion-, polyion-, gas-, and bio-selective electrochemical/optical sensors suitable for direct measurements of clinically important analytes in physiological samples. He also has a very active research program in the area of biomaterials, especially the development and characterization of novel nitric oxide (NO) releasing/generating polymeric materials. He and his collaborators have authored more than 380 original research papers on these and other topics over the past 40 years since beginning his independent academic career at Michigan. Meyerhoff received the ACS-Division of Analytical Chemistry Award in Electrochemistry in 2003, the Society for Electroanalytical Chemistry's Reilley Award in 2006, the University of Michigan's Outstanding Graduate Mentoring Award in 2006, the University of Michigan's Distinguished Faculty Achievement Award in 2011, and the Ralph Adams Award in Bioanalytical Chemistry from the Pittsburgh Conference on Analytical Chemistry in 2014.

Thursday, May 14

"From Gene to Device: The Route to Diagnostics in Low Resource Countries"

Elizabeth A. H. (Lisa) Hall, *University of Cambridge*

Department of Chemical Engineering & Biotechnology, University of Cambridge

Lisa Hall is Professor of Analytical Biotechnology and Head of Department in the Department of Chemical Engineering and Biotechnology, University of Cambridge. She is an internationally recognized authority in the field of biosensors. Her research is focused on understanding how biology can be interfaced with electronic, mechanical, and optical systems and new ways to answer fundamental and applied questions concerning new measurement regimes to achieve diagnostic systems. She was awarded the Gold Medal by the Analytical Division of the Royal Society of Chemistry in 2005, and the Alec Hough-Grassby Memorial Award by the Institute of Measurement & Control in 2009. In 2015, she was appointed a CBE for services to higher education and sport for the disabled in the Queen's Birthday Honours List.

Special Events

(Check the meeting app for times.)

Opening Reception

Come join us for an evening of fun, as we kick off IMCS 2020 with some traditional Indian music at the rooftop garden and lounge at the Palais des congrés de Montréal. This is an excellent opportunity to meet old and new friends, so make sure to stop by for some food, drinks, music and great conversation!

Sponsors Forum

This event is an opportunity to hear from invited presenters from different funding organizations, and government agencies concerning their prospective on current programs and strategies regarding securing research funding and sustaining research activities at universities and other institutions on chemical and biosensors.

Industry Round Table

Sensors is a dynamic and constantly evolving field and one of the easiest to translate to real world applications. There are many commercialization and entrepreneurship opportunities. A range of interesting sensor companies have agreed to participate at this round table discussion regarding key steps and barriers for the commercialization processes for chemical and biosensors.

Networking Session for Young Professionals

Young people will have a chance to meet session chairs, conference organizers, invited speakers, and industry leaders in an informal setting. This will help build a network, as we become acquainted with those working in the field, establish collaborations, and brainstorm for new ideas, or find a mentor.

Cocktail Reception and Banquet

The closing night banquet will be held inside the historic Marché Bonsecours, built in 1847. In addition to excellent cuisine with Canadian flavors, attendees will be entertained by Concordia University modern Laptop Orchestra and Jazz Ensemble, comprising faculty and students from the School of Music, Concordia University.

Yuehe Lin Honored by the National Academy of Inventors

Photo: Courtesy of Washington State University

ECS Member **Yuehe Lin** has been named a fellow by the National Academy of Inventors. A professor in the School of Mechanical and Materials Engineering at Washington State University since 2013, Lin is affiliated with the ECS Sensor Division. Lin also has a joint appointment at Pacific Northwest National Laboratory.

According to Mary Rezac, Dean of WSU's Voiland College of Engineering and Architecture, Dr. Lin has made significant research contributions with real-world impact in the fields of energy and health. "His hugely varied work—from finding possible new ways to treat cancer to innovations in water splitting for a future hydrogen economy and development of a better catalyst for fuel cells—often comes down to simple solutions that can provide real change and improvements in people's lives."

Lin has quite a list of impressive accomplishments. He holds more than 20 patents and has received funding from the Department of Energy, Centers for Disease Control and Prevention, Department of Defense, and National Institutes of Health. According to Google Scholar, he has over 500 peer-reviewed publications, which have been cited over 50,000 times. For the past five years, Lin has been recognized by the Web of Science Group as a highly cited researcher. Dr. Lin will be inducted into the National Academy of Inventors on April 10.

In Memoriam

Yutaka Okinaka
(1926-2019)

Yutaka Okinaka passed away on November 7, 2019 at the age of 93. Okinaka was an ECS Life Member. Since joining The Electrochemical Society in 1964, he was actively involved in ECS functions, and notably served as an associate editor of the *Journal of The Electrochemical Society* for the Electrodeposition Division from 1978 to 1987. For his research work, he was honored with the Battery Division Research Award in 1970, the Electrodeposition Division Research Award in 1981, and ECS Fellow in 1995. His main research field was electrodeposition. He was a pioneer in the electrolytic and electroless deposition of gold and precious metals. He made numerous contributions not only to the scientific understanding of complex plating mechanisms, but also to the development of various plating processes for fabricating electronic devices and packages used in the telecommunication industries. As a leading expert in the field of gold plating and an inventor of an electroless gold bath, he wrote several important review articles in this field.

Okinaka was born in 1926 in Osaka, Japan. He received a PhD from Tohoku University, Japan. During his graduate work, he also studied at the University of Minnesota under the guidance of Prof. Izaak M. Kolthoff. After obtaining his doctorate, he remained at Tohoku University as an associate professor. He then moved to the United States in 1963 to join Bell Laboratories in Murray Hill, NJ as a member of the technical staff. Okinaka was later promoted to the rank of Distinguished Member of the Technical Staff, and spent 31 years there until his retirement in 1994. At Bell Laboratories, he made a number of important technical contributions in the areas of printed circuit boards and electrical contact materials.

Among many technical achievements Okinaka made at Bell Laboratories, there are two research projects that made him a pioneer in the electrodeposition field. The first project was to determine why copper interconnect lines laid on printed circuit boards were cracking during field service. Since the copper lines were fabricated using an electroless plating process, his expert skill in electrodeposition made a perfect match for him to tackle this problem. He found that the cause of the cracking was due to hydrogen embrittlement in the copper. Here he has shown that the hydrogen originates during the electroless plating process and then goes into the copper deposit as pressured hydrogen gas bubbles. The high pressure of hydrogen gas developed inside the bubbles caused embrittlement in the copper by the so-called pressure effect. Through these studies, he further discovered that the room-temperature ductility recovery in the copper was occurring by the outdiffusion of hydrogen from the occluded hydrogen gas bubbles, confirming that the pressure effect was indeed operative.

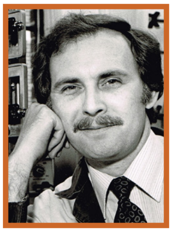
The second major project Okinaka had undertaken was to solve the cause of an increased contact resistance in electrical gold contacts. The gold (known as hard gold) deposit used in this application was prepared by electrodeposition. Again, his expert knowledge in gold electrodeposition helped solve this problem. This problem arose because the gold layer thickness has to be reduced due to an increase in gold price. The thickness reduction created shorter diffusion paths for copper atoms to migrate through the pores/grain boundaries and to arrive at the gold surface, forming a high-resistance copper oxide film. To solve this problem, he conducted an extensive study on understanding the microstructure of the hard gold and the nature of the inclusions. This pioneering research encouraged many investigators to look into alternative contact metals, such as palladium and palladium-nickel alloy. Similarly, he developed a so-called additive-free hard gold bath from a conventional soft gold bath without the addition of additives and succeeded in producing a hard gold deposit by simply lowering the bath temperature. Among numerous other contributions he made at Bell Laboratories, the construction of a microprocessor for controlling a copper plating bath is one notable example.

After retirement from Bell Laboratories he was invited to Waseda University, Tokyo, Japan, as a visiting professor. He also worked as a consultant for several institutes and companies in Japan. He enjoyed research, education, and frequent travel between the United States and Japan, and was an enthusiastic student of music, astronomy, magic, and the game of Go. Okinaka is survived by his wife Masayo, son Masato Okinaka, daughter Naomi Heck, and four grandchildren.

This notice was contributed by Takayuki Homma.

In Memoriam

Eric Brooman
(1940-2019)



Eric William Brooman passed away on February 10, 2019. Brooman was born on September 15, 1940 to parents William and Ethel. He grew up in Tottenham, England with his younger sister Brenda. Brooman had a love for science and technology, and studied profusely. When not studying, he was with the Boy Scouts, and enjoyed playing the violin, ballroom dancing, and painting—winning first place in an art competition.

Brooman earned a degree from the Battersea College of Technology, and a PhD from Cambridge University. While attending college, he was injured playing rugby. During his recovery, he met a beautiful physiotherapist named Irene Yelland. They were married in 1962. Eric and Irene moved to the United States in 1966, where Eric began his career at Battelle Memorial Institute in Columbus, OH. He held various research leadership roles, specializing in metallurgy and electrochemistry. His forte was the study and prevention of corrosion. After retiring from Battelle, he continued as a consultant for several technology companies, as well as the U.S. Air Force Research Laboratory.

Dr. Brooman was a lifelong member and contributor to The Electrochemical Society. He was an Emeritus member, joining back in 1963. Since 1968, he was affiliated with the Electrodeposition Division. From 1988-1992, Brooman served as ECS secretary. In 1999, he was honored as a fellow. Over the years, he published numerous books and papers.

He also liked to get away. Brooman enjoyed spending time outdoors with his family—exploring the Great Smoky and Blue Ridge mountains—camping, fishing, hiking, and boating. He also loved to return to the United Kingdom, especially to Cornwall. Dr. Brooman is survived by his sister Brenda, son Andrew, and daughter Susan. He will be greatly missed.

This notice was contributed by Andrew Brooman.

Joanna M. McKittrick
(1954-2019)

Joanna McKittrick passed away in November of 2019. Prof. McKittrick was a member of The Electrochemical Society since 2013. She was affiliated with the Luminescence and Display Materials Division.

Hadis Hayatdavoudi
(1992-2020)

Hadis Hayatdavoudi passed away in January of 2020. She was a member of The Electrochemical Society since 2018. Ms. Hayatdavoudi was affiliated with the Canada Section, as well as the Corrosion Division.

PRIME PACIFIC RIM MEETING ON ELECTROCHEMICAL AND SOLID STATE SCIENCE 2020

PRiME 2020
Honolulu, HI
October 4-9, 2020
Hawaii Convention Center & Hilton Hawaiian Village

SYMPOSIUM TOPICS & DEADLINES

A— Batteries and Energy Storage

A01—Intercalation Chemistry for Electrochemical Energy Storage Technologies: In Honor of M. Stanley Whittingham

A02—New Materials for Next Generation Batteries

A03—Fast Energy Storage Processes and Devices-Capacitors, Supercapacitors, and Fast-Charging Batteries

A04—Electrolytes, Interfaces, and Interphases

A05—Advances, Challenges, and Development of Solid State Battery Electrochemistry and Materials

A06—Progress and Critical Assessment of Large Format Batteries

B— Carbon Nanostructures and Devices

B01—Carbon Nanostructures: From Fundamental Studies to Applications and Devices

C— Corrosion Science and Technology

C01—Corrosion General Poster Session

C02—High Temperature Corrosion and Materials Chemistry 14

C03—Pits and Pores 9: Nanomaterials-Fabrication, Properties, and Applications

C04—Light Alloys 6: In Honor of Hideaki Takahashi

C05—High Resolution Characterization of Corrosion Processes 5: In Honor of Philippe Marcus

C06—Atmospheric and Marine Corrosion 2

C07—Corrosion Protection 2

D— Dielectric Science and Materials

D01—Semiconductors, Dielectrics, and Metals for Nanoelectronics and Plasma Nanosciences

D02—The Science and Applications of Topological and Correlated Materials

E— Electrochemical/Electroless Deposition

E01—Electrodeposition for Energy Applications 5

E02—Electrochemistry for Material Science: In Memory of Ken E. Nobe

E03—Electrochemical and Electroless Deposition of Thin-films and Nanostructures-Theory, Numerical Simulations, and Applications

E04—Applied Electrodeposition: From Electrowinning to Electroforming

F— Electrochemical Engineering

F01—Advances in Industrial Electrochemistry and Electrochemical Engineering

F02—Advances in Application and Theory of Electrochemical Impedance Spectroscopy

F03—Modeling Electrochemical Systems for Transportation Applications

G— Electronic Materials and Processing

G01—Semiconductor Wafer Bonding: Science, Technology, and Applications 16

G02—Atomic Layer Deposition Applications 16

G03—SiGe, Ge, and Related Compounds: Materials, Processing, and Devices 9

G04—Thermoelectric and Thermal Interface Materials 6

G05—Materials and Processes for Semiconductor, 2.5 and 3D, Chip Packaging, PCB, FPCB and Wafer Bonding 3

H— Electronic and Photonic Devices and Systems

H01—Joint Symposium: State-of-the-Art Program on Compound Semiconductors 63 (SOTAPOCS 63)-and-GaN and SiC Power Technologies 10

H02—Photovoltaics for the 21st Century 16: New Materials and Processes

H03—Thin Film Transistors 15 (TFT 15)

H04—Low-Dimensional Nanoscale Electronic and Photonic Devices 13

H05—Optics, Electronics, and Electrochemical Properties of Metal Organic Frameworks (MOFs): Technology, Applications, and Emerging Devices 2

H06—Nonvolatile Memories and Artificial Neural Networks

H07—Electrochromic and Photoelectrochromic Materials and Devices

I— Fuel Cells, Electrolyzers, and Energy Conversion

I01—Polymer Electrolyte Fuel Cells & Electrolyzers 20 (PEFC&E 20)

I02—Solid State Ionic Devices 13

I03—Frontiers of Chemical/Molecular Engineering in Electrochemical Energy Technologies: In Honor of Robert Savinell's 70th Birthday

J— Luminescence and Display Materials, Devices, and Processing

J01—Recent Advances in Wide-Bandgap III-Nitride Devices and Solid State Lighting: In Honor of Isamu Akasaki

K— Organic and Bioelectrochemistry

K01—New Developments in Synthetic and Mechanistic Organic Electrochemistry: In Memory of Junichi Yoshida

K02—Towards Interdisciplinary Fusion of Bioengineering and Electrochemistry

L— Physical and Analytical Electrochemistry, Electrocatalysis, and Photoelectrochemistry

L01—Fundamentals and Applications of Physical and Analytical Electrochemistry, Electrocatalysis, and Photoelectrochemistry

L02—Molten Salts and Ionic Liquids 22

L03—Electrode Processes 13

L04—Photocatalysts, Photoelectrochemical Cells, and Solar Fuels 11

L05—Advanced Techniques for In Situ Electrochemical Systems 3

L06—Fundamental Aspects of Electrochemical Conversion of Carbon Dioxide 2

L07—(Photo)Electrochemistry and Electrocatalysis for Water-Energy Nexus

L08—Advanced Nano-Photovoltaics

M— Sensors

M01—Microfabricated and Nanofabricated Systems for MEMS/NEMS 15

M02—Chemical Sensors 13: Recent Advances in Chemical and Biological Sensors and Analytical Systems

M03—In Vivo Nano Biosensors

Z— General

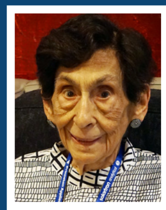
Z01—General Student Poster Session

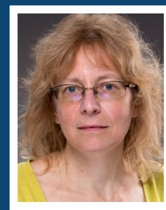
Z02—4DMS+SoRo: 4D Materials & Systems + Soft Robotics

IMPORTANT DATES AND DEADLINES

Meeting abstract submission deadline .... April 17, 2020
Notification to corresponding authors of abstract acceptance or rejection .... June 2020
Technical program published online .... June 2020
Meeting registration opens .... June 2020
ECS Transactions submission site opens .... June 19, 2020
Travel grant application deadline .... July 29, 2020
ECS Transactions submission deadline .... July 17, 2020
Meeting sponsor and exhibitor deadline (for inclusion in printed materials) .... July 24, 2020
Travel grant approval notification .... August 17, 2020
Hotel and early registration deadlines .... August 31, 2020
Release date for *ECS Transactions* issues .... No later than September 25, 2020


Kathy Ayers


Joan Berkowitz

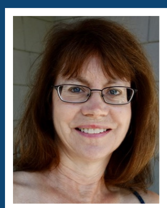

Christina Bock


Kathryn Bullock


Roque Calvo


Lili Deligianni


Elizabeth Endler


Karen Hanson


E.J. Taylor


Johna Leddy


Janine Mauzeroll


Roberta Rincon


Steen Schougaard


Carrie Shelper


Jesus Soriano Molla


Hikari Sakaebe


Alice Suroviec


Robin Susko


Esther Takeuchi


Jan Talbot


Sannakaisa Virtanen

40 YEARS AFTER: A Workplace for All

by Alice Suroviec

Diversity and inclusion are key to the modern work environment. A recent study by *Forbes Insights*, "Global Diversity and Inclusion: Fostering Innovation through a Diverse Workforce," produced significant findings on this. On top of the list was that diversity is a key driver of innovation and is a critical component of being successful on a global scale. According to the study, senior executives recognized that a diverse set of experiences, perspectives, and backgrounds is crucial to innovation and the development of new ideas. A second finding was that a diverse and inclusive workforce is crucial for companies that want to attract and retain top talent. The competition for talent is fierce in our global economy. As such, top employers are increasingly putting plans in place to recruit, develop, and retain a diverse workforce. Although significant progress has been made to build and retain diverse workforces, progress still needs to be made in the areas of age, gender diversity, and disability. Members will agree—The Electrochemical Society is on the forefront of diversity and inclusion.

At the 236th ECS Meeting held October 13-17, 2019 in Atlanta, a groundbreaking symposium was held on inclusion and diversity: *40 Years After: A Symposium on Diversity*. During this special event, the statement on diversity and inclusion was presented: The Electrochemical Society strives to be an inclusive organization that promotes and values diversity. We recognize and respect the rights of all, and are committed to building and maintaining a culture that encourages, supports, and celebrates the unique backgrounds and experiences of our members, volunteers, employees, and constituents. Diversity is our strength. It fuels innovation, enhances collaboration, enables our best accomplishments, brings us closer to the communities we serve, and advances our mission to promote electrochemical and solid state science worldwide. The ECS also highlighted their Ad-Hoc Committee on Diversity and Inclusion to help the Society maintain best practices and work to keep diversity and inclusion visible throughout the year, as well as increasing education of this important topic.

> *Diversity and inclusion are growing in recognition as beneficial components in creating positive work environments and meetings, broadening and deepening perspectives in science and technology, promoting research and development and innovation, and enhancing technology.*
>
> —ECS

A major component of the symposium was the 40th anniversary of the first female ECS president Joan Berkowitz (1979-1980). The groundbreaking efforts of Berkowitz have led to many other female leaders and female presidents of ECS. Johna Leddy (2017-2018) and Christina Bock (2019-2020) have served as mentors during my time at the Society. Kathryn Bullock (1995-1996), Jan Talbot (2001-2002), Robin Susko (2004-2005), and Esther Takeuchi (2011-2012) are among the seven female ECS presidents who also have made an impact.

Invited speakers also contributed to this symposium. Jesus Soriano Molla, Program Director of the National Science Foundation's Partnerships for Innovation program, spoke on the challenges faced by academic institutions when trying to commercialize the output of federally funded research. He specifically spoke to the lack of diversity in many of these programs and ways that academic and federal programs can increase and support diversity. Molla was followed by Roberta Rincon from the Society of Women Engineers. Rincon spoke to the issue of women leaving engineering at their mid-career point. The data shows that more women are choosing STEM careers, but are leaving due to workplace climate and culture.

The next segment of the symposium included personal stories of women and their path to success. Lili Deligianni (ECS Life Member) and Kathy Ayers (Proton Onsite) both spoke to the importance of trusted advisors, mentors, and colleagues who form a support network that can help through the lulls and setbacks in your career. Hikari Sakaebe (National Institute of Advanced Industrial Science and Technology) reflected on her experience as a group leader in her department where there are only 10% female researchers and even fewer group leaders. Esther Takeuchi (ECS President 2011-2012) told her story of being a female engineer in a small company and then her move to academics. She repeated the theme of the importance of having a network of supportive colleagues and how that can contribute to persistence and success in STEM fields.

In the afternoon session, Janine Mauzeroll (McGill University) and Steen Schougaard (Universite du Quebec a Montréal) shared their story as a married couple and how they have had to navigate their respective careers. Karen Hanson (AT&T) and Elizabeth Endler (Shell Technology Center) both spoke of their experiences in being the only females in engineering departments. Both agreed it was challenging, but also provided opportunities to change the climate of the workplace.

The final talk of the afternoon was by Roque Calvo (Former ECS Executive Director). Calvo discussed the growth of ECS during his 38-year career. He shared how Joan Berkowitz being elected vice president in 1976 and president in 1979 shaped his first few years as the Society's executive director. He pointed out that the ECS community has always made diversity and inclusion a priority. The ECS community and meetings continue to offer support and mentorship.

40 Years After: A Symposium on Diversity concluded with a panel discussion. On the panel were Esther Takeuchi, Jesus Soriano Molla, Kathy Ayres, Roque Calvo, and Carrie Shelper (Georgia Tech). The panelists discussed through experiences what specific things an organization can do to ensure it makes the best use of a diverse workforce and how to support and retain those colleagues. There was a very good discussion among the panel and the audience about the universal issues of diversity and inclusion, as well as advice for specific issues.

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Acknowledgments

The symposium was a celebration of the past and a look to the future. I wanted to give back to the Society by providing the same opportunity to new scientists and engineers. This symposium was a labor of love for many people. While I was the main organizer for the event, many others helped in the effort. I would personally like to thank Christina Bock, E.J. Taylor, Lili Deligianni, Johna Leddy, and Sannakaisa Virtanen for their help in organizing this very successful symposium. As chair of the Ad-Hoc Committee on Diversity and Inclusion, I welcome programming suggestions and invite members to volunteer their time to be a part of the committee.

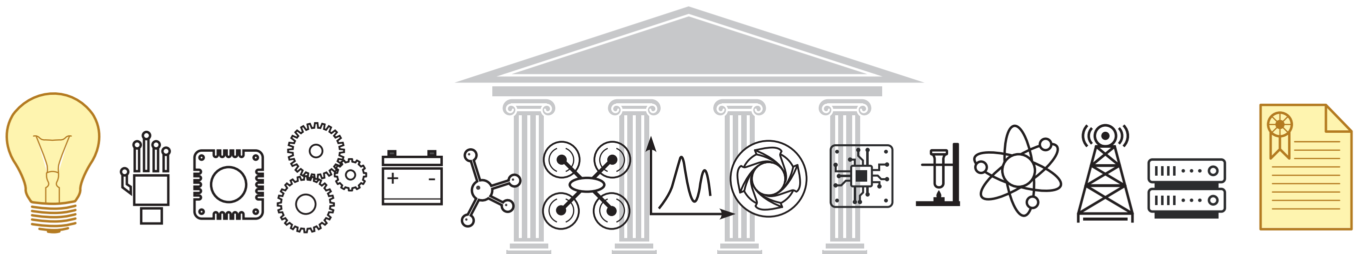
About the Editor

Alice Suroviec is professor of bioanalytical chemistry and chair of the Department of Chemistry and Biochemistry at Berry College. She earned a BS in chemistry from Allegheny College in 2000. She received her PhD from Virginia Tech in 2005 under the direction of Dr. Mark R. Anderson. Her research focuses on enzymatically modified electrodes for use as biosensors. She is currently associate editor of the PAE Technical Division for the *Journal of The Electrochemical Society.* She can be reached at asuroviec@berry.edu.

https://orcid.org/0000-0002-9252-2468

Looking at Patent Law:
Patenting a Unitized Regenerative Fuel Cell System for Space Energy Storage Applications—A Case Study

by E. Jennings Taylor and Maria Inman



In this installment of the "Looking at Patent Law" articles, we present a case study of a unitized regenerative fuel cell system. We have chosen this invention to align with the focus of this issue of *Interface* on the "Electrochemistry in Space" symposium held at the 236th ECS Meeting in Atlanta, GA, October 13-17, 2019.

Recall from our previous article,[1] the prosecution (examination) history of a patent application is publicly available in the file wrapper on the U.S. Patent & Trademark Office (USPTO) Patent Application Information Retrieval (PAIR) system.[2] With the PAIR system as the primary source of information for this case study, we illustrate the prosecution "events" encountered leading to the issuance of U.S. Patent No. 7,410,714, "Unitized Regenerative Fuel Cell."[3] Kenneth Burke, an engineer at the National Aeronautics and Space Administration (NASA) Glen Research Center in Cleveland, OH, is the inventor on the '714 patent. The *unitized* regenerative fuel cell (URFC) is an improvement on regenerative fuel cell (RFC) systems.

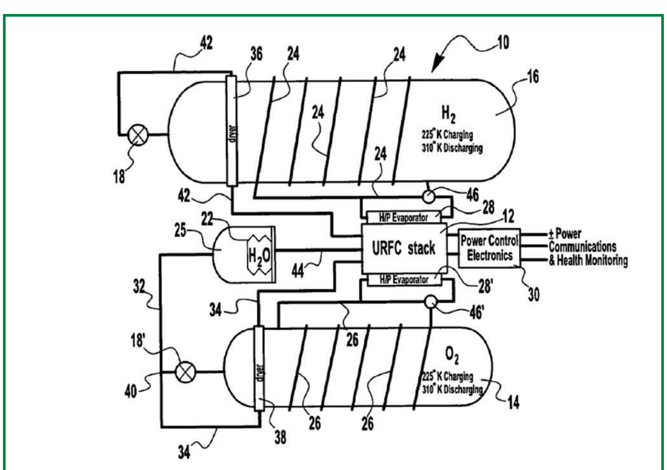


Fig. 1. *Fig. 1 from '714 patent depicting the unitized regenerative fuel cell (URFC) system.*

NASA has a long history of using fuel cell and electrolysis technologies for space missions for primary power, water, and oxygen/hydrogen generation. The first use of a fuel cell on a spacecraft was in 1965 on *Gemini V*. Subsequent space missions, specifically *Apollo*, the *Space Shuttle*, and the *International Space Station*, continued to use fuel cell technology for drinking water generation and various primary power applications.[4] In addition, water electrolyzers are also used as part of the oxygen generation system for manned space missions and are envisioned to continue to play an important role in future long duration space exploration missions.[5]

NASA's experience with electrochemical technologies and hardware suggested the possibility of coupling a fuel cell with an electrolyzer to form an energy storage system, termed a regenerative fuel cell.[6] During the charge cycle, the electrolyzer produces hydrogen and oxygen, which are stored in separate gas tanks. During the discharge cycle, the hydrogen and oxygen are consumed in the fuel cell to produce energy. The URFC improves upon the RFC concept by using the same electrodes to perform both the electrolyzer and fuel cell functions in the same cell stack. The '714 patent represents an improvement on URFC technology.

Utility Patent Application

On July 15, 2004, a utility patent application titled "Unitized Regenerative Fuel Cell System" was filed by attorneys on behalf of inventor Kenneth A. Burke, an employee of NASA Glenn Research Center. A key figure from the patent application is depicted in Fig. 1. Figure 1 illustrates the oxygen and hydrogen gas storage tanks as well as the "unitized regenerative fuel cell" (URFC) stack. The patent application describes the use of the gas storage tanks as heat sinks/sources with heat pipes *in communication* with the fuel cell stack for waste heat utilization and water management.

(continued on next page)

In order to **establish** a filing date, a utility patent application must include:

1. Specification[7]
"…a written description of the invention, and the manner and process for making it…to enable any person skilled in the art…to make and use [the invention]…"
2. Minimum of one claim[8]
"…particularly pointing out…the subject matter…as the invention…"
3. Drawings[9]
"…where necessary for understanding the subject matter…to be patented…"

In order to **maintain** the filing date, the following additional material must be submitted upon a notice to file missing parts from the USPTO:

1. Filing fee in accordance with the current USPTO schedule[10]
2. Inventor oath or declaration asserting[11]
   a. The patent application was authorized by the inventor(s),
   b. The inventor(s) believe he/she is the original inventor or they are the original joint inventors.

The subject patent application included a specification, claims, drawings, filing fee, and inventor oath. Consequently, the requirements to **establish** and **maintain** a filing date were met in the July 15, 2004 patent application. The patent application was assigned number 10/891,599.

The specification included a description of the prior art, problems within the prior art, a summary of the invention describing various embodiments of the invention addressing the prior art problems, and a detailed description of the invention for integrating waste heat and water management in the URFC. The meaning of the terms used in the written description of the invention are defined by their use in the specification. Furthermore, the inventors are permitted to be their own lexicographer.[12]

"An applicant is entitled to be his or her own lexicographer…* [even by] *setting forth a definition of the term that is different from its ordinary and customary meaning(s)."

The utility patent application contained claims directed towards two statutory patent classes, an *apparatus* (a fuel cell system), and a *method* (for water and waste heat management).[13] Exemplary independent claims[14,15] from the patent application illustrating the *apparatus* and *method* statutory classes are

Claim 1 (as filed in the '714 patent). A unitized regenerative fuel cell (URFC) system
comprising:

1. reactant gas storage tanks, a water storage reservoir, a fuel cell stack, fuel cell pressure control devices, reactant gas feed lines communicating between the fuel cell stack and the reactant gas storage tanks, and power input/outputs and controls, the URFC being characterized by:
2. the reactant gas storage tanks being sized and shaped to act as heat sinks and radiators of waste heat to the ambient environment;
3. heat pipes that convey waste heat from the fuel cell stack to the reactant gas storage tanks;
4. a reactant gas dryer disposed within each of the respective reactant gas feed lines communicating between the respective reactant gas storage tanks and the fuel cell stack;
5. an expandable water storage reservoir contained within a pressure dome; and
6. a gas pressure line communicating between one of the reactant gas feed lines and the pressure dome that contains the expandable water storage reservoir.

Claim 9 (as filed in the '714 patent). A method for managing waste heat associated with the operation of a unitized regenerative fuel cell (URFC) system comprising:

1. reactant gas storage tanks, a water storage reservoir, a fuel cell stack, fuel cell pressure control devices, reactant gas feed lines communicating between the fuel cell stack and the reactant gas storage tanks, and power input/outputs and controls, the method of waste heat management being characterized by:
2. providing evaporators on the fuel cell stack and, connecting to one of the evaporators a first heat pipe for conveying waste heat from the fuel cell stack to one of reactant gas storage tank surface and connecting to another of the evaporators a second heat pipe for conveying waste heat from the fuel cell stack to another reactant gas storage tank surface;
3. sizing and shaping the reactant gas storage tank surfaces to act as heat sinks and radiators of waste heat to the ambient environment; and
4. providing a reactant gas dryer within each of the reactant gas feed lines communicating between the fuel cell stack and the respective reactant gas storage tanks.

The declaration included an assertion by the inventor stating,

"…I believe I am the original, first and joint inventor with the other named inventor(s) of the subject matter which is claimed…"

As previously discussed, the **"named inventors"** must be correctly represented on a U.S. patent application.[16] Specifically, *inclusion* of a colleague as a coinventor who did not participate in the conception of the invention is known as a *misjoiner* and invalidates an otherwise valid patent. Similarly, *exclusion* of a coinventor who participated in the conception is known as a *nonjoiner* and also invalidates an otherwise valid patent. If an inventor is erroneously omitted or erroneously included as an inventor, the *misjoiner/nonjoiner* may be corrected and the patent remains valid.[17]

A power of attorney appointed a registered patent practitioners from the firm Patent Attorney LLC to

"…prosecute this application and to transact all business in the United States Patent and Trademark office connected therewith…"

Assignment

As noted above, the inventor was an employee of the NASA Glenn Research Center. In this case, the government owns the entire right and title to the subject invention if[18]

1. the employee made the invention during working hours, or
2. the employee used government facilities, or
3. the invention is related to the employee's official duties.

The patent application was assigned to The United States of America as represented by the Administrator of NASA. The specification included a statement regarding invention by a federal employee and government use rights, specifically

"The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for Government purposes without the payment of any royalties thereon or therefore."

Information Disclosure Statement

The attorneys for the applicants submitted an "Information Disclosure Statement" (IDS) in accordance with US patent laws. The IDS includes the submission of relevant background art or information to the USPTO by the applicant. The "Duty of Candor" requires that the inventor submit an IDS within a reasonable time of submission of the patent application disclosing[19]

"…to the Office* [USPTO] *all information known to that individual to be material to patentability…"

The "Duty of Candor" is specific to any existing claim and requires that the IDS be continually updated while the claim is pending. The "Duty of Candor" ceases only when the claim is allowed and the patent issue fee is paid. As required by the USPTO, additional IDSs were submitted during the prosecution of the patent application as the applicants became aware of additional related prior art.

The "Duty of Candor" extends to any individual *associated* with the filing of the patent application including

1. Inventor(s),
2. Patent Counsel, or
3. Persons who are substantially involved in the preparation or prosecution of the patent application.

Substantial involvement could include technical assistants, collaborators, or colleagues. Substantial involvement would generally not extend to clerical workers. Furthermore, the inclusion of a reference in an IDS[20]

"…is not taken as an admission that the reference is prior art against the claims."

If a finding of a violation of the "Duty of Candor" resulting in "inequitable conduct" regarding any claim in a patent application or patent is determined, then all the claims are rendered invalid.[21] Finally, in spite of the requirement of the "Duty of Candor," the applicant is cautioned not to "bury" the examiner with a long list of non-material references in hopes that the examiner will not notice the relevant material references.

Secrecy Review

The USPTO has procedures to review all patent applications to avoid publication of material that would compromise national security interests.[22]

"…*[patent] *applications are screened upon receipt in the USPTO for subject matter that, if disclosed, might impact the national security…"

If patent applications that could potentially adversely impact national security are identified[23]

"Such applications are referred to the appropriate agencies for consideration of restrictions on disclosure of the subject matter…"

The USPTO determined the potential for national security concerns during screening of the '599 patent application. As a consequence the patent application was referred to the Department of Defense for national security review. The individuals designated by the DoD to review the patent application assert that they will[24]

"…not to divulge any of the information from this application for any purpose other than administration of* [secrecy review]*…"

The patent application was reviewed by individuals from the Army, Air Force Research Laboratory, and the Office of Naval Research. All concluded "Secrecy Not Recommended."

Election/Restriction Requirement

The USPTO issued a requirement for "Restriction/Election" for the patent application in accordance with US patent laws. The "Restriction/Election" basically says that the patent application contains two or more inventions and the examination of both inventions would place an undo burden on the examiner.[25]

Table I. Subject Patent and Prior Art used in Obviousness Rejection

Application No.	Patent No.	Title	Filing Date
10/891,599	7,410,714	Unitized Regenerative Fuel Cell	Jul. 15, 2004
10/635,446	6,821,663	Solid Oxide Regenerative Fuel Cell	Aug. 7, 2003
477,792	5,064,732	Solid Polymer Fuel Cell System: High Current Density Operation	Feb. 9, 1990
10/223,706	N/A	Regenerative Dryer Device and Method for Water Recovery, Primarily in the Cathode Side of a Proton Exchange Membrane Fuel Cell	Aug. 20, 2002
10/810,715	N/A	Fuel Cell System	Mar. 29, 2004

"If two or more independent and distinct inventions are claimed in one application…*[the USPTO] *may require the application to be restricted to one of the inventions…"

The restriction requirement separated the claims into two distinct inventions. Specifically,

Invention I: …drawn to a fuel cell system…

Invention II: …drawn to a method of managing waste heat associated with the operation of the fuel cell…

The examiner noted that Inventions I and II are related as a method and apparatus for its practice, respectively. The examiner further noted that Invention I and Invention II are distinct if either[26]

1. The method (Invention II) as claimed can be practiced by another and materially different apparatus or by hand, or
2. The apparatus (Invention I) as claimed can be used to practice another and materially different method.

The examiner used the second rationale to distinguish the inventions and noted

1. The apparatus (Invention I) can be used to practice a materially different method, and
2. The apparatus (Invention I) can be used in a method that does not require providing evaporators to the fuel cell stack.

The attorney for the applicant provided a "provisional election" to prosecute Invention I first, which was subsequently affirmed in writing. The claims directed towards Invention II were never filed and those claims became abandoned by the applicant.

Non-Final Office Action (NFOA)

The utility patent application was not preceded by a provisional patent application. Consequently, for purposes of prior art searching, the priority date for the '714 patent application is the filing date.

On January 31, 2007, the USPTO issued a NFOA containing

1. List of references cited by the applicant and considered by the examiner,
2. the examiners search strategy for the subject patent application,
3. list of references cited by the examiner, and
4. a non-final rejection of the subject patent application.

All of the claims associated with the patent application were rejected as being obvious in view of the prior art.[27] Independent Claims 1, as well as 3-5, 7, and 8 were rejected based on McElroy et al. (U.S. Pat. No. 6,821663) in view of Meyer (U.S. Pat. No. 5,064,732), Cargnelli et al. (U.S. Pat. Appl. No. 10/223,706) and Sato et al. (U.S. Pat. Appl. No. 10/801,715), see Table I. A patent claim essentially is a series of key elements and their associated connectivity. In order to establish an obvious rejection of a claim, an examiner must

1. identify all of the elements of a claim in one or more prior art references, and
2. establish a teaching or motivation or suggestion to combine the prior art references.

(continued on next page)

The teaching-motivation-suggestion to combine must be based on the knowledge or skill level at the time of the invention. This requirement avoids hindsight bias as most inventions are "obvious" in hindsight. As an illustration of combining prior art references to build an obviousness rejection, we will summarize the examiner obviousness logic using key figures from the prior art patents.

To aid in this analysis, we have rewritten independent Claim 1 to highlight the key elements (**bold**) along with how they are connected (*italic*). Specifically, Claim 1 is directed towards a unitized regenerative fuel cell system with

1. **reactant gas storage tanks** sized and shaped to act as *heat sinks* and *radiators* of waste heat to the ambient environment,
2. **heat pipes** that *convey* waste heat from the **fuel cell stack** to the reactant gas storage tanks,
3. a **reactant gas dryer** disposed within each of the respective **reactant gas feed lines** *communicating* between the respective **reactant gas storage tanks** and the **fuel cell stack**,
4. **an expandable water storage reservoir** *contained* within a **pressure dome**; and
5. a **gas pressure line** *communicating* between one of the **reactant gas feed lines** and the **pressure dome**.

The examiner noted McElroy discloses a solid oxide regenerative **fuel cell** with **reactant gas storage tanks** for oxygen (not shown) and hydrogen (250), functioning as *heat sinks* and *radiators* as shown in Fig. 2. The examiner concedes McElroy does not explicitly teach **heat pipes** that thermally communicate with the **reactant gas storage tanks**. The examiner further noted Meyer discloses a **heat pipe system** (10) for removing waste heat from a solid polymer fuel cell that is in *thermal communication* with a *heat sink* such as a **reactant gas storage tank** as shown in Fig. 3. The examiner concludes it would have been obvious to "one of ordinary skill in the art at the time of the invention" to modify the fuel cell system of McElroy to include the **heat pipe system** of Meyer.

However, as noted by the examiner, the McElroy reference in combination with Meyer does not explicitly teach a **reactant gas dryer** within the **gas feed lines** that operates reversibly to remove water from the reactant gases evolved during electrolysis and return water to the reactant gases for consumption in the fuel cell. The examiner further noted Cargnelli discloses a **regenerative dryer device** (40) for a proton exchange membrane fuel cell system in *communication* with a **fuel cell stack** (42) that humidifies an incoming reactant gas stream and dehumidifies an exhaust reactant gas stream as shown in Fig. 4. The examiner concludes it would have been obvious to "one of ordinary skill in the art at the time of the invention" to modify the fuel cell system of McElroy/Meyer to include the **regenerative dryer device** of Cargnelli.

However, as noted by the examiner, the McElroy reference in combination with Meyer and Cargenelli does not explicitly teach an **expandable water storage reservoir** within a **pressure dome** in *communication* with the **reactant gas feed lines**. The examiner further noted Sato discloses a fuel cell system with an **expandable water tank** (71b) *contained* within **pressure dome** (71a) which is pressurized through **pipe** (53) by reactant gas pressure from the **fuel tank** (13) as shown in Fig. 5. The examiner concludes it would have been obvious to "one of ordinary skill in the art at the time of the invention" to modify the fuel cell system of McElroy/Meyer/Cargnelli to include the **expandable water storage reservoir** within a **pressure dome** in *communication* with one of the **reactant gases** of Sato.

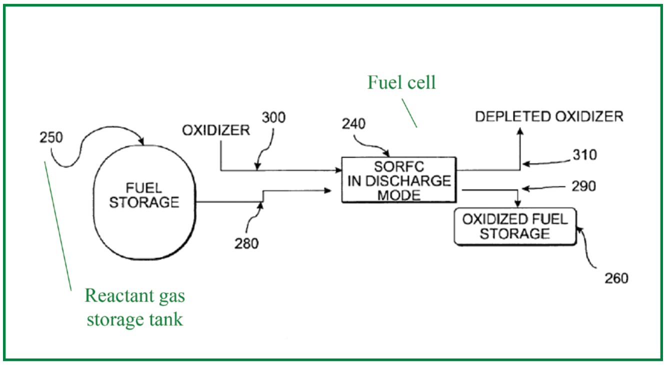


Fig 2. *Fig. 5 from U.S. Patent No. 6,821,663 (McElroy) depicting a solid oxide regenerative fuel cell system.*

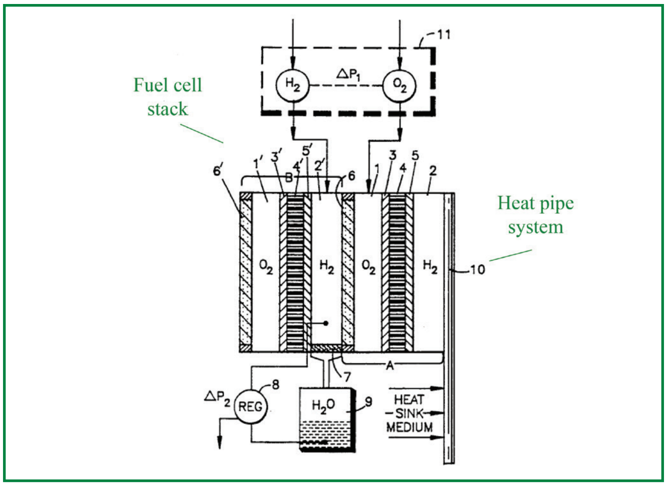


Fig 3. *Fig. 2 from U.S. Patent No.5,064,732 (Meyer) depicting a solid polymer fuel cell system.*

Based on the above combination of prior art references, the examiner rejected independent claim 1 (and those which depended from Claim 1) as "obvious to one of ordinary skill in the art at the time of the invention." The rejection was based on combining prior art references including two issued patents and two published patent applications. To combine prior art references to produce the claimed invention as the basis for an obviousness rejection, the examiner must establish a teaching, motivation, or suggestion to do so. These can be established either in the references themselves or in the knowledge generally available to "one of ordinary skill in the art at the time of the invention."[28,29] The examiner used the latter to establish the teaching-motivation-suggestion to combine the prior art references.

In addition to the drawings used in our illustrative discussion of the obviousness rejection, the basis of the rejection relied on the written specification and claims of the prior art publications. Note, the terms in the prior art references are not required to be exactly the same as the terms used in the '714 patent application. However, the prior art terms must be "equivalent" terms from the perspective of "one of ordinary skill in the art at the time of the invention."

Response to NFOA

On April 30, 2007, the applicants responded to the NFOA and presented arguments regarding the obviousness rejection along with amended claims.[30] Because the response was filed within three months, an extension of time and payment of applicable fees was not required.[31]

Final Rejection

On June 22, 2007, the USPTO issued an office action rejecting all of the claims in the patent application. The final rejection was based on obviousness and included additional prior art references.

Response to Final Rejection

On August 24, 2007, the applicant and attorney of record conducted a telephone interview with the USPTO examiner to discuss the final rejection. During the interview, the applicant discussed proposed amendments to the claims to overcome the obviousness rejection. The examiner interview was summarized in writing as

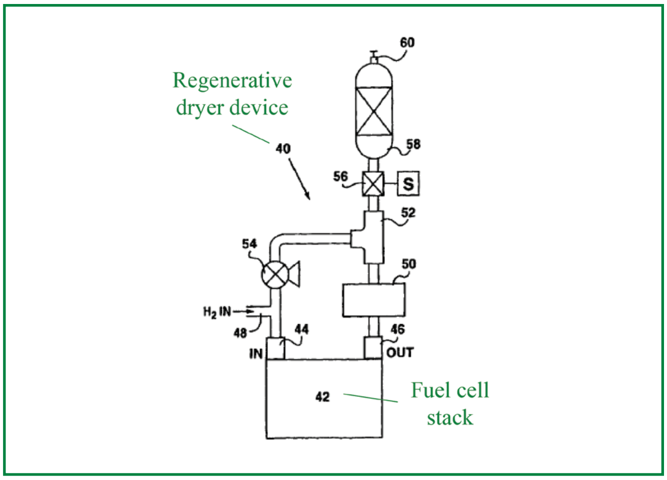


Fig 4. *Fig. 8 from U.S. Patent Application No. 10/223,706 (Cargnelli) depicting regenerative dryer device (40) in communication with a fuel cell stack (42).*

"Proposed amendment to the claims discussed…does not overcome the previous* [obviousness] *rejections…no agreement was reached."

An interview with the examiner[32]

"…does not remove the necessity to reply to Office actions…"

On December 24, 2007, the applicants requested an extension of time to respond to the final rejection and paid the appropriate extension fees. On January 2, 2008, the applicant and attorney of record conducted another telephone interview with the examiner to discuss proposed amendments to the claims to overcome the obviousness rejection. The examiner interview was summarized in writing as

"Claim 1 was discussed in light of the…references. The proposed amendment…does appear to overcome the previous* [obviousness] *rejections…amendment changes the scope of the claims and would require further search and consideration."

The amendment to independent Claim 1 included added limitations and detailed description of the key elements connectivity to avoid the prior art resulting in a claim of limited scope. Specifically, the claim elements and interconnectivity is summarized as

1. first and second **reactant gas feed lines** *communicating* between the **fuel cell stack**…,
2. first and second **reactant gas storage** tanks acting as *heat sinks*…,
3. first and second **heat pipes** *thermally communicating* with said **fuel cell stack**…,
4. first and second **reactant dryers** in *thermal communication*…,
5. an **expandable water storage reservoir** formed as a bellows *contained* within a **pressure dome**…,
6. a **gas pressure line** *communicating* between the first **reactant gas feed lines** and the **pressure dome** that *contains* the **expandable water storage reservoir** for *directing* pressurized gas from the first **reactant gas storage tank** into the **pressure dome** and outside of the bellows so that the water pressure in the bellows is less than the gas pressure outside the bellows.

Allowance of Patent Application

The examiner conducted a new prior art search based on the amendment and did not find a new basis for rejection. On March 17, 2008, the USPTO issued a notice of allowance for the patent application with the amended claims associated with the invention. After payment of the issue fee, the 10/891,599 patent application issued as U.S. Patent No. 7,410,714 on August 12, 2008.

Summary

In this installment of our "Looking at Patent Law" series, we present a case study of the prosecution of U.S. Patent No. 7,410,714, "Unitized Regenerative Fuel Cell," invented by Kenneth A. Burke, an engineer at the NASA Glenn Research Center. This case was chosen to coincide with the "Electrochemistry in Space" focus of this issue of *Interface*. The case study begins with a brief synopsis of the background of the invention followed by 1) filing of a utility patent application, 2) submission of Information Disclosure Statements (IDS), 3) national security screening by the Department of Defense, 4) examiner rejection arguments for an obviousness rejection, 5) the use of examiner telephone interviews to better understand the basis for the rejections and traversing the same, and 6) the allowance of the patent. More specifically, the article illustrates the combination

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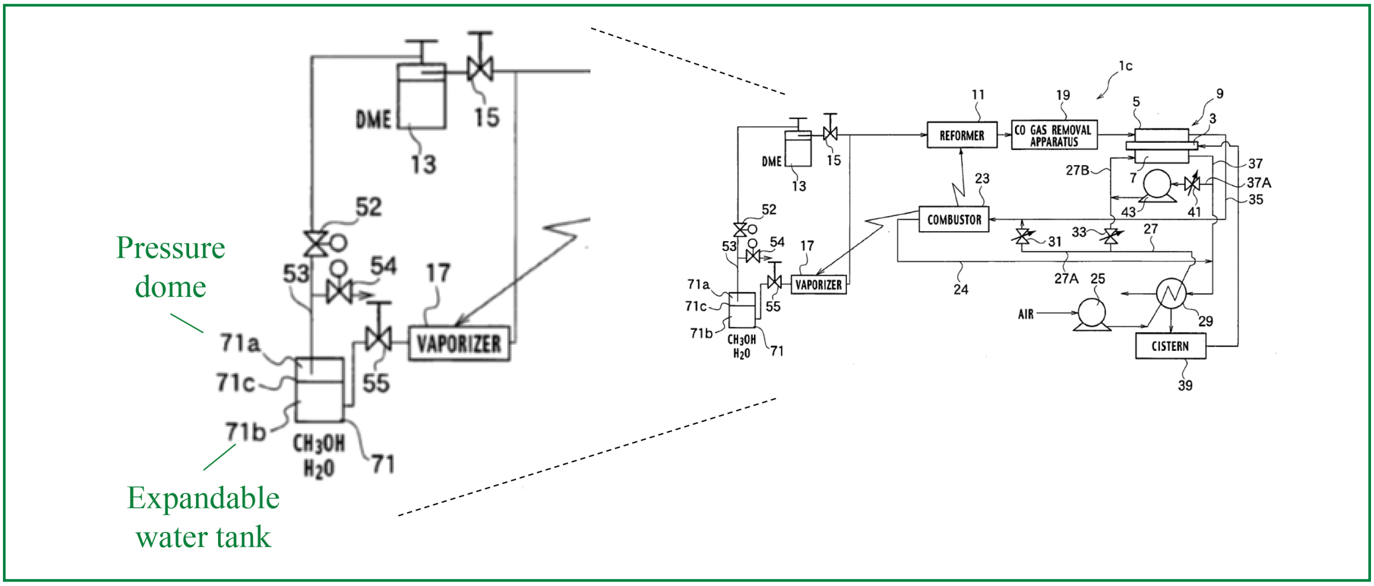

Fig 5. *Fig. 5 from U.S. Patent Application No. 10/810,715 (Sato) depicting an expandable water tank (71b) contained within pressure dome (71a) which is pressurized through pipe (53) by reactant gas pressure from the fuel tank (13).*

(continued from previous page)

of prior art references as the basis for an obviousness rejection of an invention. Further, the article notes that the examiner must establish a teaching-motivation-suggestion to combine prior art references to establish an obviousness rejection. Finally, the article discussed the ownership rights of the government by federal employees. These rights generally apply to private companies and their employees as well. With this case study, we hope to demystify the patent prosecution process and better prepare electrochemical and solid state scientists, engineers, and technologists to interact with their patent counsel regarding their inventions.

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Optimized Synthesis of Ultrahigh-Surface-Area and Oxygen-Doped Carbon Nanobelts for High Cycle-Stability Lithium-Sulfur Batteries

Low active material utilization and poor cycle life continue to hinder the widespread commercialization of lithium-sulfur (Li–S) batteries. Hierarchical porous carbons (HPCs) have been identified as a promising sulfur host as they help to alleviate issues associated with the insulating nature of sulfur, the polysulfide shuttle effect and the volume expansion of sulfur. Researchers from Shenzhen University and Cranfield University have recently presented the synthesis of oxygen-doped carbon nanobelts (CNBs) and their application as a S host for Li–S batteries. The CNBs were prepared via carbonization and KOH activation of phenolic resin-based nanobelts. KOH activation is a well-established method to prepare activated carbons and by adapting this method CNBs with a high specific surface area of 2,300 m^2 g^{-1} and a large pore volume of 1.29 cm^3 g^{-1} could be prepared. When loaded with S and cycled as a cathode material, the CNBs demonstrated a high initial discharge capacity of 1,245 mAh g^{-1} and a low capacity decay rate of ~0.16% per cycle after 200 cycles at 0.1 C. These results suggest that polar oxygen-containing functional groups are important for improving the cycling stability of carbon-based S hosts.

J. Zou, Y. Niu, W. Tu, et al.,
J. Electrochem. Soc.*, **166**, A3464 (2019).*

Experimental and Modeling Studies of the Hysteresis Behavior and Dendrite Suppression Efficacy of an Electrolyte Additive in Zinc Electrodeposition

Those who desire a safe battery at high rate are drawn to Zn anodes. Zn is water-compatible and inexpensive, and its plating/stripping have good kinetics. However, its propensity to form dendrites during charging has kept rechargeable Zn metal anodes from widespread adoption. Typical plating additives to level metal layers work by adsorption and polarization of the surface. However, this presents a challenge, as an additive such as polyethylenimine polarizes the entire electrode surface. Researchers at Case Western Reserve University report the additive benzyltrimethylammonium hydroxide (BTMAH), which displays a distinctive hysteresis during CV tests. This hysteresis indicates two possible states of the Zn surface, either polarized or depolarized. This additive is shown to be highly effective at suppressing Zn dendrite growth under certain conditions, and a model reveals the possibility of the two surface states is key. Effectively, the dendrite tips are polarized while the surrounding flat Zn surface is depolarized. Why is BTMAH different from many other Zn electrolyte additives? Unlike many, BTMAH is not incorporated into the metal layer in appreciable amounts, but rather undergoes another type of additive deactivation. The nature of this deactivation is unknown, but the team promises further work to establish it.

X. Liu, O. Bolton, and R. Akolkar,
J. Electrochem. Soc.*, **166**, D583 (2019).*

Solar-Electrochemical Platforms for Sodium Hypochlorite Generation in Developing Countries

Onsite electro-chlorination has been gaining increased attention recently as it helps avoid transport of dangerous chemicals and helps improve access to disinfecting technology locally in developing countries. For these decentralized chlorinators, the design can be either a batch type or a flow-based reactor. Researchers from the School of Engineering at EPFL, Switzerland, have done a comprehensive study of these reactors coupled with solar cells, the results of which are described in detail in this Editors' Choice paper. While investigating the efficiency of the two reactor types, the authors found the batch type reactor suffered Faradaic efficiency losses, which they mitigated by modifying the electrodes with through holes. The authors backed up their study with a detailed computational model. System level optimization was carried out by considering the right type of solar cell technology. The team completed a detailed techno-economic analysis as well. While the flow type cell is good from the first cost point of view, low maintenance aspects of the batch type reactor can enable optimum total cost of ownership. This work is a great start to enable access to low-cost on-site chlorination systems.

E. Chinello, S. M. H. Hashemi, et al.,
J. Electrochem. Soc.*, **166**, E336 (2019).*

Spray-Deposited Al_2O_3 for Rear Passivation and Optical Trapping in Silicon Solar Cells

The deposition of high-quality and defect-free thin films for electronic systems is predominantly performed using vacuum-based techniques, such as atomic layer deposition (ALD) and chemical vapor deposition (CVD). Due to the high cost associated with these vacuum-based deposition technologies, investigations are ongoing into lower cost and scalable production-ready solutions. A research group based at Arizona State University has developed a spray deposition technique for the synthesis of sub-100 nm Al_2O_3 thin films for rear passivation and optical trapping layers in silicon solar cells. A single, thicker Al_2O_3 layer can replace current Al_2O_3/SiN films. Spray deposition is a solution processing method, which deposits a thin film through precise spraying of a prepared solvent onto the substrate. Shin *et al.* demonstrated an 80 nm Al_2O_3 thin film that was both crack- and pore-free with a sufficient charge density for use as a passivation layer in a Si solar cell. The optical characteristics of the Al_2O_3 films were identical between the spray-deposited and ALD/CVD samples. This paper has shown the promise of spray deposition techniques for decreasing the manufacturing cost of next generation solar cells.

W. J. Shin, W. H. Huang, and M. Tao,
ECS J. Solid State Sci. Technol.*, **8**, N151, (2019).)*

Investigation into the Effect of CMP Slurry Chemicals on Ceria Abrasive Oxidation State using XPS

Ceria finds applications in chemical mechanical polishing (CMP) of thermal silicon oxides in the semiconductor industry due to its high removal rate of oxides. Previous studies have shown that incorporation of active Ce^{3+} sites, which actually participate in removal reactions, leads to increased removal rates; therefore, maximizing the Ce^{3+}/Ce^{4+} ratio on the surface of ceria CMP slurries abrasive is critical to achieving increased oxide removal rate. To that end, researchers from SUNY Polytechnic Institute utilized X-ray photoelectron spectroscopy (XPS) to investigate the effects of pH, peroxide, and surfactant on the Ce^{3+}/Ce^{4+} ratio for ceria particles with three different sizes (58, 15, and 6 nm). It has been found that: pH barely has any effect on the ratio; peroxide can either increase or decrease the ratio depending on its concentration and initial ceria particle size; the effect of surfactant is only obvious for particles with larger size (58 nm), and surfactant decreases the ratio upon addition of peroxide, although it can improve particle dispersion. These findings can be utilized to develop optimized ceria CMP slurries to achieve higher oxide removal rate.

C. M. Netzband and K. Dunn,
ECS J. Solid State Sci. Technol.*, **8**, P629 (2019).*

Tech Highlights was prepared by Colm Glynn of Analog Devices International; Joshua Gallaway of Northeastern University; David McNulty of Paul Scherrer Institute; Chao (Gilbert) Liu of Shell; Chock Karuppaiah of Vetri Labs; and Donald Pile of Rolled-Ribbon Battery Company. 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.*

Current and Future Roles of Electrochemistry in Space

by Gregory S. Jackson

One needs only be a reasonably astute observer of Hollywood's depiction of space travel to assess that electrochemical systems play a critical role in space systems operation. Ron Howard's relatively accurate retelling of the *Apollo 13* mission reminded his audience that the dramatic rupture of the spacecraft's second O_2 tank impaired the electrical power system, which ran on three H_2-O_2 alkaline fuel cells that also provided water for the crew. Thankfully, the tank rupture only disabled two of the three fuel cells. The remaining fuel cell enabled a historic on-the-fly engineering response that relied on the remaining fuel cell and was worthy of a movie reminder one quarter of a century later.

In the fictional movie realm, the 2015 film adaptation of Andy Weir's novel *The Martian* brings real technology developments to life in presenting the "oxygenator." The oxygenator electrochemically splits the CO_2 in the Martian atmosphere to make O_2 that supports Matt Damon's character inside his habitat. Such electrochemical technology has been developed with support from NASA by a team from OxEon Energy, MIT, and the Jet Propulsion Laboratory (JPL). A subscale version of this "oxygenator," known as *MOXIE*, relies on a groundbreaking solid oxide electrochemical cell. The *MOXIE* system is described in the feature article on in-situ resource utilization and plans to be delivered for testing on the red planet by the *Mars 2020* mission launching this July.

Amongst the many space movie scenes, perhaps one of the most memorable is the gripping scene in Stanley Kubrick's movie of Arthur Miller's novel *2001: A Space Odyssey*, when the astronaut Dave disengages the clear magical crystals that form the electronic brains of HAL (Heuristically Programmed Algorithmic), the rogue AI computer that is trying to take over the mission. What else could those crystals be but some mixed ionic-electronic conducting oxide that so many in The Electrochemical Society have been developing for a wide range of applications other than murderous supercomputers?

The role of electrochemistry in space, today and in future missions, is and will be far more diverse than what is portrayed by Hollywood. It extends beyond electrochemical cells for power or O_2 generation. The diverse applications of electrochemistry in space were highlighted in the inaugural *Electrochemistry in Space* symposium this past fall in Atlanta and in the feature articles of this *Interface* issue. The abundance of solar radiation and our ability to convert significant fractions of it to electrical power enables not only effective battery energy storage in space, but also the use of electrical power for electrochemical life support, electrochemical sensors, and in-situ electrochemical material processing.

The diverse ways in which electrochemistry does and can play a role in space activities motivated a sizable group of ECS members from a wide array of technical divisions to organize last fall's symposium. The symposium was sponsored by the society's Interdisciplinary Science and Technology Subcommittee and the contributing divisions brought together people from the United States, Japan, and Europe to discuss current and developing electrochemical systems for energy storage and power generation (batteries and fuel cells), for human life support (waste recycling and environment controls), for sensors (chemical and life detection), and for in-situ resource utilization (production of fuels and materials).

These various areas are highlighted in the feature articles in this *Interface* issue. *Energy Storage for the Next Generation of Robotic Space Exploration* by JPL's Kumar Bugga and Erik Brandon highlights the various reliable and energy-dense battery chemistries used for orbiters, rovers and landers, and probes for distant solar system exploration. Jessica Koehne and co-authors Milton Cordeiro, Seamus Thomson, and M. Meyyappan from NASA Ames Research Center present *Electrochemical Sensors in Space Missions* highlighting the range of electrochemical sensors developed for space, not only for detection of various inorganic ions for resource assessment, but also for detection of biological molecules such as amino acids or proteins. The article further discusses the use of electrochemical sensors for environmental controls and health monitoring critical for life support of human explorers. A third article, *Electrochemistry for Space Life Support*, by George Nelson of the Univ. of Alabama in Huntsville, collaborators from Faraday Technologies (Santosh Vijapur and Tim Hall), the Univ. of Puerto Rico (Carlos Cabrera and Armando Peña-Duarte), and NASA Marshall Space Flight Center (Brittany Brown), presents further the role of electrochemistry in critical functions for human life support, such as recycling waste products like CO_2 and urine, and the production of disinfectants like hydrogen peroxide. *Electrochemical Approaches to "Living off the Land" in Space* by S. Elangovan (OxEon Energy), Paul Hintze (NASA Kennedy Space Center), and myself (Colorado School of Mines) highlights the role that electrochemistry is envisioned to play in a future space economy that thrives on in-situ resource utilization to make fuels and critical materials from what is available in space.

Such resource utilization will be key to the long-term viability of space operations that will undoubtedly rely on robust electrochemical systems for a host of critical applications. The value of continuing this broad, interdisciplinary, and international conversation on the role of electrochemistry in space extends beyond just the science and engineering accomplishments that enable the possibility of a space economy and more effective space exploration. Humankind's desire to explore and "conquer" the challenges of space provides motivation for the next generation (as it did for many of us) to not only pursue technical careers, but also to ask meaningful questions about our place in the Universe. We hope you enjoy the feature articles in this issue of *Interface* and consider participating in future ECS symposia on *Electrochemistry in Space*.

© The Electrochemical Society. DOI: 10.1149/2.F05201IF.

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Gregory Jackson is a professor and previous department head of mechanical engineering at the Colorado School of Mines. Before joining Mines in 2013, he was a professor at Univ. of Maryland for 16 years, where he served as acting and associate director of the campus-wide Energy Research Center (now Energy Institute). From 2017 to 2019, he served on the executive board of ECS as the chair of the High-Temperature Energy Materials and Processes Division. At Mines, Dr. Jackson manages a research group active in energy storage and solid oxide electrochemical systems, including a broad effort on redox cycles of reducible oxide particles for high-temperature energy storage in concentrating solar applications. His group currently partners with Mines Center for Space Resources and OxEon Energy to develop a system for using solid oxide electrolysis to split water found on the Moon. He received his PhD from Cornell University. After his PhD, he worked at Precision Combustion, Inc., where he led research and development on catalytic reactors for low-NO_x combustion and aircraft engine ignition. He may be reached at gsjackso@mines.edu.

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Electrochemistry for Space Life Support

by George J. Nelson, Santosh H. Vijapur, Timothy D. Hall, Brittany Brown, Armando Peña-Duarte, and Carlos R. Cabrera

Introduction

Our inherent curiosity drives humans to explore, yet like many new frontiers, space presents us with a hostile environment that necessitates new solutions to sustain human life. When considering the confined environments of a spacecraft, which has limited access to resupply, the effective management and reutilization of the byproducts of basic human life is mandatory.

The necessity of Environmental Control and Life Support System (ECLSS) for space exploration was thrust into public awareness with the *Apollo 13* mission, when failure of an oxygen tank on the spacecraft ~200,000 miles from Earth cut the supply of electricity, light, and water to the command module. Using the lunar module as a lifeboat, the crew weathered the return to Earth.

Electrochemical systems have supported space life support needs and are playing an increasing role in next generation ECLSS technology. In the nearer term, advanced ECLSS technologies will continue to support missions aboard the *International Space Station* (ISS) and in cislunar (i.e., between the Earth and the Moon) exploration efforts. Further afield support of manned missions to Mars will require extension of these systems to provide sustenance and maintain a habitable environment.

Environmental Control and Life Support System Aboard the *International Space Station*

The ECLSS system aboard the *ISS* comprises multiple subsystems and their components that maintain habitable conditions for the *ISS* crew, Fig. 1. This system currently meets the requirements for the given mission duration with the availability of ground support[1,2].

The *ISS* ECLSS subsystems contain a diverse set of thermal-fluid, chemical, electronic, and electrochemical components. An electrolyzer within the Oxygen Generation Assembly (OGA) of the Atmospheric Revitalization subsystem is the key electrochemical component of the current *ISS* ECLSS. As of April 2019, the OGA electrolyzer has produced over 16,000 lbs. of oxygen and over 2,000 lbs. of hydrogen in support of *ISS* missions.[3] This electrolyzer is a cathode-fed, polymer electrolyte system containing 28 cells. Liquid water to feed the electrolyzer is gathered from condensation of sweat and exhaled water vapor, as well as the distillation of urine. These byproduct streams are converted to potable water by the Water Recovery System (WRS). The functions of a WRS are limited to treating only urine and condensate, which may include hygiene water, laundry water, and water recovered from brines and solid wastes.[4] Urine is stabilized through the addition of pretreatment chemicals (chromium trioxide and sulfuric acid) at the waste collection system.[5] Water is recovered from the pretreated urine by Vapor Compression Distillation (VCD).[5] A portion of the treated water is circulated through the cathode side of the electrolyzer, where it is converted to hydrogen (H_2) and oxygen (O_2). The circulating flow of water serves to remove hydrogen and cool the electrolyzer. Hydrogen is subsequently vented to space or sent to a Sabatier reactor to aid in oxygen recovery from carbon dioxide (CO_2). After passing through a water absorber, the oxygen is routed to the cabin.

While electrolytic production of oxygen is the key current electrochemical application for ECLSS, there are several electrochemical technologies emerging that could improve system sustainability, recyclability, and durability. The three emerging systems highlighted within this review include:

1. Currently, a Sabatier reactor is coupled with the OGA to reduce CO_2 and produce oxygen and methane. Electrochemical methods could enable further improvement in CO_2 utilization efficiency and O_2 recovery via the work being undertaken at the NASA Marshall Space Flight Center (MSFC).
2. Similarly, the *ISS* ECLSS system currently relies on VCD to process urine into potable water. Bioelectrochemical processes for urine recycling present a viable alternative to this distillation process leading to higher reliability and lower dependence on ground-based support.
3. Finally, disinfection needs of the *ISS* are currently supported via ground supplies of disinfecting wipes. Electrochemical processes could produce the disinfecting solutions for hygienic living within a closed system.

Moreover, as missions are foreseen to be extended with the potential for Earth's resupply being diminished, the ECLSS will need to become a more durable/sustainable, closed-loop living system that has less reliance on ground support. The following sections discuss each of these areas of innovation and their potential to achieve a self-sustainable system in closed-loop living applications.

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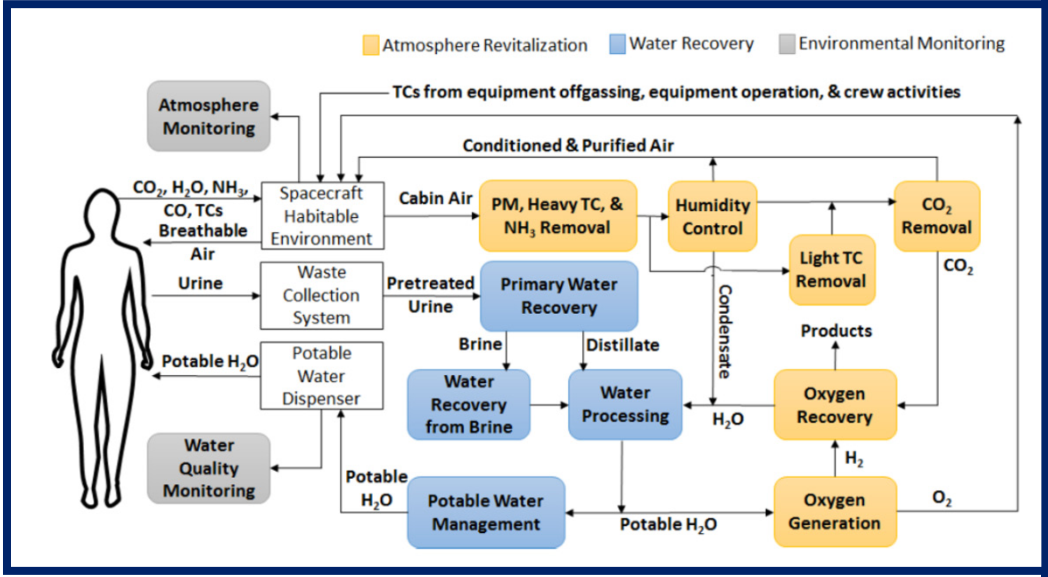

Fig. 1. *Life Support System (LSS) architecture for the International Space Station (ISS) adapted from Reference 2.*

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Emerging Technologies for Space Life Support

Carbon Dioxide Reduction for Atmosphere Revitalization

The state-of-the-art CO_2 Reduction Assembly (CRA) became fully operational aboard the *ISS* in June 2011. The CRA utilized the Sabatier reaction, Equation 1, to convert CO_2 to methane (CH_4) and water.

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O \quad (1)$$

The water produced is fed to the water purification system and then to the OGA to produce H_2 and O_2. Hydrogen is recycled to the CRA; O_2 is released into the cabin, and CH_4 is vented overboard. The CRA recovers ~50% of O_2 from CO_2 due to H_2 loss in the vented CH_4. For long-duration, crewed missions beyond Low Earth Orbit, a minimum 75% O_2 recovery from CO_2 is required with a targeted goal of 90%. Development of alternative technologies, including electrochemical methods, to increase O_2 recovery is underway at NASA.

The baseline oxygen recovery exploration architecture includes the CRA with the addition of the Plasma Pyrolysis Assembly (PPA). The PPA receives CRA-produced CH_4 and uses a magnetron to generate a H_2/CH_4 plasma targeting CH_4 conversion to H_2 and acetylene (C_2H_2). The outlet stream of the PPA is H_2-rich, but it also consists of C_2H_2, unreacted CH_4, trace amounts of water, carbon monoxide (CO), ethylene (C_2H_4), ethane (C_2H_6), and solid carbon.[6,7] To recover the H_2 from the PPA effluent, an electrochemical H_2 separator was developed by Skyre, Inc. under NASA's Small Business Innovative Research Program. As shown in Fig. 2a, electrochemical H_2 separation occurs when H_2 is electro-oxidized to protons and electrons and the protons are electro-reduced in a separate chamber.[6] At typical PPA operating temperatures of 150°C, the CO present in the outlet stream interferes with the catalytic electrodes' ability to oxidize H_2. Mitigating this interference is possible, but the acidic polymer electrolyte typically used is not serviceable above 150°C.[6] In 2015, Skyre developed electrolyte materials compatible with PPA operating conditions and delivered two single-cell stacks to NASA MSFC. Results from single-cell stack testing showed no detectable contaminants from the purified H_2 outlet stream, making this technology highly desirable for integration with Sabatier-based processes.[6] In 2018, Skyre fabricated and delivered a full-scale, four-crewmember cell stack. The full-scale design was iterated upon, resulting in the subsequent delivery of two three-cell stack H_2 separators to MSFC for characterization and optimization testing.

Another O_2 recovery technology under development at MSFC is a microfluidic electrochemical reactor (MFECR), which electrochemically reduces CO_2 to C_2H_4 using water as a proton source. The MFECR single cell design, shown in Fig. 2b, consists of two gas channels and an electrolyte channel each separated by a gas diffusion layer. Oxygen is produced when the water in the electrolyte is consumed at the anode. The protons react with CO_2 at the cathode. In 2016, the University of Texas (UT) Arlington designed and tested an Engineering Design Unit (EDU) under NASA's Game Changing Development Program. Although the technology has a 73% theoretical recovery rate, the results of the initial EDU were lower than anticipated. MSFC is collaborating with UT Arlington to redesign the EDU to achieve a higher metabolic CO_2 recovery rate and scale up the system hardware to achieve a one-crewmember conversion rate.

The Bosch reaction supports an additional O_2 recovery method that can theoretically achieve 100% recovery, which is desirable for long duration crewed missions. The Bosch process, Equation 2, catalytically reacts CO_2 with H_2 to produce water and elemental carbon.

$$CO_2 + 2\,H_2 \rightarrow C(s) + 2\,H_2O \quad (2)$$

The carbon produced fouls the catalyst, and replacement is required. Historically, Bosch reaction-based systems require >1kg of catalyst resupply per day to meet the crew's O_2 metabolic demand. Eliminating catalyst resupply may be accomplished by utilizing Ionic Liquids (IL). An IL-based Bosch process involves three major steps: electrolysis with an IL to electroplate catalyst onto a substrate, the Bosch process to convert CO_2 to recoverable O_2 and carbon, and catalyst regeneration using an IL to separate the catalyst from the solid carbon. The IL is recycled to the first step of the process after carbon filtration. Feasibility studies have proven the use of an IL to generate catalyst substrates and regenerate carbon fouled catalyst substrates. Currently, efforts are underway to develop an IL-based Bosch carbon formation reactor capable of performing all three functions in a single stage.

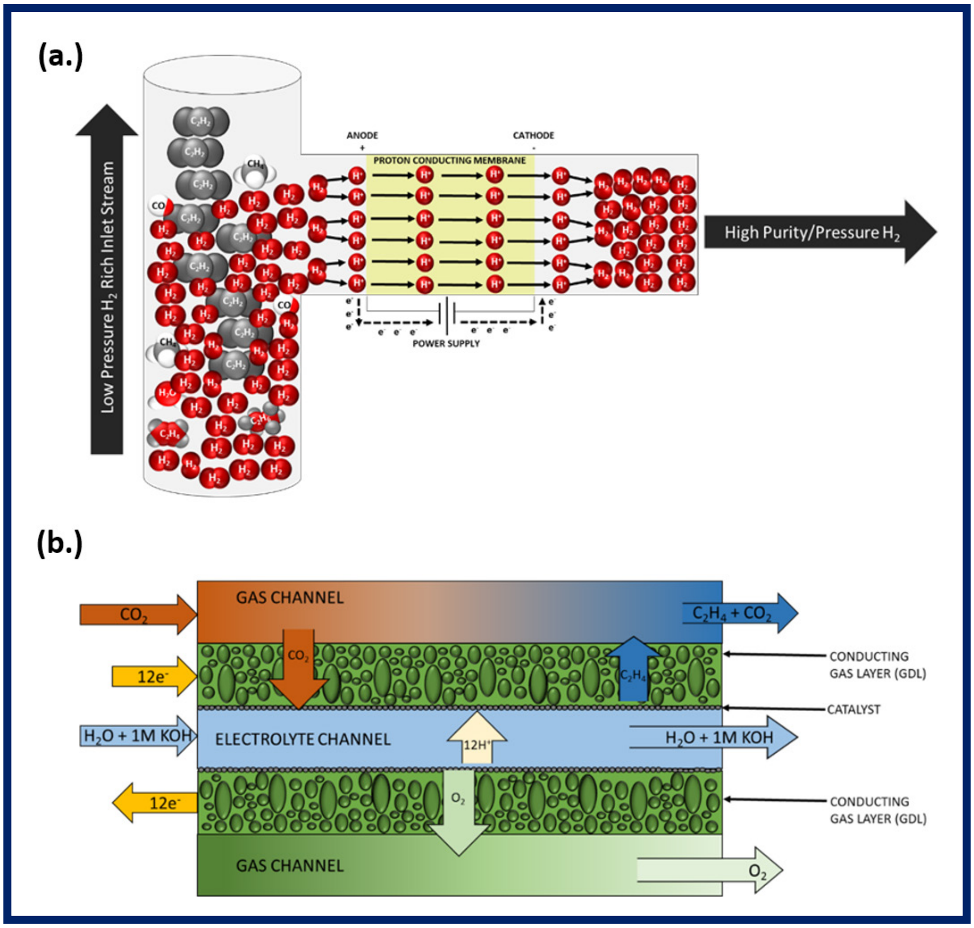

Fig. 2. *(a.) Electrochemical hydrogen separation of Plasma Pyrolysis Assembly effluent. (b.) Cross section of the single cell microfluidic electrochemical reactor for carbon dioxide reduction.*

Ammonia Oxidation for Urine Processing

Current techniques to recover water from urine utilize VCD that must be regularly cleaned with ground support chemicals and disinfectants. New thermodynamic,[8] chemical,[4] and biological[9] systems that accelerate decomposition of urea can improve water recovery and utilization from urine (95% water–2% urea). Biological systems utilizing microorganisms are stable and have advantages over other processes due to minimal use of energy and lower operating cost.[9] A microorganism that produces the enzyme of interest will result in a more stable and self-sustainable system that is compatible with microbial fuel cells (MFC). Cabrera et. al., have utilized urease, an enzyme that catalyzes the conversion of urea to ammonia, and *Proteus Vulgaris* bacteria to create an ureolysis system for urine recycling[8,10-14]. The bacteria has been used to catalyze the conversion of urea to ammonia in a bioreactor. Later, this ammonia can be oxidized in an electrochemical reactor using a platinum electrode to eliminate the ammonia and produce an oxidation current that may be used to self-sustain the system[8,13-15].

Faraday Technology, Inc. and Prof. Cabrera's research group at the University of Puerto Rico-Río Piedras Campus (UPR) currently are developing equipment and tools to scale this integrated bioelectrochemical system for a *zero-gravity* environment. The integrated bioelectrochemical system consists of a bioreactor (Fig. 3a, left) for urea to ammonia conversion and an electrochemical reactor (Fig. 3a, right) for ammonia oxidation. This bioelectrochemical system recycles urine by eliminating contaminants such as creatinine and organic carbons that may be detrimental to production of the desired potable water feed. Moreover, it eliminates the need for hazardous chemicals used for urine stabilization.

Cabrera et. al., also have evaluated electrode structures for ammonia oxidation under *zero-gravity* conditions, Fig. 3b[13,14]. The first study was done by cyclic voltammetry using different Pt modified glassy carbon electrodes.[13] A range between 20% and 65% peak current reduction for the ammonia oxidation reaction was observed under microgravity, Fig. 3c. Prof. Cabrera's group will be studying the ammonia oxidation reaction at the *International Space Station* this coming spring in collaboration with NuVant Systems and Universidad de Alicante.

Different carbon nanomaterial supports, such as carbon nano-onions, reduced graphene oxide, and boron doped diamond, have been used for the ammonia oxidation reaction[14-17]. Different Pt catalysts nanostructures were compared under microgravity conditions[18] in an electrochemical system assembled in a *zero-gravity* electrochemical setup. This work demonstrated that platinum with preferential (100) facets deposited on carbon nano-onions gave the best performance increase in microgravity versus ground at 0.4 V (99%) in an electrochemical system. The high surface area and spherical morphology of the carbon nano-onions (> 984.3 m^2/g vs. 262 m^2/g for carbon Vulcan) provides more nucleation sites where the stagnant electrochemically-formed nitrogen gas that hinder ammonia oxidation can grow and be released.[19] These data represent a bioelectrochemical approach to rapidly decompose urea and remove ammonia from recyclable urine waste streams potentially reducing or eliminating the need for VCD.

Hydrogen Peroxide Generation for Sterilization

Surface sterilization aboard the *ISS* is accomplished using premoistened wipes supplied from ground. *In-situ* resource utilization for generation of disinfectants will enable these solutions to be applied to reusable fiber-based wipes for disinfection and eliminate the need for ground support for surface sterilization. Hydrogen peroxide can be produced from resources currently aboard the *ISS*. Peroxide is an ideal disinfectant for closed systems due to its benign nature, wide industrial use, and suitable non-toxic decomposition products (O_2 and H_2O). Furthermore, peroxide can be electrochemically synthesized from on-board *ISS* resources (O_2 and H_2O). Electrochemical hydrogen peroxide generation is attractive because it offers on-demand production and would require no reactive precursors or the final product to be stocked.

Ongoing activity between Faraday Technology, Inc. and UPR has demonstrated electrochemical generation of 3 w/w% hydrogen peroxide in a "H-cell" electrochemical laboratory set-up utilizing a sodium sulfate electrolyte.[20] Preliminary "kill" studies using *e. coli* demonstrated that ~1 w/w% hydrogen peroxide was an effective disinfectant concentration. To avoid the need for sodium sulfate, the peroxide generation reactor was transitioned from the bench-scale

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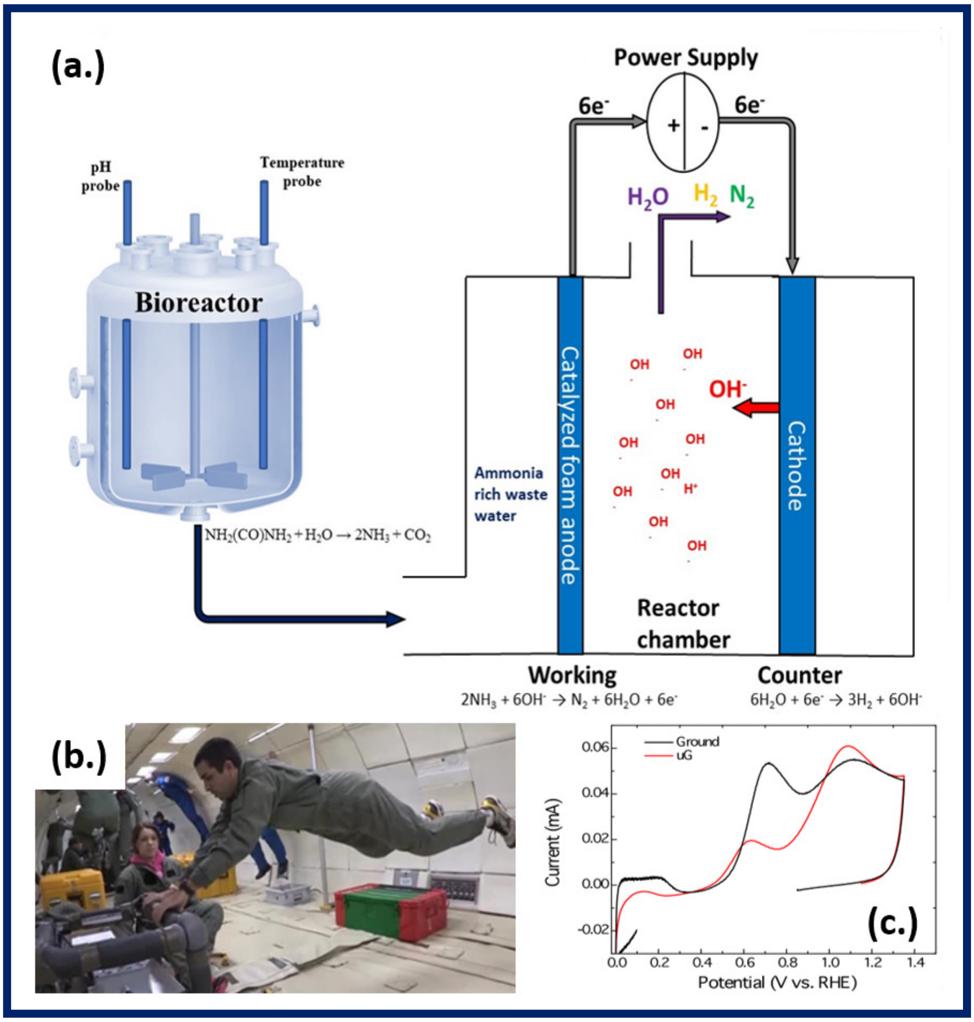

Fig. 3. *(a.) Conceptual schematic of an integrated bioelectrochemical system with a urea bioreactor (left – adapted from Reference 22) and an electrochemical ammonia reactor (right) for urine recycling. (b.) Photo of Dr. Luis Betancourt working under microgravity conditions with the electrochemical system. (c.) Cyclic voltammetry of ammonia oxidation reaction in ground and microgravity conditions at a Pt modified glassy carbon electrode (adapted from Reference 9a).*

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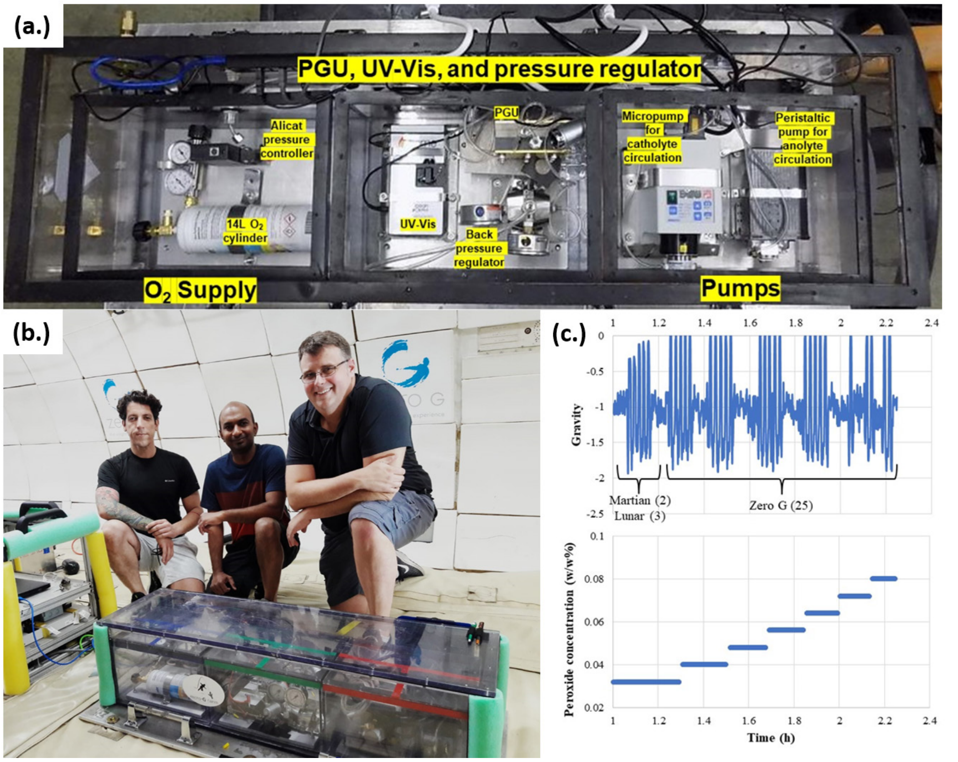

Fig. 4. *(a.) Top view of subscale hydrogen peroxide generation system with components in the electrochemical microgravity test setup. (b.) Zero-gravity hydrogen peroxide flight test team, (left to right) Armando Peña-Duarte, Dr. Santosh Vijapur, and Dr. Timothy Hall. (c.) Accelerometer data from the zero-gravity flight demonstrating the Martian, lunar, and zero-gravity profile (top); Hydrogen peroxide generated during the zero-gravity flight (bottom).*

"H-cell" to fuel cell/electrolyzer hardware. Available drinking water aboard the *ISS* comes directly from the reverse osmosis system.[21] To facilitate the low conductivity RO water, ion conductive resin was included in the electrolyte chamber. Based on this requirement, Faraday designed and constructed an electrochemical subscale reactor for generating hydrogen peroxide enabled by ion conductive resin that is compatible with this low conductivity water stream.

The next step in reactor demonstration activities was to understand the effects of *zero-gravity* on the hydrogen peroxide reactor. The electrochemical reactor and components were assembled in a *zero-gravity* test setup (Fig. 4a). Optimized conditions from ground-based performance data were implemented during the *zero-gravity* flight test to evaluate the feasibility of producing hydrogen peroxide in *zero-gravity* environment. The Faraday-UPR *zero-gravity* flight test team are shown in Fig. 4b. Accelerometer data in Fig. 4c (top) shows the flight profile with 2 Martian, 3 lunar, and 25 *zero-gravity* loops with each loop having a 17 s zero gravity time. Simultaneously, hydrogen peroxide generated was measured *in-situ* utilizing UV-Vis. Figure 4c (bottom) exhibits the generation of about 0.08 w/w% hydrogen peroxide at the end of the *zero-gravity* parabolas, demonstrating the feasibility of generating hydrogen peroxide in *zero-gravity*. The low concentration of the generated peroxide is due to the short residence time to account for the periodic 17 sec *zero-g* loop. At scale, the reactor will be able to produce hydrogen peroxide concentrations approaching 2 w/w% without penalty of the zero gravity at the rate of 1 L per day.

While more engineering development is needed, the flight tests indicated that there were no adverse effects of *zero-gravity* on the performance of the hydrogen peroxide generation system vis-à-vis ground operation. The system can readily be scaled to deliver ~2% w/w% peroxide for disinfectant applications from RO water feed stream. The on-demand disinfectant system is an interesting adaptation of fuel cell gas diffusion cathode technology with the catalyst selected to promote the two-electron reduction pathway to hydrogen peroxide. This system eliminates the need to ferry disinfectant wipes to manned space capsules and is a critical enabling technology for future Moon-based missions and beyond. Ongoing activities are defining the effects of capsule air and contaminants in the RO water on performance of the hydrogen peroxide generator.

Future Applications and Opportunities

The examples herein demonstrate some of the emerging applications of electrochemical science and engineering to support current and future manned space missions. Specifically, electrochemical reduction of carbon dioxide, oxidation of urea/ammonia, and reduction of oxygen (to peroxide) are based on well-established electrochemical principles and derived from fuel cell and electrolysis technologies. Adaptation of the *ISS* ECLSS architecture, enhanced by the capabilities discussed above, will support cislunar travel and further exploration of the Moon. These lunar exploration efforts will provide a base for human exploration of Mars. On Mars *in-situ* resources can be converted to support oxygen production with solid oxide technologies, while ammonia may be processed electrochemically to produce fertilizer supporting human sustenance. Through these efforts electrochemical scientists and engineers will play a growing role in human space exploration.

Acknowledgments

Faraday Technology, Inc. would like to acknowledge financial support from NASA contract no. 80NSSC18C0222, and NNX17CJ12C. Faraday also acknowledges Dr. Steven H. Collicott and undergraduate aerospace engineering students in his "AAE418 Zero-Gravity Flight Experiment (under NASA contract no. 80NSSC18K1287)" class at Purdue University.

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Armando Peña-Duarte is a PhD candidate in chemical physics at the University of Puerto Rico at Rio Piedras Campus, supported by a PR NASA EPSCoR Space Grant Fellowship. He is doing research in electrochemistry under the supervision of Dr. Carlos R. Cabrera. His work is based specifically in the synthesis, by the rotating disk slurry electrodeposition technique (RoDSE), of iron non-precious metal nanoparticles supported on nitrogen-doped carbon nanostructures for oxygen reduction reaction, focused on its essential role in fuel cells in microgravity conditions. Associated to this research, he has done three internships with Faraday Technology, Inc., and has visited Brookhaven National Laboratory (BNL) in New York. He received his master of science in physics at the University of Puerto Rico at Mayaguez, with Dr. Maharaj Tomar, financed by the Center for Research Excellence in Science and Technology (CREST) of the National Science Foundation (NSF). He has a BS in chemistry from the Simon Bolivar University (USB) in Caracas, Venezuela under the supervision of Dr. Julio Puerta. He may be reached at armando.pena@upr.edu.

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Electrochemical Sensors in Space Missions

by Milton Cordeiro, Seamus D. Thomson, M. Meyyappan, and Jessica E. Koehne

Sensors to Support Planetary Exploration

A wide range of electrochemical sensors have been developed and/or used for a broad range of planetary exploration missions. Their benefits include small size, high accuracy and sensitivity, and low power consumption. Electrochemical sensors are able to evaluate a variety of chemistries and chemical processes and are therefore useful for in-situ analysis of interesting targets such as planets and their moons. For example, the recent *Phoenix* mission electrochemically measured the high perchlorate chemical composition of the Martian soil, possibly important to water sequestration and habitability.[1] As highlighted throughout this section, electrochemical sensors are being developed to interrogate the chemical environment of several planets and their moons and represent an important subset of the next generation of planetary exploration instruments.

Ion Selective Electrodes in Planetary Exploration

Ion selective electrodes (ISEs) are a category of electrochemical sensors used to quantify ionic concentration through a potentiometric measurement. Ion selectivity is achieved by ion exchange or ion transport processes across a selective membrane, thereby allowing the measurement of a variety of ions using different membranes. ISEs offer robust identification and quantification of different anions and cations important to geochemistry, providing a method for evaluating the chemical environment and thus potential habitability of other planets and planetary moons. The capability to selectively determine ionic concentrations is thus highly important for planetary exploration to the extent that they were key components onboard NASA's *Phoenix Lander* (Fig. 1A)[2] that touched down on Mars in 2008 as part of the Wet Chemistry Laboratory (WCL) (Fig. 1B).[3,4] This unique electrochemical instrument was critical for the characterization of the Martian soil that enabled the measurement of pH and inorganic ions Ca^{2+}, Mg^{2+}, K^+, NH_4^+, Na^+, Cl^-, Br^-, and I^-. Use of ISEs in future NASA missions has been a topic of current research and development interest, with the creation of miniaturized Solid Contact Ion Selective Electrodes (SC-ISEs) designed to survive the rigors of long-duration spaceflights and reside in microfluidic channels (Fig. 1C,D).[4] This addresses a major concern for in-situ electrochemical devices, where exploring the outer solar system requires instrumentation that is sufficiently durable to survive and reliably function following almost a decade of spaceflight. The NASA Jet Propulsion Lab is currently developing the microWCL—a miniaturized version of the WCL device that includes ISE sensors as well as electrodes capable of measuring conductivity, pH, and redox potential.[5]

Voltammetry in Planetary Exploration

In addition to the use of ISEs to evaluate the chemical environment, voltammetry sensors are being developed to look for evidence of life. Electrochemical detection of biological redox species offers a powerful means of detecting signs of life, as many biological redox species are ubiquitous across terrestrial living organisms. Previous work highlighted the use of a glassy carbon electrode for the detection of the following classes of biomolecules involved in the transport and transfer of electrons: flavins, nicotinamides, porphyrins, and quinones, in a terrestrial seawater analogue solution used to mimic the icy moons of Europa (a moon of Jupiter) and Enceladus (a moon of Saturn) (Fig. 2C).[6] Cyclic voltammetry also has been applied for the detection of enzymes, where an electrochemical assay was used to evaluate the presence of alkaline phosphatase by monitoring a converted redox signature, p-aminophenyl phosphate to p-aminophenol (see Fig. 2D).[6] In the context of future instrumentation developed for exploration of Europa and Enceladus, the incorporation of electrochemical sensors into a microfluidic block for in-situ measurement would be ideal as sampling of liquid oceans is a future possibility. This analysis capability can be achieved with the use of micromachining as well as the use of 3D printing to achieve unique geometries and accommodate electrodes as shown in a current electrochemical device pictured in Fig. 2A,B.

Capillary Electrophoresis for Identifying Ions and Amino Acids

Capillary electrophoresis (CE) is an electrokinetic separation technique used to separate analytes within an electrolyte solution using their variance in ionic charge and mobility. This separation is achieved by applying a potential across a liquid-filled capillary, which is the driving force behind the movement of ions (Fig. 3A). Use of CE for liquid-based analysis appears to be an attractive technique for in-situ sample characterization instrumentation, wherein samples acquired from ocean worlds may already be in a natural liquid state. Furthermore, samples acquired from Enceladus or Europa are believed to be of high salinity and so this technique seems to be the most logical for analyzing its ionic constituents. CE microchip technologies have been developed for planetary exploration devices geared towards these ocean moons. This approach has been further refined to target non-aqueous CE in ethanol for the detection of amines with powerful detection limits as low as 1.0 nM for the

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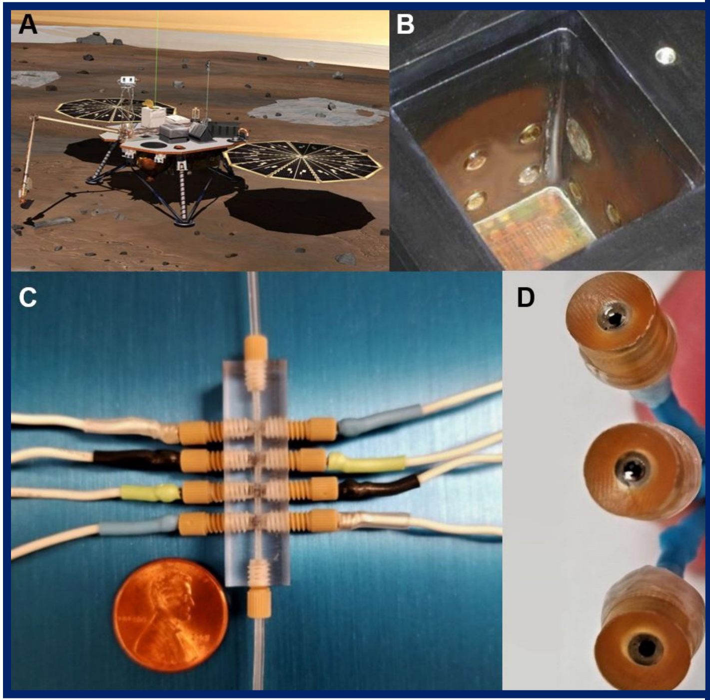

Fig. 1: *(A) NASA's Phoenix Lander that landed on Mars in 2008.[2] (B) The Wet Chemistry Laboratory (WCL) that was onboard Phoenix and characterized the Martian soil using Ion-Selective Electrodes (ISE).[3] (C) Microfluidic channels with integrated ISEs for future spacecraft instrumentation and (D) Miniaturized solid-contact ISEs.[4]*

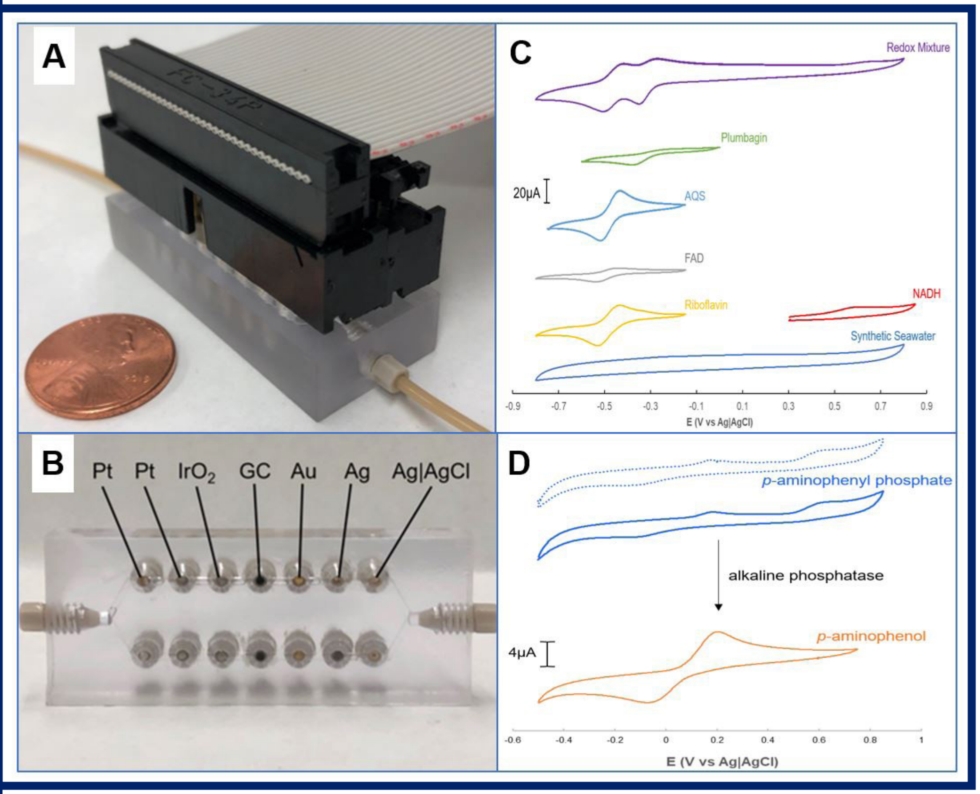

Fig. 2: *(A) A 3D-printed microfluidic flow cell with integrated electrodes and electrical contact. (B) Side view of the electrochemical cell showing dual channels with different electrode materials. (C) Cyclic voltammograms of biological redox species in a synthetic seawater solution. (D) Enzymatic conversion of substrate to product using redox signatures.*[6,7]

Saturn moon, Titan.[7] Inorganic cations and amino acids in high salinity samples have been analyzed using CE in the context of in-situ ocean world exploration.[8] This study further applied CE to analyze samples taken from terrestrial waters with varying salinity, and the CE technique had sensitivity similar to that of gas chromatography and mass spectrometry instruments previously developed for spaceflights. A further consideration of this study was the selection of electrolyte, wherein a 5.0 M acetic acid background electrolyte was found to be the most suitable for simultaneous measurement of inorganic cation and amino acid across a range of sample salinities.[8] Use of CE with sample collection and processing also has been discussed and demonstrated in the context of extracting analyte from aerogels proposed for sample capture in an Enceladus plume flyby mission, where amino acids were successfully extracted and analyzed using CE from silica aerogel.[9] Extension of the CE technology into a microchip electrophoresis (ME) is at the forefront of in-situ instrumentation proposed for future planetary exploration missions. The "Chemical Laptop"—an end-to-end astrobiology instrument capable of ME, laser-induced fluorescence, and capacitively coupled contactless conductivity detection—is an autonomous, low-power device developed at the Jet Propulsion Lab for future planetary exploration missions (Fig. 3A-C).[10–12]

Nanopores for Detection of Biological Polymers

A promising technology for instrumentation development geared towards life-detection purposes is the detection of biological polymers (including polyelectrolytes) such as DNA, RNA, and proteins using nanopores.[13,14] Translocation of polyelectrolytes through this nanopore is driven by an applied electric field, and a change in ionic conductivity can be measured across the membrane that provides insight as to the features of the biological polymers passing through this pore.[15] One advantage of using this system over other types of instrumentation is that this device does not require amplification of these biological polymers to detect them, a feature usually required for large sequencing equipment and experimentation. NASA Ames Research Center is currently developing the latest nanopore system for life detection purposes, coupled with sample preprocessing and microfluidics.[16]

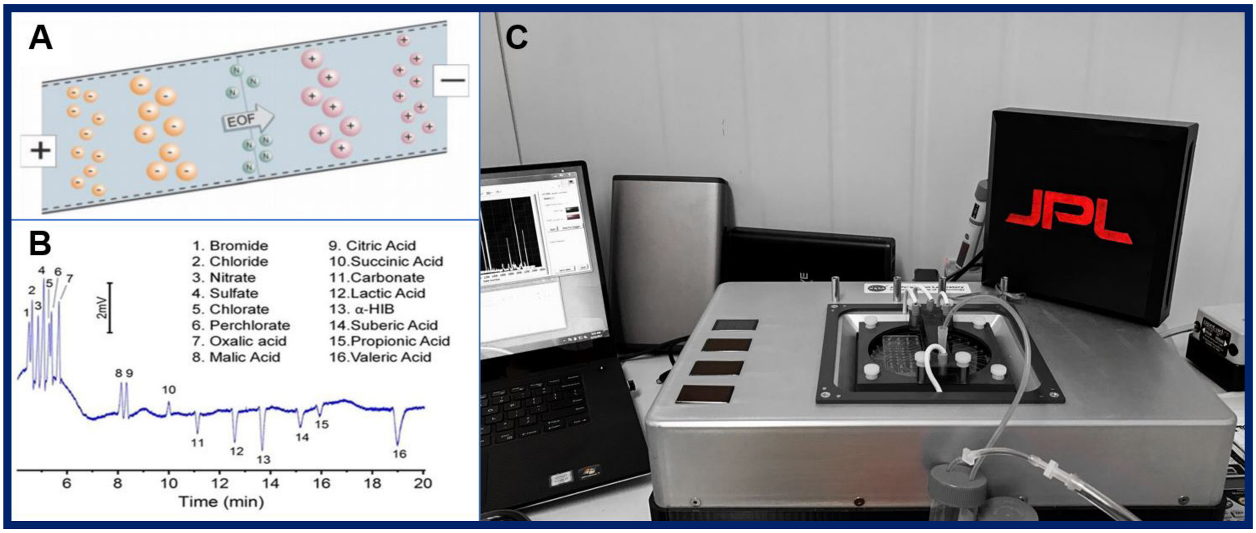

Fig. 3: *(A) Mechanism of action behind capillary electrophoresis (CE) instrumentation, smaller charged ions migrate faster towards their opposite charge polarity than larger ions using an applied potential across a capillary filled with electrolyte.*[10,11] *(B) Separation of inorganic and organic ions using capillary electrophoresis with optimized background electrolytes shows time-dependent detection.*[11,12] *(C) Jet Propulsion Laboratory's "Chemical Laptop," an automated, battery-powered, and reprogrammable microfluidic CE instrument.*[12,13]

Sensors to Support Human Exploration

The success of long-term human exploration missions hinges on the well-being and performance of the astronauts. To ensure the safety and health of crewmembers in space, it is imperative to have the technological capabilities to: 1.) maintain a habitable environment; 2.) sustain the health and performance of the crew; and 3.) produce/harvest energy to power all required support systems. To create a habitable environment, different sensors are required to monitor their surroundings and work with different life support systems on closed feedback loops to allow for tight control of environment parameters.[17] These systems need constant surveillance and maintenance to ensure optimal performance and crew survivability.

To ensure the health and performance of the crew, constant clinical evaluation is required to deploy the most appropriate countermeasures to mitigate the physiological impact of the space environment. Clinical evaluation is currently performed by comparing several biomarkers before and after flight, and by collecting samples at different time points for ground base analysis (except for some imaging techniques such as ultrasounds).[18] For a long-term mission, it is not practical for samples to be shipped for ground analysis and it does not allow personalized countermeasures to be deployed in a timely manner.

Mechanical energy harvesting technologies (conversion process from various ambient sources into usable electricity) are an efficient addition to the conventional energy harvesting system in use—photovoltaic cells—as these are susceptible to dust storms (frequently observed in Mars).[19]

In-Space Manufacturing

When considering long-duration human exploration missions, especially faraway targets like the Moon and Mars, resupply of consumables is no longer convenient and in some cases may not be viable. Therefore, an approach to manufacture, repair, and reutilize supplies is critical. An In-Space Manufacturing (ISM) approach will allow devices, such as electrochemical sensors, to be manufactured on-demand and according to the mission's needs. This capability contributes to a significant risk reduction for human exploration by the optimization of resources, reduction of the risk associated with supply chain disruption, and easing of repair procedures by manufacturing custom repair parts, while simultaneously decreasing the launch mass significantly and thus, the cost associated with the space flight. Printing technologies are advantageous for in-space manufacturing due to their ease of automation, small printer size, ability to print a variety of material inks, and minimal waste generation. In this section, we will describe examples pertaining to the in-space manufacturing of gas sensors, point-of-care sensors (POC), and energy harvesting devices.

Sensors for Life Support Systems

Life support systems are crucial for humans to survive in the harsh conditions of the space environment. Atmospheric management is responsible for maintaining the levels of several gases (oxygen, carbon dioxide, ammonia, etc.) within adequate control levels. Carbon dioxide and ammonia are byproducts of human metabolism, and ammonia is used as a coolant for the ISS photovoltaic panels. Thus, it is necessary to keep a close surveillance on both gases, as they can be deadly to the crew.[20] Figure 4A illustrates a fully inkjet-printed carbon nanotube (CNT) gas ammonia sensor.[21] This device is composed of 16 silver electrodes that are connected through a CNT sensing network. This sensor is able to measure the chemisorption of ammonia to the CNT network based on the increase of the electrical resistance through the CNT network. In this configuration, it is possible to perform 120 measurements from one device, using all combinations of the 16 electrodes as a two-electrode measurement, lending to its classification as a single input and multiple output (SIMO) sensor. In contrast, a traditional two-electrode sensor has to employ 240 electrodes to produce the same number of measurements as one 16-electrode SIMO device. Additionally, the SIMO sensor configuration was compared to conventional two-electrode configuration and it showed a higher average response, a lower standard deviation (left panel of Fig. 4B), and a higher batch-to-batch reproducibility than the conventional configuration. The high number of measurements of the SIMO sensor allows the minimization of the inherent batch-to-batch variability and decreases the need for sensor calibration using probabilistic analysis approach (right panel of Fig. 4B). This high level of data also allowed the detection and exclusion of outliers, allowing for measurements that are more precise. This sensor showed a linear response between 1–50 ppm and the extrapolated limit of detection was determined to be 115 ppb.

An alternative CNT gas sensor was developed that allowed for the simultaneous quantification of ammonia and carbon dioxide.[20] A printed circuit board (PCB) with an array of 16 electrodes (gap size of 102 μm) was used as substrate. Carboxylated CNTs (CNT-COOH) were deposited on PCB electrodes to act as the sensing material. The deposited CNT-COOH was tailored to present different levels of protonation. Low levels of protonation allowed the detection of carbon dioxide (acidic gas) and high levels of protonation allowed the detection of ammonia (basic gas). The detection mechanism is based on the surface pH alteration that affects the CNT-COOH resistivity, meaning that the CNTs that start with a high protonation level are more sensitive towards ammonia, while the CNTs with a low level of protonation are more sensitive towards carbon dioxide. An artificial neural network was trained for the correct concentration determination.

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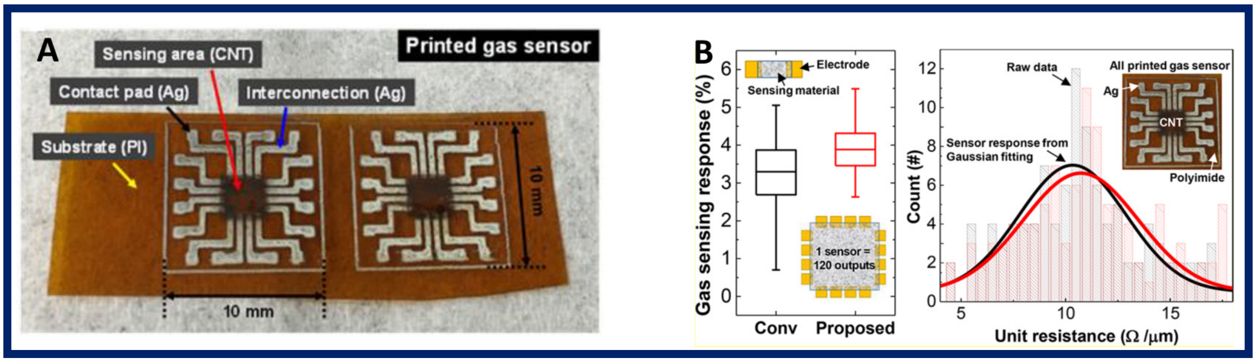

Fig. 4: *Inkjet printed gas sensor. (A) Architecture and features of the gas sensor. (B) Left panel: comparison between the two electrode system and 16-electrode system; Right panel: Resistance distribution (bar) and Gaussian fitting (line) before (black line) and after (red line) ammonia exposure.*[21]

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Point-of-Care Sensors

The capability to monitor crew health parameters as frequently as possible will allow the ground and flight surgeons to take proper and timely steps needed for the mitigation of adverse impacts of the space environment on human health. Having the technologies that allow the diagnosis on site, for point-of-care (POC), is of paramount importance as it avoids the need for sample transportation and ground base analysis.[22] In addition, POC testing allows further insight into human physiology adaptation, which paves the way to the development of improved countermeasures to combat the harmful effects of space travel on the human body.

Due to the unique environment and conditions involved in human spaceflight, astronauts are under significant physical and psychological stress. This stress can lead to reduced cognitive performance and greater sense of dissociation and distress,[23] which can have severe implication on mission success as fatal errors may occur. Cortisol is a known biomarker for stress, and its levels can be monitored via sweat.[24] Therefore, continuous monitoring of sweat cortisol levels via a wearable cortisol-sensing device is desired as it can obviate the need for blood draws. A print-on-demand electrochemical sensor for cortisol detection currently is being developed at NASA Ames (Fig. 5A). This sensor is made entirely by inkjet printing and consists of a CNT working electrode, a CNT counter electrode, and an Ag/AgCl reference electrode. As cortisol binds to an immobilized probe, a decrease in oxidative current by a redox reporter is observed, as shown in Fig. 5B.[25] Frequent monitoring of cortisol levels is expected to help guide flight surgeons to decrease the stress levels of astronauts and optimize their levels of mental acuity.

Energy Harvesting to Power Sensors and Sensor Networks

The capability of harvesting energy is paramount for sustainability in long-duration space missions, including human settlement. Currently, photovoltaic cells are the main energy harvester approach in use. However, due to low solar irradiance on Mars, supplements should also be considered. Mars has significant wind systems that can be exploited for energy harvesting.[19] On Earth, this mechanical energy conversion is performed using conventional electromagnetic motors, heavy permanent magnets, and metal coils. Their bulky size and weight is not compatible with space missions. Triboelectric nanogenerators (TENG) are viable alternatives as they can be manufactured via printing technologies and made to be very small and lightweight. The TENG operates by the generation of contact electrification followed by charge separation. This separation induces the redistribution of electrostatic potential and the created charge flow can be used as electrical energy. The possibility of 3D printing TENGs and their inherent light weight make them a promising supplement to the photovoltaic cells currently in use.[19,26] A TENG with a grating disk configuration was manufactured using exclusively 3D printing.[26] This configuration can be easily adapted for wind energy harvesting by coupling the TENG to a vertical wind blade. This device is comprised of the following components: 1.) Cover, 2.) Electrode layer (EL) with an inner electrode (IE) and an outer electrode (OE), and 3.) Triboelectric layer (TL). A cover aligns the electrode layer and the triboelectric layer. When the TE contacts the EL, the TE gains a static charge. This static charge then attracts charges with the opposite polarity. As the TE rotates between the IE and OE, a reversible mobile charge flow loop (current) is created between the IE and OE electrodes.[27] The frequency of charge flow is defined by the sequential contact between the IE and OE, therefore, the frequency of the charge flow can be controlled by the number of gratings or by rotational speed.[26] For a wind energy harvesting approach, the number of gratings should be increased because the rotational speed will be proportional to the wind speed, which is outside human control.

Final Thoughts and Future Directions

Electrochemical sensors have been applied to answering basic science questions about our solar system as well as aiding the well-being of the astronauts who explore space and our solar system. These sensors applied towards future planetary exploration could unlock further questions about our solar system including whether it has supported life. Electrochemical sensors applied towards future human exploration could benefit from novel in-space manufacturing to enable sustainable human exploration. Further developments in miniaturization, microfluidic integration, and in-space manufacturing offer insight into the future of electrochemical sensors for space.

 DOI: 10.1149/2.F07201IF.

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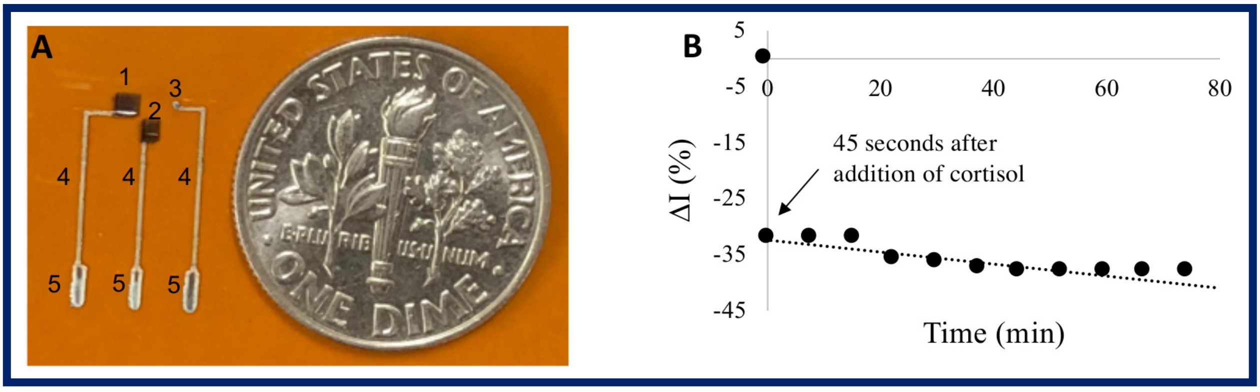

Fig. 5: *Inkjet printed cortisol sensor. (A) Features of a printed 3-electrode sensor on polyimide including a carbon nanotube counter electrode (1.), a carbon nanotube working electrode (2.), an Ag/AgCl reference electrode (3.), silver electrical leads (4.), and contact pads (5.). (B) Variation of differential pulse voltammetry output after addition of cortisol (black arrow).*[25]

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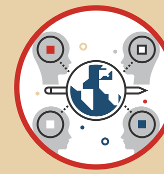

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Energy Storage for the Next Generation of Robotic Space Exploration

by Ratnakumar V. Bugga and Erik J. Brandon

Introduction

Since the beginning of the space age in the 1950s, energy storage technologies have supported the exploration of the solar system, either as the sole source of spacecraft power or in conjunction with other power sources, such as solar arrays or radioisotope thermoelectric generators (RTG). Robotic space exploration involves the use of a wide variety of spacecraft, including orbiters, fly-by missions, landers, rovers, and probes (Fig.1). Depending on the specific mission type and destination, both primary and rechargeable batteries can be used to provide power during launch and post-launch (until the deployment of solar panels), for spacecraft attitude control during trajectory control maneuvers, for peak power needs, and during nighttime eclipse periods for communication and science operations.

Examples of Missions and Energy Storage Needs

Orbiters

Orbiters typically are deployed for mapping the surface of planets and moons, and for monitoring planetary atmospheres and weather. They also serve as a communications link between the Earth and planetary rovers or landers. Rechargeable batteries for orbiters require a long cycle life (~5,000 cycles/year for 10 years or more), adequate calendar life, a high specific energy and energy density, and in some cases, radiation tolerance. Orbiters used for Mars exploration from the *Viking Orbiters* (1976) up to the current orbiter missions, such as *Mars Odyssey* (2001), the *Mars Reconnaissance Orbiter* (2005), and *MAVEN* (2013), have utilized a wide variety of cell formats (including large prismatic and small cylindrical cells) and chemistries (e.g., nickel-cadmium, nickel-hydrogen, and lithium-ion).

Landers and Rovers

Landers and rovers provide the opportunity to conduct in-situ exploration on planetary surfaces. Landed missions typically use rechargeable batteries, wherever a main power source for recharging is available. Examples of these missions include the *Viking Landers* in the 1970s (using nickel-cadmium batteries recharged by RTGs) or the *Phoenix Lander* (2007) on Mars (using lithium-ion batteries with a solar array for recharging). Unlike fixed landers, rovers provide for surface mobility, enabling exploration at different sites. These rechargeable batteries should be mass and volume efficient, to maximize the science payload and reduce launch costs. Recent examples of rovers using lithium-ion batteries are the *Mars Exploration Rovers* (MER) *Spirit* and *Opportunity* (2003). Rechargeable batteries also enable the use of relatively low power output RTG technologies (such as the current Multi-Mission RTG or MMRTG) used on the *Mars Science Laboratory* or the *Curiosity Rover* (2012). The batteries can provide the peak power needed (1,200 W) to support rover operations, recharged from the ~100 W of electrical power provided by the MMRTG.

The temperature of the avionics and batteries on these spacecraft are controlled within a narrow range, with the aid of electrical heating and/or heat generated by plutonium heat sources (either a radioisotope heater unit, RHU, or an RTG). This temperature control enables the batteries to operate under generally Earth-like temperatures, despite many missions operating in low-temperature environments. For example, the *MER* batteries were heated by two RHUs integrated with the batteries, with occasional use of electrical heaters as needed.

The introduction of high reliability rechargeable batteries was an enabling technology for the use of solar arrays in missions beyond Mars. For earlier deep space orbiters and fly-by missions such as *Voyager* (1977), *Galileo* (1989), and *Cassini* (1997), high specific energy, high reliability, long-life rechargeable batteries were not

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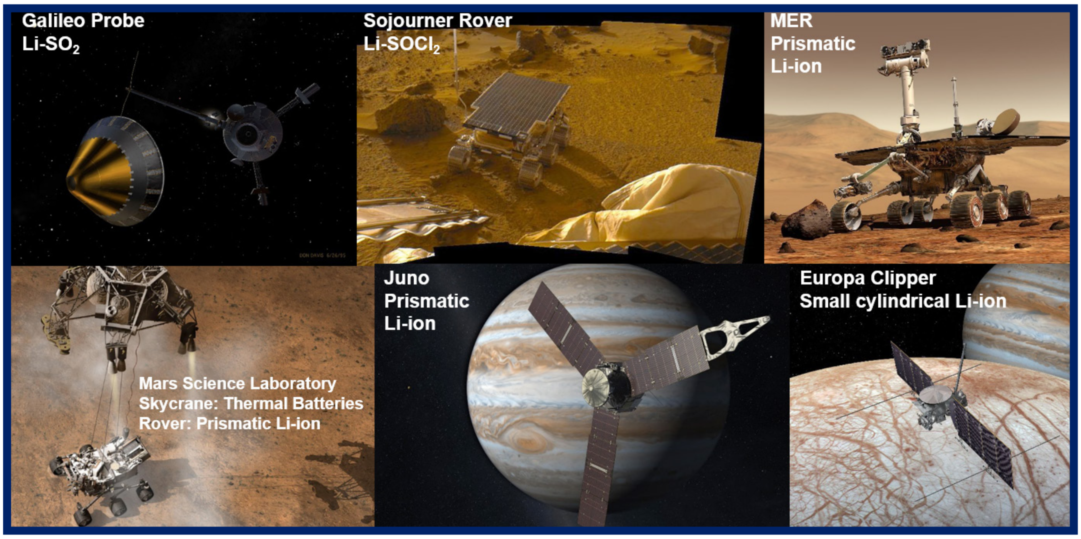

Fig. 1. *Representative solar system exploration missions over the last 30 years using primary and rechargeable batteries.*

available, and all spacecraft power had to be provided by the RTG technology available at the time. In cases where higher power was needed (such as the *Cassini* radar system), capacitor energy storage was used. However, with the advent of improved low irradiance/low temperature (LILT) photovoltaics combined with high performance batteries, deep space solar arrays now can be used in some missions targeted for Jupiter, with solar array/battery mission concepts now planned for distances as far as Saturn. This use of batteries can reduce mission costs and address long-term concerns over RTG availability. Deep space missions using solar arrays and batteries include the *Juno* (2011) mission to Jupiter and the planned *Europa Clipper* mission.

Probes

Probes typically feature small science payloads and are used to investigate planetary atmospheres (such as the *Galileo* probe to Jupiter) and surfaces (such as the *Huygens* probe to Titan, delivered by the *Cassini* orbiter). These missions often are powered by a primary battery alone, or a rechargeable chemistry used in a primary mode (e.g., silver-zinc batteries used on the *Pioneer Venus Multi-Probes* in 1978). As with rechargeable batteries, the avionics and battery thermal environments are carefully controlled. For example, the *Galileo* and *Huygens* probes employed 35 RHUs (each producing about 1 W of thermal energy) to maintain the batteries at an acceptable temperature (~>20°C). Primary battery powered probes have been used to support re-entry into the Earth's atmosphere to return samples from comets (*Stardust* from the comet Wild 2), asteroids (the Japanese Space Agency *Hayabusa* mission, from the asteroid 25143 Itokawa), and the solar wind (*Genesis*). Some probes are designed to impact and penetrate below planetary surfaces (such as the Mars *Deep Space 2* microprobes in 1998), requiring batteries that are impact resistant and low-temperature capable.

Battery Chemistries in Robotic Space Exploration

Primary Batteries

Primary batteries typically are used for missions where solar energy availability is low and options for accommodating other power sources on the spacecraft are limited. Primary batteries used in early spacecraft were largely aqueous-based, including the *Sputnik* (1957) and *Explorer* (1958) missions, which used silver-zinc and zinc-mercury oxide batteries respectively. Recent missions have used more energetic Li-based systems, with liquid cathodes, such as Li-SO_2 and Li-$SOCl_2$, which yield higher voltages, higher specific energies, longer shelf lives, and wider operating temperature ranges.

Thermal Batteries

Thermal batteries are a special type of primary battery chemistry (Fig. 2). They typically are used to support high-power pulses for firing the pyrotechnic charges needed for critical spacecraft events. These events include parachute deployment, separation from the heat shield, and firing of retrorockets, during the entry, descent, and landing (EDL) operations to planetary surfaces. These one-time use batteries utilize a molten salt electrolyte and a lithium alloy anode combined with an iron disulfide cathode. Activated by a pyrotechnic pellet incorporated in the battery, these cells operate in the 350 to 550ºC range.

Lithium Sulfur Dioxide

Li-SO_2 is the most widely used aerospace primary battery system and belongs to the class of liquid cathode systems, with sulfur dioxide dissolved in a 1 M solution of lithium bromide in acetonitrile serving as the catholyte (cathode as well as electrolyte) and Li metal as the anode. Sulfur dioxide is reduced over a carbon cathode current

Fig. 2. *Various thermal batteries used for powering the entry and descent and landing sequences on the Mars Exploration Rover and Mars Science Laboratory rover missions. These batteries incorporate pyrotechnic devices to activate the cells and generate the molten electrolyte.*

collector to form an insoluble lithium dithionate as the discharge product. Spirally wound designs generally are adopted for realizing high specific energies, minimum voltage delay, good low-temperature performance down to -40ºC, long shelf life (>10 years), and high pulse power capability. NASA has utilized Li-SO_2 batteries for the *Galileo*[1] and *Huygens*[2] probes, the *Genesis* and *Stardust* sample return capsules, and the lander for *MER*.[3]

Lithium Thionyl Chloride

Li-$SOCl_2$ is a high-energy Li primary system often used in space applications. This system features lithium as the anode and liquid thionyl chloride ($SOCl_2$) containing lithium tetrachloroaluminate ($LiAlCl_4$) salt as the cathode. Spirally wound designs generally are adopted for realizing high specific energies, especially at moderate discharge rates (390–410 Wh/kg, 875–925 Wh/l at typically <100 W/kg). It has poor performance at low temperatures (-40˚C) with a noticeable voltage delay. NASA utilized this high-energy battery system in several space missions, including the *Mars Sojourner Rover* (1996) and *Deep Impact* (1995) mission to impact comet Tempel 1. A modified version of the Li-$SOCl_2$ system was used for the *Mars Deep Space 2* microprobes, designed for a tolerance to high impacts of ~80,000g and the ability to operate at temperatures of -80ºC (Fig. 3).[4]

Lithium Carbon Fluoride

Another Li primary system, displaying possibly the highest specific energy (~700 Wh/kg at rates C/5), is Li-CF_x (Fig. 3). It utilizes fluorinated carbon as a solid cathode against a Li anode in an electrolyte containing 1 M $LiBF_4$ dissolved in either a propylene carbonate (PC)/dimethoxyethane (DME) blend or in γ-butyrolactone (GBL). It has seen limited use in space, including Panasonic Li-CF_x cells, which were used in the *Hayabusa* mission.

Rechargeable Batteries

As both robotic and human space exploration have progressed, rechargeable batteries have assumed a more prominent role in missions. Different cells have been used as the technologies and mission needs have evolved. These chemistries include Ag-Zn, Ni-

Cd, as well as the nickel-hydrogen (Ni-H_2) chemistry, which has been used for various Mars orbiters over many decades. Of these chemistries, only the Ni-H_2 technology still is in active use, on the *Mars Odyssey* (2001) and *Mars Reconnaissance Orbiter* (2005). Despite the widespread use of these legacy chemistries, Li-ion technology now has become the workhorse aerospace battery for almost all the missions.[5-11]

Li-ion cells employing a coke-type carbon as the anode material, lithium cobalt oxide (LCO) as the cathode material, and an organic electrolyte containing 1.0 M $LiPF_6$ in propylene carbonate and diethyl carbonate, were used in the first commercial cells introduced by Sony in 1991. Following this commercial introduction, Li-ion technology was considered for use by the small satellite community.[6] The first space mission to successfully use Li-ion cells (the *PROBA* Earth orbiting mission launched by the European Space Agency, ESA, in 2001) is still operational 18 years later, with the batteries continuing to support the mission power needs.[9]

Two main approaches to implementing Li-ion cells in robotic spacecraft have been employed (Fig. 4). One involves the use of commercial small, cylindrical cells coupled with extensive performance screening and acceptance testing, which takes into account the unique space environment (e.g., testing under thermal vacuum conditions, etc.).[5-10] With highly automated and reliable fabrication processes in place, commercial off-the-shelf 18650 format cells from reputable manufacturers can provide such uniformity and consistency that cell balancing electronics are not required, particularly with the good cell screening and matching strategies pioneered by ABSL Space Products. The cells are arranged in a series-parallel configuration, and have the added benefit that individual cells possess built-in safety devices along with a multi-string architecture providing modularity and improved redundancy.

ABSL successfully implemented Li-ion batteries in the *Mars Express* (2003) mission by ESA, which represents the first Li-ion battery to orbit Mars, as well as the *Rosetta* mission to the comet Churyumov–Gerasimenko (2004). Subsequently, space batteries of different capacities were made with Sony HC18650 cells for various NASA missions, including the *Space Technology 5* demonstration (2006), *Kepler* (2009), *Lunar Reconnaissance Orbiter* (LRO) and *Lunar CRater Observation and Sensing Satellite* (LCROSS, 2009), *NuSTAR* (2011), *Aquarius* (2012), and the Earth-orbiting *Soil Moisture Active Passive* mission (2015).

Since these early days, commercial Li-ion cells have undergone several changes with respect to electrode materials, electrolytes, and cell designs. Most Li-ion cells used for aerospace applications employ graphitic type carbons including hard carbon, mesocarbon microbeads (MCMB) graphite as anode materials and mixed metal oxides, such as $LiCoO_2$, $LiNiCoO_2$ (NCO), or $LiNiCoAlO_2$ (NCA), as cathode materials. Electrolytes are based on mixtures of linear and cyclic carbonates such as ethylene carbonate (EC), dimethyl carbonate (DMC) and diethylene carbonate (DEC). With the Sony HC18650 cell no longer available, recent missions are utilizing newer Li-ion cells. Examples include the Panasonic NCRB 18650 cells used in the *Mars Cube One* (MarCO) batteries (2018) as seen in Fig. 5, Moli ICR 18650 M cells in *Lucy* (the upcoming mission to Jupiter's primordial asteroids), and the LG Chem MJ1 cells for *Europa Clipper*.

An alternative approach to implementing Li-ion cells involves the use of large prismatic cells, often customized for space operations (for example, using custom electrolytes to support wider temperature operation).[11] The use of prismatic cells typically has been in conjunction with battery management systems so that the individual cells can be monitored, controlled, and balanced with respect to one another. This type of Li-ion battery system has found wide use in long-life applications and/or missions that require a wide temperature range of operation. Manufacturers of large capacity Li-ion cells include EaglePicher Technologies, SAFT, Quallion/EnerSys, and GS Yuasa.

NASA (JPL) developed and qualified a low-temperature Li-ion battery technology (-20 to +40°C) for Mars surface missions (the proposed *Mars Surveyor Lander*, which never flew) in early 2001, utilizing a MCMB anode, NCO cathode, and an electrolyte containing 1 M $LiPF_6$ in 1:1:1 EC:DMC:DEC.[11] This technology was used for the first time on a NASA mission in 2003 to power the *MER* rovers on Mars. The MER Rover Battery Assembly Unit (RBAU) consisted of two parallel 8-cell (10Ah) batteries. Though designed to support operations for a minimum of 100 cycles and 90 days in conjunction with solar cells, these batteries provided power to the *Opportunity* rover for well over 14 years and 6,000 sols, further highlighting the durability and longevity of Li-ion battery technology (The *Spirit* rover, however, failed earlier due to mechanical problems). Spurred by this success, the same cell chemistry has been used on a number of other missions, including *Juno*, a mission to Jupiter which required the batteries to have a long life and radiation tolerance; the *Mars Phoenix Lander*, the first mission to Mars poles in search of water; *Gravity Recovery and Interior Laboratory* (GRAIL) (2011) used for high-quality gravitational field mapping of the Moon to determine its interior structure; and the *Mars Science Laboratory* or *Curiosity* (2011), which is a car-sized rover designed to explore the crater Gale on Mars. An MMRTG power source is used to charge the ~3kWh Li-ion battery (8S2P of 45Ah prismatic cells). The rover is still operational after ~13 km and 2,600 sols (or Mars days) of roving.

A similar Mars rover with enhanced capabilities will be launched in 2020 (*Mars 2020 Rover*). This rover will have similar batteries as in *MSL*, but with an NCA cathode (instead of NCO) and a graphite anode (in place of MCMB). This chemistry also was used in the recent *Mars InSight* (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) lander, but with a next generation low-temperature electrolyte featuring a 20% ester solvent content which extends the operable battery range to -35°C. They also are being used in orbiter applications, such as *MAVEN* (2013), which has batteries (8S2P) using similar prismatic cells (55 Ah) made by Yardney/Eagle Picher. This mission has completed ~9,000 cycles in Martian orbit.

Other commercially available large cells are available for deep space applications. SAFT produces long-life Li-ion cells with a specific energy of 150-165 Wh/kg for a variety of Earth satellite applications. SAFT's primary and rechargeable cells also have been used on the *Philae* lander, which landed on the comet 67P/Churyumov–Gerasimenko in 2014.

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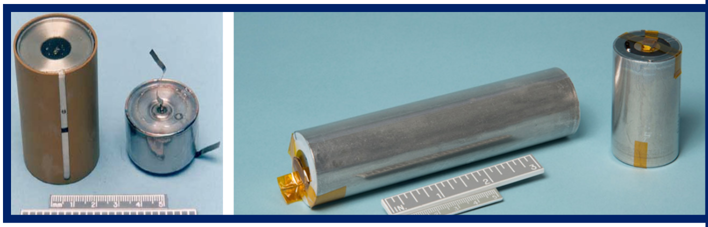

Fig. 3. *Two primary cells targeted for use in deep space landed missions. Deep Space-2 Li-$SOCl_2$ based chemistry designed for high-impact and low-temperature operations manufactured by EaglePicher Technologies, Yardney Division (left), and developmental Li-CF_x cells for use in a proposed Europa Lander, manufactured by Rayovac (right).*

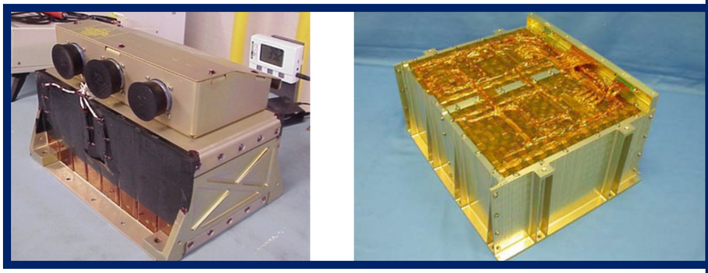

Fig. 4. *Two rechargeable Li-ion battery types: a large prismatic cell design used on Juno (left) and a small cell design similar to those used in Soil Moisture Active Passive and the planned Europa Clipper mission (right). Courtesy of EaglePicher and ABSL.*

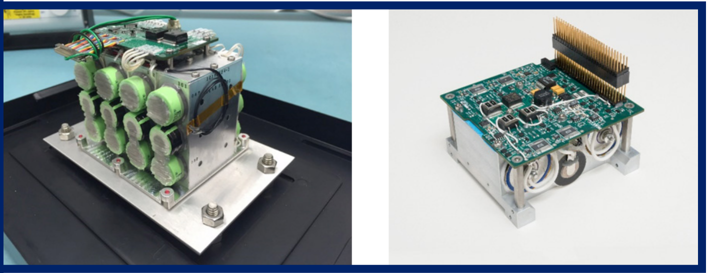

Fig 5. *Two battery packs designed at JPL for use in CubeSat missions. The Mars Cube One (MarCO) battery is pictured on the left, using Panasonic NCR18650B cells that were selected using a limited cell screening process developed at JPL. A hybrid lithium-ion battery/supercapacitor energy storage module that was demonstrated on the JPL/CSUNSat1 Cubesat is shown on the right. The module uses a cylindrical 26650 lithium iron phosphate cell from Navitas customized with a low-temperature electrolyte, and two Maxwell Boostcap electrochemical capacitors. It is designed to support high current pulses at low (-40ºC) temperatures.*

Future Directions

The future of solar system exploration will depend on continued development of energy storage technologies. Space applications require high reliability and durability, which often are met by advanced primary battery chemistries. An example is the $Li-SO_2$ chemistry, which was largely developed by NASA and Honeywell for the *Galileo* probe. Typically, these primary cells have been used for days or even hours on missions, however, future proposed missions (including a proposed *Europa Lander*) could require weeks of operational time.[12] This increased service life will require a much higher specific energy option than is available in current space qualified primary cells, prompting the development of improved performance (>700 Wh/kg) $Li-CF_x$ cells by NASA and JPL working with several vendors (Fig. 3).[13-15] These cells must also operate in the high radiation environment present in the Jupiter system.

New higher power density energy storage technologies are under evaluation and development for space applications. For example, a recent Earth-orbiting mission launched in 2017 *(JPL/CSUNSat1)* flew the first electrochemical capacitor (or "supercapacitor") in space, indicating commercial off-the-shelf electric double-layer capacitors are suitable for use in the space environment (Fig. 5).[16-17] Another application of high-power rechargeable batteries is as a possible thermal battery replacement. As discussed earlier, thermal batteries provide a critical function for many missions, in particularly in support of the EDL phase of mission operations. However, given the fact these are one-time use cells, the extensive electrical screening used to qualify and select modern commercial lithium-ion cells used in aerospace is not possible. Leveraging improvements in higher power energy storage, rechargeable technologies (such as supercapacitors and high-power lithium batteries) are under consideration as testable replacements for thermal batteries. Other potential applications of high-power energy storage include high-power drilling on planetary surfaces or through planetary ices, which can support the growing interest in exploring the ocean worlds of the solar system, such as Europa and Enceladus.[18]

With respect to rechargeable chemistries, the role of "beyond lithium" technologies is unclear. The current approach to aerospace battery development capitalizes on incremental improvements in commercial cylindrical cells, which have exceeded the capability of large cell technology in terms of specific energy and safety. These advances may involve improvements in manufacturing and cell designs, or utilizing emerging materials (such a Si anode and Ni-rich NMC cathode). Given that Li-ion technology did not fly in space until 10 years after first commercialization, it is not clear what rechargeable technology may displace lithium-ion cells in the near term, particularly with regard to the combined need for high specific energy and long cycle life. Solid state technologies could provide an additional layer of protection at the cell level, by eliminating the liquid electrolyte and the potential for leakage and thermal runaway. Lithium-sulfur chemistries are under development with an eye toward improving cycle life, and may eventually play a role in space applications.[19-20] There also are NASA-sponsored developmental efforts underway for primary and rechargeable batteries to support Venus mission concepts operating at +465ºC. Regardless of the direction of all of these development efforts, it is clear that energy storage will continue to play a key role in space exploration in the coming decades.

 DOI: 10.1149/2.F08201IF.

Acknowledgments

A portion of the work reviewed in this article was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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Electrochemical Approaches to "Living off the Land" in Space

by Gregory S. Jackson, S. Elangovan, and Paul E. Hintze

Introduction

The mode of shipping all necessary materials, propellants, and supplies to space out of Earth's gravity well cannot support long-term, robust space activities and space missions that enable a vital economy or long-term human exploration. The propellant and overall cost required to lift large masses and volumes (including the propellant itself) grows geometrically with the mass of the payload. A recent extensive overview by Kornuta and co-authors from the space industry, academia, and U.S. government agencies analyzed the geology, technology, and overall value statement of producing propellant from ice in the permanently shadowed regions (PSRs) of the Moon .[1] As stated in their analysis, justification for Moon-based electrolysis systems to convert lunar ice to liquid H_2 (LH2) and O_2 (LOX) is derived from the exorbitant cost of sending the same fuel to the Moon from Earth, ~\$36,000/kg. Such costs for shipping to the Moon also apply to high-density structural and functional materials and have motivated numerous research and development efforts on molten electrolysis to convert lunar oxide minerals into O_2 and metals such as Si, Fe, Al, and various alloys.[2-6] For missions and activities beyond the Moon, most notably to Mars, required propellant and costs per kg of mass shipped from Earth become significantly more prohibitive, and as such, many future missions for expanding Mars operations rely on producing propellant and materials from the Moon as well as on the Red Planet.[7]

The extraterrestrial production of useful chemicals and materials to support space operations is generally referred to as in-situ resource utilization (ISRU). A principal challenge with ISRU lies in the fact that most available compounds and materials on near-earth bodies, such as the Moon, Mars, and neighboring asteroids, are in low energy states, such as metal oxides, CO_2, H_2O, H_2S, etc. To upgrade these compounds and materials economically to useful propellants, metals, or other structural or functional materials requires highly selective, energy-intensive processes that must utilize abundant energy sources like solar energy. To this end, electrochemical processes driven by photovoltaic conversion of sunlight or perhaps by an installed nuclear power source present a logical approach to meet the energy challenges for ISRU deployment. Electrochemical processes can provide high selectivity of products, but future integrated systems must be automated and extremely robust to survive the harsh requirements of transport to space and operation in extraterrestrial environments.

As mentioned before, electrolysis for LH2/LOX propellants from lunar ice presents a noteworthy example of how electrochemistry can play a vital role in ISRU. However, there have been numerous other research and development efforts that involve electrochemical systems that can support space-related activities, such as the soon-to-be-launched *Mars Oxygen In-Situ Resource Utilization Equipment* (MOXIE) system to convert atmospheric CO_2 on Mars into O_2 and CO, which is a vital precursor for a range of hydrocarbon and oxygenate chemistries.[8-10] The availability of significant ice deposits on Mars[11] provides the further potential of converting CO to fuels like CH_4 with chemical processes[12] or to life supporting chemicals or plastic precursors with biologically mediated photochemical processes.[13,14] Just as significant as making propellants and chemicals, the electrochemical production of metals and structural materials via molten salt electrolysis[6,15-17] from regolith on Mars, the Moon, and perhaps even asteroids, represents a critical step in building out the infrastructure to support large-scale ISRU operations. The deployment of such processes will require significant long-term design and testing programs on Earth that assess key elements, including electric power, thermal management, and reliable electrochemical processing and product capture and separation.

The investments required for successful deployment of first-generation, electrochemical ISRU systems to produce metals, O_2, and/or propellants are nothing short of enormous. Required investments in ISRU are complicated by the unique challenges of extraterrestrial environments related to extreme temperatures, radiation hazards, and limited accessibility for maintenance. In addition, design criteria for initial electrochemical systems delivered from Earth include optimized mass, autonomy, and extreme resistance to mechanical and thermal failures in flight and may lead to different designs than their terrestrial analogs. This paper presents some efforts to date on designing and testing electrochemical ISRU system prototypes. The paper will initially focus on electrochemical ISRU processes relevant for providing valuable chemicals to support transportation (propellants) and human activity (O_2, H_2O, and hydrocarbons/oxygenates). A subsequent section will focus on past and possible future developments in electrochemical engineering for producing structural and functional materials from lunar and Martian regolith. The paper then will discuss the efforts by government agencies, such as NASA and the ESA, to address the development on Earth and deployment in space of first generation integrated ISRU systems, and in particular, systems that rely on electrochemistry. The unique challenges of space transport and deployment require long and extremely thorough product development cycles, but the enormous potential for electrochemistry for ISRU to support a future space economy make such long and arduous cycles worthwhile.

ISRU for Chemicals

One of the most impactful opportunities for deploying ISRU, as overviewed in Kornuta et al.[1], involves the processing of lunar ice into propellants as well as purified water. The significant efforts to gain an understanding of the nature of water resources in the PSRs of the Moon, highlighted by the *Lunar Crater Observation and Sensing Satellite* (LCROSS) PSR affect experiment and resulting spectroscopic measurement of the plume[18,19] highlights the challenge of developing electrochemical systems to support ISRU for water purification and electrolysis. The LCROSS experiment and additional flux measurements from the neutron detector on the *Lunar Reconnaissance Orbiter* (LRO) spacecraft[20] provide qualitative information about the fraction of water in near surface regions of specific PSRs and the nature of the principal impurities—notably H_2S (~ 1:6 moles H_2S to moles H_2O) and NH_3 (~1:16 moles NH_3 to moles H_2O). These principal impurities, along with other impurities such as C_2H_4 and SO_2, place a challenge on processes and functional materials used for establishing a robust, autonomous system for water purification and subsequent electrolysis. In addition, the fraction of the water in ice vs. hydrated minerals is not well known, which provides uncertainties in the temperature and energy requirements for a water purification system.

Uncertainties associated with lunar H_2O resources make it clear that deployed systems must rely on highly selective processes such as cold traps (for H_2O vapor capture) and regenerable scrubbers

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(for removing NH_3 and other impurities) in order to facilitate robust electrolyzer operation. A current system under development by Paragon Space Development Corp. and Giner Inc. with support from NASA[21] relies on an H_2O cold trap and multiple clean-up steps with gas compression to facilitate high-purity water feeds into Giner's high-pressure PEM electrolysis stack[1] with H_2O removal from the separated H_2 and O_2 product streams. OxEon Energy and the Colorado School of Mines have started development of an alternative approach to splitting lunar H_2O based on solid oxide electrochemical cells (SOECs), which avoid the complications of liquid-phase water handling by operating at high temperatures ≥ 700°C. SOEC electrolysis with steam requires less electrical energy input (35 to 37 $kWh_{elec}/kg\ H_2$) than liquid-phase PEM or alkaline electrolysis (50 to 58 $kWh_{elec}/kg\ H_2$), but the higher operating temperatures require additional thermal energy input and present challenges with energy balances during start-up and shutdown that must be addressed in a development effort for operation in the low temperatures of the lunar PSRs (~ 40 K). Lunar-based H_2O electrolysis systems may be adopted for future Martian operations, and massive ice sheets on Mars near the poles and under the Martian surface may present a higher-grade resource for water purification and propellant production than the ice bound in lunar regolith.[22]

Unlike the Moon, Mars provides not only H_2O but also an abundance of CO_2, which makes up 95% of the atmospheric pressure totaling just over 600 Pa. The potential to convert CO_2 in the Martian atmosphere to O_2 and CO provided the impetus for *MOXIE*. As one of seven instruments selected for the *Mars 2020 Rover* payload, *MOXIE* is the first electrochemistry-based ISRU system to be deployed for demonstration. The use of atmospheric CO_2 does not constrain the landing and operation site on Mars. Illustrated in Fig. 1a, the heart of *MOXIE* is a high-temperature SOEC stack utilizing an oxygen-ion conducting doped zirconia electrolyte that ensures exceptionally high-purity product O_2.[9,10] The cathode material is a Ni cermet and the anode is a mixed-conducting lanthanum strontium cobalt iron (LSCF) oxide perovskite—both electrode materials being derived from development of SOEC electrolysis stacks for terrestrial applications. The interconnect material, Cr-Fe-Y_2O_3 (CFY) alloy from Plansee SE, has close thermal expansion match to the electrolyte to enable joining with a hermetic glass seal that provides robustness to thermal cycling. Such reliable sealing and operation favored an internally manifolded stack design, which also provides robust mechanical architecture to survive severe vibrations during the early stages of flight and landing at Mars. Figure 1b shows the installation of the *MOXIE* unit into the chassis of the *Mars Rover*. The proposed *Mars Ascent Vehicle* (MAV) for a manned mission would require 30,000 kg of O_2 for propellant at a purity > 99.6%. *MOXIE*'s SOEC stack is designed to produce only 0.01 kg/h of high purity O_2, which is ~0.5% scale of a full-scale unit. *MOXIE*'s balance of plant includes CO_2 acquisition and compression, measurement of composition, flows, and a section for process monitoring and controls featuring power electronics.

Production of H_2, O_2, and/or CO from electrolysis on Mars presents a first step in developing more complicated intensified or multi-reactor processes that enable production of additional compounds, such as hydrocarbons for propellant or plastic production or oxygenates for other needs as shown in Fig. 2a. Numerous studies focused on Sabatier reactors ($CO_2 + 4 H_2 \leftrightarrow CH_4 + 2 H_2O$) for Mars that would enable the production of energy-dense CH_4 propellant from atmospheric CO_2 and H_2 derived from electrolysis.[12,23,24] However, advances in high-temperature electrolysis and membrane reactors based on proton-conducting ceramics, such as doped barium zirconates (BCZY),[25] present opportunities for developing ionic-membrane reactor systems that can make olefins[26] for plastics with the integration of selective catalysts or can make other higher hydrocarbons directly[27] or in combination with downstream Fischer-Tropsch processes.[24,28] Membrane reactor concepts that rely on proton-conducting ceramics can be designed to selectively react CO_2 with H_2 to desired higher hydrocarbon products as illustrated in Fig. 2b. With selective catalysts that restrict pathways to CH_4 conversion, Fig. 2c shows how thermodynamics can favor production of olefins, which can provide precursors for plastics and numerous other valuable chemicals for human activities. Delivery of these developing intensified processes that are relying on emerging electrochemical processes will require years of Earth-based testing and qualification, as well as system design for robustness and automation before finding their way to the Red Planet, but such investments can be vital not only for ISRU on Mars but for advancing atmospheric CO_2 utilization here on Earth to combat global warming.

ISRU for Structural and Functional Materials

Just as significant as developing and deploying processes and systems to produce propellants and chemicals in space, establishing ISRU for manufacturing vital materials, such as sintered regolith bricks for structures, silicon for solar panels, and iron or titanium for structural components of storage facilities and/or transport vehicles, will play a vital role in developing long-term operations on the Moon and Mars. Manufacturing of sintered regolith for radiation shielding and habitat structures will likely rely on thermal sintering of abundant oxides using lasers or concentrated solar radiation, and additive manufacturing approaches are under development for such regolith processing.[29,30] While thermal sintering of regolith may induce redox reactions, electrochemical reactions do not play a principal role in such systems. On the other hand, thermal processing in the presence of carbon can drive redox reactions that reduce regolith cations[15,31],

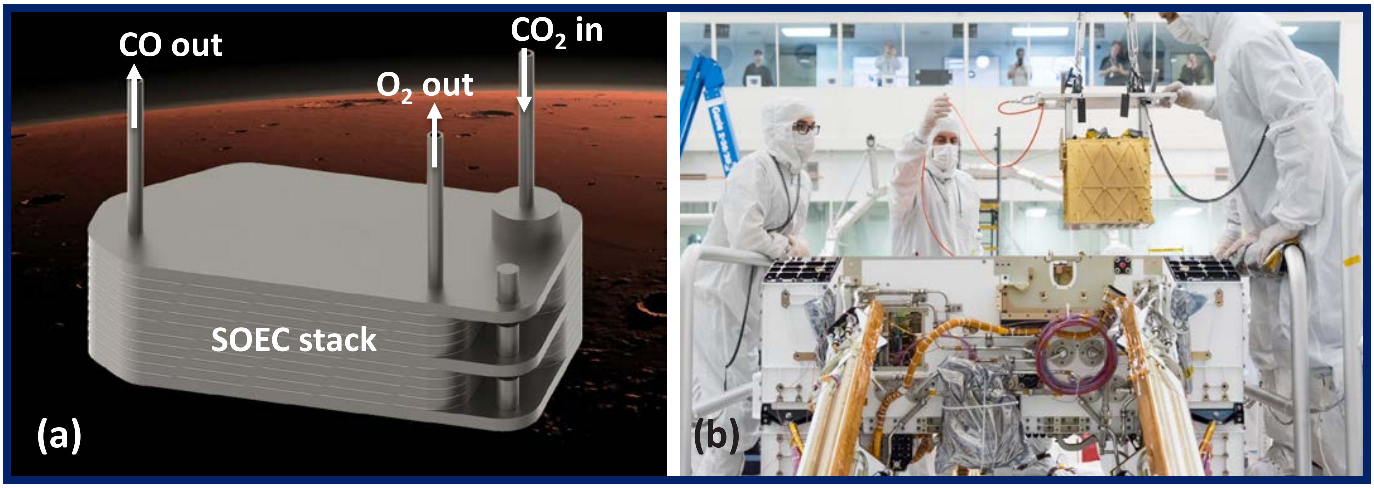

Fig. 1. *a) Rendered image of solid oxide electrochemical stack for CO_2 electrolysis to be delivered to Mars on the upcoming Mars 2020 mission; b) installation at NASA's Jet Propulsion Laboratory of the MOXIE electrolysis system into the Rover that will host it on Mars (provided by the Jet Propulsion Laboratory).*

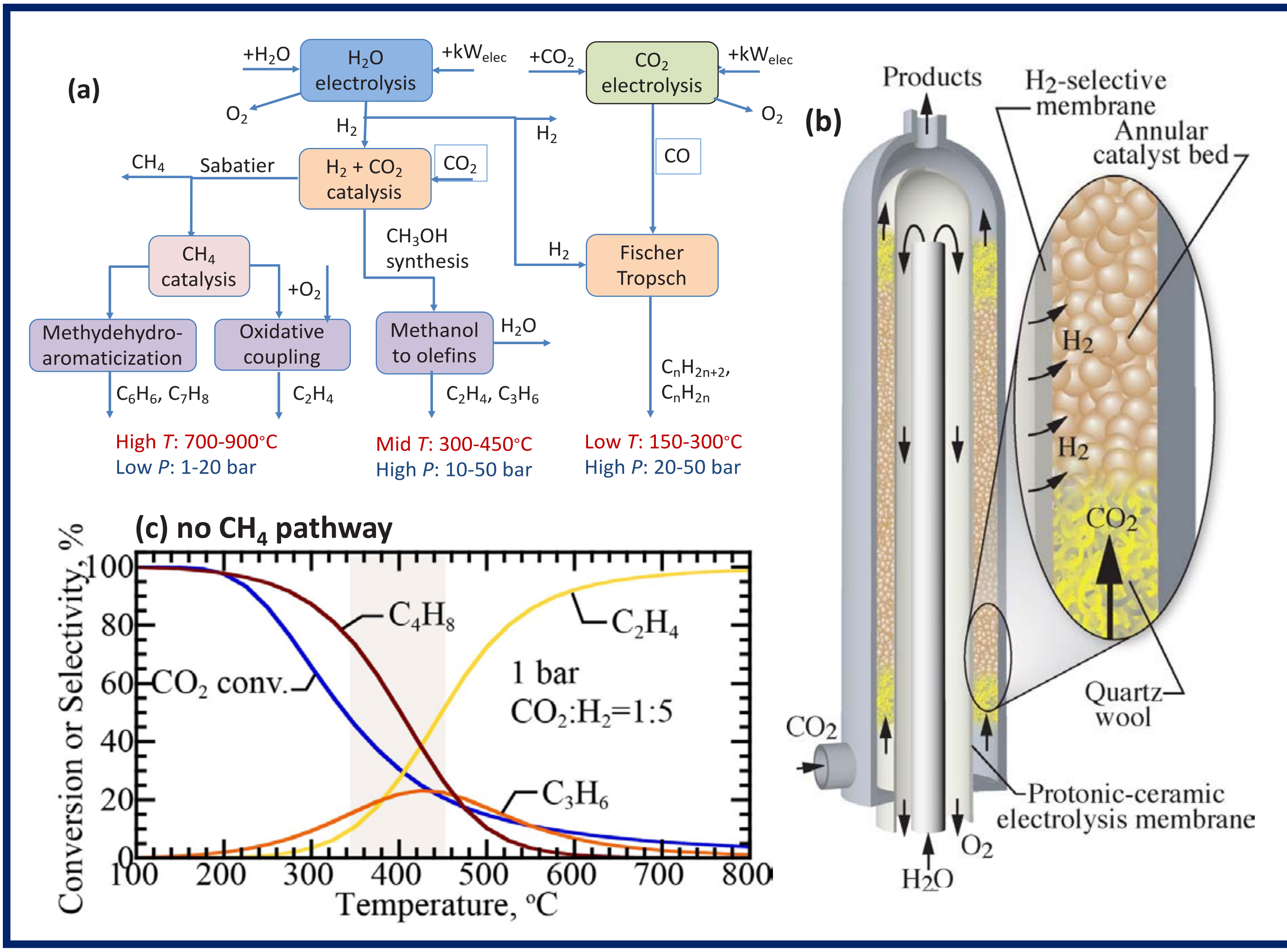

Fig. 2. *a) Diagram showing ISRU pathways for producing useful chemicals on Mars supplied by electrolysis of captured H_2O and CO_2 either in separate stacks or in a single co-electrolysis; b) reactor diagram for process intensification by combining high-temperature H_2O electrolysis providing H_2 across a proton-conducting ceramic electrolysis membrane to react with CO_2 in a selective catalytic process (provided by Robert Kee and Canan Karakaya at the Colorado School of Mines); c) equilibrium calculations of low-pressure CO_2 + H_2 reactor products with catalyst that restricts pathways to CH_4 production.*

and thereby produce metals, most notably iron. Over the past decade, several studies have focused specifically on more selective, high-temperature electrochemical processes, in particular on molten salt electrolysis for processing regolith into valuable metals both on the Moon and Mars. With this paper's focus on electrochemistry for ISRU, this section will overview recent developments on these electrochemical processes for regolith materials.

The viability of electrochemical processing of regolith with molten salt electrolysis depends upon a strong knowledge of the mineral composition of the material inputs. Numerous spectroscopic studies of the lunar surface, as well as the analysis of samples taken from the lunar landings in the *Apollo* and *Luna* missions, provide a broad range of compositions of lunar regolith. A summary of lunar samples by Heiken et al.[32] provide compositions in terms of principal oxides and the approximate range of those compositions are presented in Table 1. These compositions do not account for the complex mixed oxide compounds that can be found in plagioclase minerals due to past lunar volcanic activity,[33] and present mixed oxides, such as ilmenite, $FeTiO_3$,[34] provide opportunities for chemical or electrochemical reduction that may be advantageous in producing higher purity products, including iron, as well as useful oxides such

Table 1. Range of weight fractions of principal oxide components in lunar regolith[32] and Martian regolith[42] as determined from sample measurements.

Oxide	SiO_2	FeO	Al_2O_3	CaO	MgO	TiO_2	Na_2O
Lunar	43-47%	5-16%	13-27%	10-15%	6-11%	1-4%	<1%
Martian	39-45%	17-21%	9-10%	6-7%	7-8%	~1%	2-3%

as TiO_2 that have value for photoactivity. The challenge is that these processes require confinement of molten salts at temperatures over 1,800 K.[6] A noteworthy comparison of chemical and electrochemical reduction of simulated lunar regolith emphasizes the advantages of molten salt electrolysis in that it enhances the separation of the metal such as Fe or Si from unwanted byproducts,[2,6,16] although challenges remain in identifying inert anodes, such as iridium,[3] that enable O_2 production or supplying disposable carbon anodes to support this. An alternative for iron production on the Moon involves chemical reduction using H_2 derived from electrolysis,[35,36] but such chemical reduction would benefit from extracting higher purity lunar deposits such as ilmenite. More recent studies on aluminothermic reduction-electrolysis in China has shown promise in providing an approach to produce metallic aluminum and silicon from molten regolith compositions using a nickel alloy anode at temperatures below 1,000°C[17] and such a process might provide a first step toward producing photovoltaic devices from resources on the Moon. All the same, much more development and durability testing is needed to identify stable and autonomous electrochemical processes that can tolerate expected variation in regolith composition before deployment of ISRU systems can be realized on the surface of the Moon. As an intriguing alternative to high-temperature, molten salt electrolysis, ionic liquids have been developed to dissolve lunar regolith simulant at room temperature. In conjunction with electrolysis, the ionic liquid process produces metals and oxygen and has been shown to work on a number of relevant minerals.[37]

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The surface of Mars presents similar compositions to the Moon, but in many ways more favorable compositions for production of metals. As shown in Table 1, Mars regolith on the surface has a higher iron content, and furthermore, with an abundant source of carbon from atmospheric CO_2, the potential for carbothermal reduction or production of carbon anodes for molten salt electrolysis provides a means for establishing production of iron[3,6] or ferrosilicon.[38] At the same time, processes developed and deployed on the Moon may provide valuable testing grounds for later deployments on Mars, where the increased costs for delivery of massive infrastructure will require more dependence on ISRU systems. An additional challenge for Mars is the reduced solar irradiation fluxes (~40-45% than that of Earth) for photovoltaic electricity and concentrated solar heating for high-temperature electrolysis. Developing and deploying robust system architectures for ISRU for materials production on Mars remains a long-term challenge that must be met before broader human and economic activity can occur on the Red Planet.

From Materials to Devices and Systems

Designing and assembling electrochemical systems, or any processing system, for use in space presents a set of requirements unlike what is needed for a terrestrial system. All systems delivered from Earth have unique but well-understood requirements. All devices and components must withstand the severe vibration of launch as well as the forces and shocks during subsequent stage ignitions and eventual landing. In addition, all components must fit into the mass, volume, and power envelopes of both the spacecraft and the lander. Other device/component requirements, however, are more complex and require continued research and development. Processes with chemical and/or material conversion must function efficiently and reliably in the variable thermal environments of Moon—with ~350 hour nights cooling to 100 K or less and with ~350 hours of continuous sunlight with temperatures rising above 400 K—or of Mars—with its intermittent violent dust storms. Such environments, which are very different from Earth, affect design of process balance of plant for thermal management, energy storage. In addition, the location of current ISRU components can affect design. Current landers in NASA's Commercial Lunar Payload Services (CLPS) host multiple instruments, and the specific instrument location on the lander dramatically affects the ability to release heat and can force design changes. Testing of small instruments in an environment that mimics the temperature and pressures of Moon and Mars can be achieved in small chambers, but testing a large full-scale ISRU system requires large vacuum chambers with the ability to operate over wide range of temperatures.

The amount of hardware required for establishing electrochemical, thermal, and mechanical handling systems that will process regolith are substantial, as illustrated in Fig. 3, and many components including the regolith reduction step and subsequent product separation remain in the research and development stage. For further development, prototype regolith handling systems and processes must use regolith simulants during Earth-based testing. There is no perfect simulant that matches all physical and chemical properties of the real thing. An appropriate well-characterized simulant should be chosen. Analog field sites are often used to test systems and provide many benefits.[39] Field demonstrations verify that all components work together as a system and that produced commodities can be transferred and used. For example, when demonstrating propellant production, the test can include excavation of the resource, chemical processing, and transfer of the product. In addition, control rooms can be set up remotely to identify areas where autonomy is needed, test teleoperation methods, or implement communication time lags as would happen on a Mars mission. For example, a prospecting instrument operating at an analog test site on Mauna Kea, Hawaii was operated from a control room at Kennedy Space Center.[40]

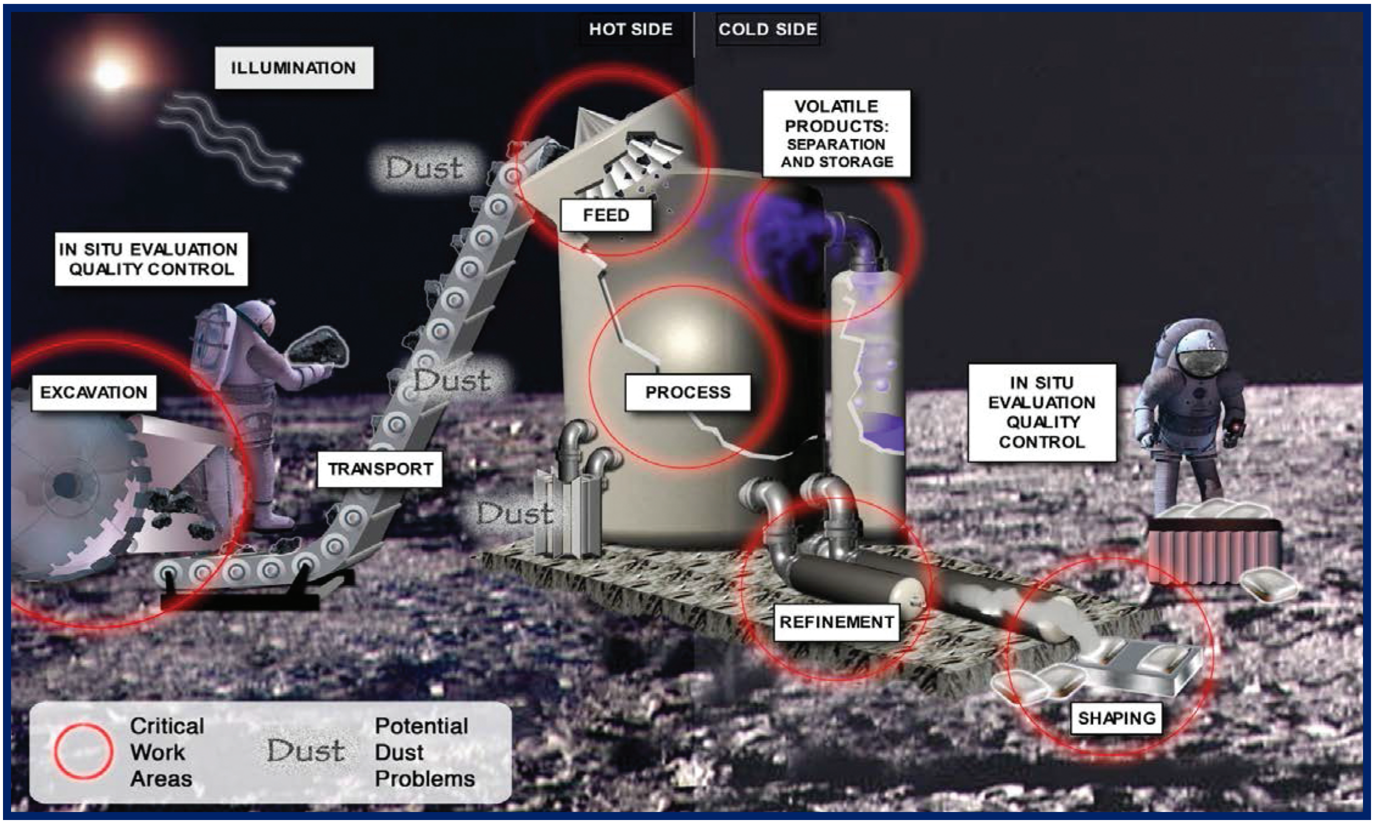

Fig. 3. *Artist sketch (provided by Laurent Sibille) of a lunar regolith processing facility to produce metals and separated volatiles such as O_2 and other byproducts. The sketch shows the multiple steps of a regolith refining process including the high-temperature process that could rely on molten salt electrolysis or high-temperature chemical reduction using H_2 derived from lunar ice electrolysis. The figure does not show the solar panels and power electronics required to drive the electrical energy inputs for the many process steps including electrochemistry.*

The aforementioned *MOXIE* system for Martian CO_2 electrolysis provides an example of how the challenges for deployment to Mars affect the design of a fully integrated electrochemical ISRU system on a Martian lander. As with any space bound instrument, the solid oxide electrochemical stack was qualified to meet shock, vibration, and cold clamping forces required for launch, entry, descent, and landing.[10] In advance of its launch, the SOEC stack has been cycled to temperatures as low as -65°C to simulate the Martian environments. The *Mars Rover* host platform for *MOXIE* imposes severe constraints on mass, volume, peak power and total cycle energy,[41] but it offers an early opportunity to demonstrate ISRU at a small scale by delivering the 15 kg system on the 1,000 kg Rover. Unlike a future stationary O_2 generation system to be developed for continuous operation to support a manned mission, the limited battery energy on the small *Mars Rover* creates extraordinary constraints to *MOXIE* operation. The stack is required to reach the operating temperature of 800 °C in 90 minutes and operate only for 120 minutes. A minimum of 10 such cycles, planned during deployment, place an enormous challenge on stack seals to maintain an O_2 purity of 99.6% or higher. Additional challenges arise for unmanned operation environment, with once daily uplink and downlink schedules, making man in the loop operation infeasible. Therefore, care must be taken to define a safe operating envelope in such a way that the system can be reliably operated without damaging itself.

As the *MOXIE* development and upcoming deployment shows, long duration space flights to Mars limit what can be brought on the mission. As such, systems that have multiple functions and can manufacture multiple commodities with the same hardware provide enormous benefits for ISRU. In this vein, proposed bio-electrochemical systems (BES) have the potential to produce a range of ISRU products including fuels, materials, and even pharmaceuticals.[14] In these systems, electrical energy input fuels the metabolism of the microbial community, which then produces a product. With modern genetic engineering and continuing studies into different microbial consortia, BES can be tailored to produce different products. The challenge, like with all ISRU systems, involves designing the confinement and balance of plant to ensure that the biochemical reactor can operate reliably in the harsh and variable extra-terrestrial environments and can survive the significant forces involved in delivery to those environments.

Conclusions

Electrochemical reactions provide ISRU engineers and proponents with a vital means for converting abundant resources in space into vital compounds for propellants, reducing agents, and life support. Near-term, the use of rapidly maturing H_2O electrolysis systems, both low-temperature PEM and high-temperature solid-oxide cells, presents a significant opportunity to enable lunar production of LH2/LOX propellants. Lunar-based propellant production can provide significant opportunities for increased space activity and more substantial transport to further bodies by removing the need to lift all fuel from Earth. In-space fueling stations in a so-called cislunar economy[1] enables travel not only between the Earth and the Moon, but also facilitates reduced fuel and cost requirements to travel to Mars. Electrochemical systems for propellant production in space will also benefit delivery of future high-mass ISRU systems for other applications, such as electrochemical regolith processing for producing metals on the Moon or Mars.

The advantages of electrochemical systems for ISRU stems in part from their ability to operate in highly selective and controllable modes that produce high quality separated products. Deployed electrochemical ISRU systems will likely rely upon the abundant solar energy for electrical energy input and as needed, thermal energy inputs. The cost of development and eventual deployment for first generation ISRU systems will require electrochemical processes rely on materials that are extraordinarily robust and efficient. As such, materials and manufacturing approaches that are considered cost prohibitive for terrestrial applications may be advantageous for ISRU because of their increased durability and operating windows. All the same, the need for high durability and energy efficiency requires substantial Earth-based testing with simulated extra-terrestrial environments and materials to ensure that deployed ISRU systems live up to specifications. Such development and testing is occurring across North America, Europe, and Asia with the expectations that in the coming years and decades, ISRU systems, that will likely rely on electrochemical processes, will be deployed in vibrant international space activities on both the Moon and Mars.

© The Electrochemical Society. DOI: 10.1149/2.F09201IF.

Acknowledgments

The authors would like to acknowledge insightful conversations with Christopher Dreyer of the Center for Space Resources at the Colorado School of Mines that helped in writing this article. The authors would also like to recognize Prof. Robert Kee and Dr. Canan Karakaya of the Colorado School of Mines for helping provide elements of Fig. 2, and Dr. Laurent Sibille of the Exploration Research and Technology at NASA Kennedy Space Center for providing Fig. 3 in the text.

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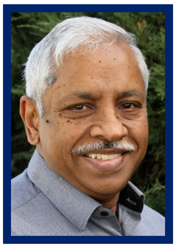

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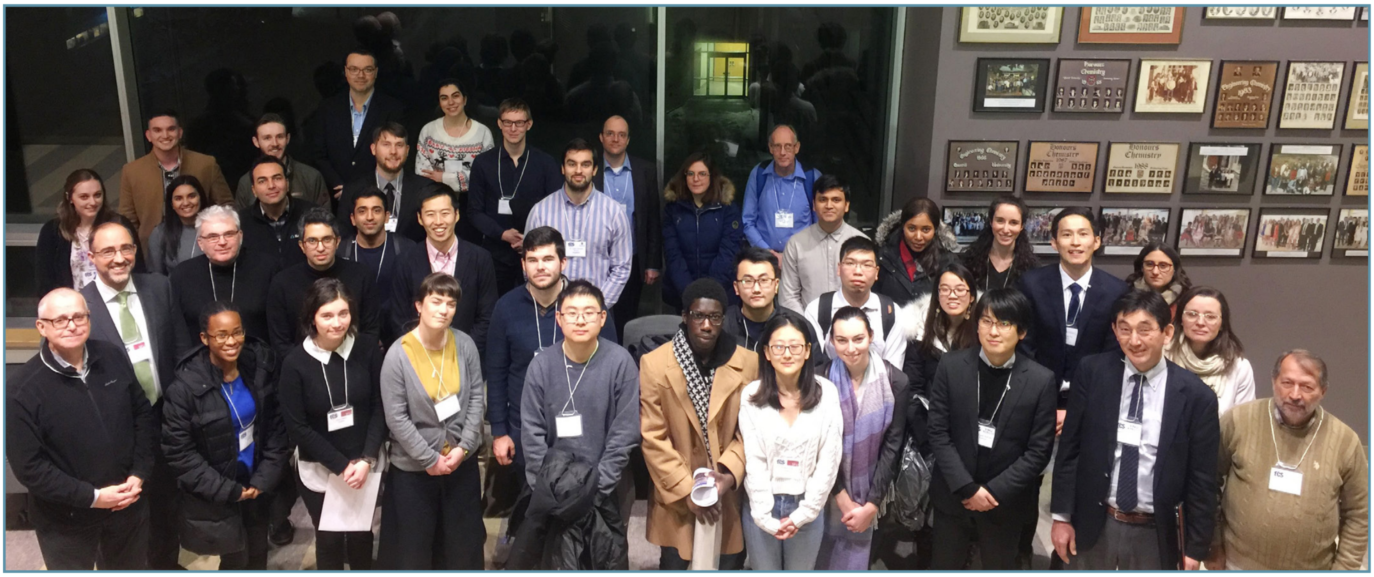
Canada Section

The **ECS Canada Section** hosted its fall 2019 meeting at Queen's University in Kingston, Ontario, on December 19, 2019. The topic of the meeting was "Current Challenges and Recent Advances in Electrochemical Technologies for a Sustainable Society." Over 60 participants from industry, research centers, and Canadian and international universities were present.

The meeting featured two keynote presentations given by Deborah Jones, University of Montpellier, and Byron Gates, Simon Fraser University. In addition, international collaborators from the "Ni Electro Can" NSERC Discovery Frontiers project participated as invited speakers and in the student poster session, providing a unique opportunity for Canadian students and researchers to connect with international research groups.

During this year's meeting, Brad Easton, chair of the ECS Canada Section, presented both the Canada Section W. Lash Miller Award and the ECS Canada Section Student Award. The Canada Section W. Lash Miller Award was given to Edouard Asselin, University of British Columbia, for his contributions to the field of aqueous processing of metals, while the ECS Canada Section Student Award was presented to Jeffrey D. Henderson, University of Western Ontario.

Over 25 students participated during the poster session and prizes were given to the best presenters. Kok Long Ng (first place, University of Toronto), Mason Sullivan (second place, the University of Ontario Institute of Technology), and Alexi Pauls (third place, Simon Fraser University) were awarded for their poster presentations. This event was only possible thanks to the support of the sponsors, namely Gamble Technologies, Metrohm, Springer Nature, Swagelok, Systems For Research, the Department of Chemistry at Queen's University, and the Natural Sciences and Engineering Research Council of Canada.



Attendees of the 2019 ECS Canada Section meeting.

Brad Easton *(left) presented* **Edouard Asselin** *(right) with the 2019 Canada Section W. Lash Miller Award.*

Brad Easton *(left) presented* **Jeffrey Henderson** *(right) with the 2019 ECS Canada Section Student Award.*

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Japan Section

On November 7, 2019, the **ECS Japan Section** and Hokuriku Division of The Electrochemical Society of Japan came together to host a program for young researchers, titled, "Y-01 Advanced Bioelectrochemical Technique for Monitoring Intracellular NADH with Redox Mediators." The event took place at Niigata University on the Igarashi Campus in Japan. A total of 40 attendees participated in the event.

On December 21, 2019, the ECS Japan Section also hosted the 3rd Kansai Denki-Kagaku Kenkyukai in 2019, taking place in the Funai Tetsuro Auditorium of the Kyoto University Katsura Campus in Japan.

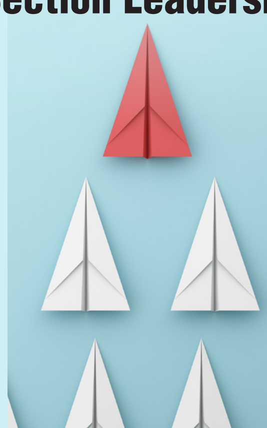
The seminar consisted of a poster session and one-minute oral presentations on poster topics of which 106 authors participated in, as well as a "high school challenge" session of which eight authors from high schools participated in. In addition, guest speaker Naoya Nishi, Kyoto University, presented a lecture on his studies on ionic liquid interfaces where he and his group explored the structure, the dynamics, and the functional applications from the electrochemical point of view. Lastly, the awards ceremony for the 106 authors was held during a mixer after the program of which 20 authors were awarded the Kansai-Denki-Kagaku-Shourei-Shou Award.

The event was sponsored by The Electrochemical Society of Japan and co-hosted by the ECS Japan Section; the Graduate School of Engineering, Kyoto University; and by Gijutsu Kyouiku Kenkyukondankai, The Electrochemical Society of Japan. A total of 288 people attended.

Awardees receive the Kansai-Denki-Kagaku-Shourei-Shou Award during the awards ceremony at the student mixer.

Authors participate in a lively discussion with researchers and students from all over the Kansai area during the poster session, held in the foyer of Funai Tetsuro Auditorium.

Section Leadership



Arizona Section – Candace Kay Chan, *Chair*
Brazil Section – Luis F. P. Dick, *Chair*
Canada Section – Bradley Easton, *Chair*
Chicago Section – Alan Zdunek, *Chair*
Chile Section – Jose H. Zagal, *Chair*
China Section – Yong Yao Xia, *Chair*
Cleveland Section – Heidi B. Martin, *Chair*
Detroit Section – Dennis Corrigan, *Chair*
Europe Section – Renata Solarski, *Chair*
Georgia Section – Seung Woo Lee, *Chair*
India Section – Vijayamohanan K. Pillai, *Chair*
Israel Section – Daniel Mandler, *Chair*
Japan Section – Masayoshi Watanabe, *Chair*
Korea Section – Won-Sub Yoon, *Chair*
Mexico Section – Felipe J. Gonzalez Bravo, *Chair*
National Capital Section – Eric D. Wachsman, *Chair*
New England Section – Sanjeev Mukerjee, *Chair*
Pittsburgh Section – Clifford W. Walton, *Chair*
San Francisco Section – Gao Liu, *Chair*
Singapore Section – Alex Yan Qingyu, *Chair*
Taiwan Section – Hsisheng Teng, *Chair*
Texas Section – Jeremy P. Meyers, *Chair*
Twin Cities Section – Vicki Gelling, *Chair*

Awards, Fellowships, Grants

ECS distinguishes outstanding technical achievements in electrochemistry, solid state science and technology, and recognizes exceptional service to the Society through the **Honors & Awards Program**. Recognition opportunities exist in the following categories: Society Awards, Division Awards, Student Awards, and Section Awards.

ECS recognizes that today's emerging scientists are the next generation of leaders in our field and offers competitive **Fellowships** and **Grants** to allow students and young professionals to make discoveries and shape our science long into the future.

See highlights below and visit www.electrochem.org/awards for further information.

Society Awards

The **ECS Carl Wagner Memorial Award** was established in 1980 to recognize mid-career achievement and excellence in research areas of interest of the Society, and significant contributions in the teaching or guidance of students or colleagues in education, industry, or government. The award consists of a silver medal, wall plaque, Society life membership, complimentary meeting registration, and travel assistance of up to $1,000.

Materials are due by October 1, 2020.

The **ECS Olin Palladium Award** was established in 1950 to recognize distinguished contributions to the fields of electrochemical or corrosion science. The award consists of a palladium medal, wall plaque, a $7,500 prize, Society life membership, and complimentary meeting registration.

Materials are due by October 1, 2020.

Division Awards

The **ECS Electronics and Photonics Division Award** was established in 1968 to encourage excellence in electronics research and outstanding technical contribution to the field of electronics science. The award consists of a framed certificate, a $1,500 prize, and the choice between travel assistance of up to $1,000 or Society life membership.

Materials are due by August 1, 2020.

The **ECS Energy Technology Division Research Award** was established in 1992 to encourage excellence in energy-related research. The award consists of framed certificate, a $2,000 prize, and membership in the Energy Technology Division for as long as the recipient is an ECS member.

Materials are due by September 1, 2020.

The **ECS Energy Technology Division Supramaniam Srinivasan Young Investigator Award** was established in 2011 to recognize and reward an outstanding young researcher in the field of energy technology. The award consists of a framed certificate, a $1,000 prize, and complimentary meeting registration.

Materials are due by September 1, 2020.

The **ECS Nanocarbons Division Richard E. Smalley Research Award** was established in 2006 to encourage excellence in fullerenes, nanotubes, and carbon nanostructures research. The award is intended to recognize, in a broad sense, those persons who have made outstanding contributions to the understanding and applications of fullerenes. The award consists of a framed certificate, a $1,000 prize, and assistance up to a maximum of $1,500 to facilitate attendance of the meeting at which the award is to be presented.

Materials are due by October 8, 2020.

The **ECS 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 consists of a framed certificate, a $1,500 prize, and possible travel assistance.

Materials are due by December 15, 2020.

The **ECS Organic and Biological Electrochemistry Division Manuel M. Baizer Award** was established in 1992 and currently recognizes outstanding scientific achievements in the electrochemistry of organics and organometallic compounds, carbon-based polymers and biomass, whether fundamental or applied, and including but not limited to synthesis, mechanistic studies, engineering of processes, electrocatalysis, devices such as sensors, pollution control, and separation/recovery. The award consists of a framed certificate and a $1,000 prize.

Materials are due by January 15, 2021.

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The **ECS Physical and Analytical Electrochemistry Division Max Bredig Award in Molten Salt and Ionic Liquid Chemistry** was established in 1984 to recognize excellence in the field and to stimulate publication of high quality research papers in this area in the *Journal of The Electrochemical Society*. The award consists of a framed certificate and a $1,500 prize. As the award presentation coincides with the International Symposium on Molten Salts and Ionic Liquids, the recipient is required to attend the corresponding Society meeting and present the corresponding lecture.

Materials are due by March 1, 2021.

Student Awards

The **ECS Georgia Section Outstanding Student Achievement Award** was established in 2011 to recognize academic accomplishments in any area of science or engineering in which electrochemical and/or solid state science and technology is the central consideration. The award consists of a $500 prize.

Materials due by August 15, 2020.

The **ECS Energy Technology Division Graduate Student Award sponsored by Bio-Logic** was established in 2012 to recognize promising young engineers and scientists in fields pertaining to this division. The award consists of a framed certificate, a $1,000 prize, complimentary student meeting registration, and complimentary admission to the Energy Technology Division business meeting.

Materials are due by September 1, 2020.

The **ECS Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Award** was established in 1989 to recognize promising young engineers and scientists in the field of electrochemical engineering. The award consists of a framed certificate and a $1,000 prize.

Materials due by September 15, 2020.

The **ECS Industrial Electrochemistry and Electrochemical Engineering Division H. H. Dow Memorial Student Achievement Award** was established in 1990 to recognize promising young engineers and scientists in the field of electrochemical engineering and applied electrochemistry. The award consists of a framed certificate and a $1,000 prize to be used for expenses associated with the recipient's education or research project.

Materials are due by September 15, 2020.

The **ECS 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 master's or PhD work, is open to graduate students who have successfully completed all the requirements for their degrees, as testified to by the students' advisers, within a period of two years prior to the nomination submission deadline.

Materials are due by December 15, 2020.

Section Awards

The **ECS Europe Section Heinz Gerischer Award** was established in 2001 to recognize an individual or a small group of individuals (no more than 3) who have made an outstanding contribution to the science of semiconductor electrochemistry and photoelectrochemistry, including the underlying areas of physical and materials chemistry of significance to this field. The award consists of a framed certificate and 2,000 EUR prize and, if required, financial assistance for unreimbursed travel expenses incurred to receive the award, not to exceed 1,000 EUR.

Materials are due by September 30, 2020.

Awards Winners

In May, ECS will recognize the following award winners at the 237th biannual meeting in Montréal, Canada.

Society Award Winners

Henry B. Linford Award for Distinguished Teaching

Arumugam Manthiram is currently the Cockrell Family Regents Chair in Engineering and Director of the Texas Materials Institute and the Materials Science and Engineering Program at the University of Texas at Austin (UT-Austin). He received his PhD in chemistry from the Indian Institute of Technology Madras in 1981. After working as a postdoctoral researcher at the University of Oxford and at UT-Austin with 2019 Chemistry Nobel Laureate John B. Goodenough, he became a faculty member in the department of mechanical engineering at UT-Austin in 1991. Dr. Manthiram's research is focused on batteries and fuel cells. He has authored more than 770 journal articles with 59,000 citations and an h-index of 122. He has provided research training to more than 250 students and postdoctoral fellows, including the graduation of 60 PhD students and 26 MS students.

Dr. Manthiram is a fellow of Materials Research Society, The Electrochemical Society, American Ceramic Society, Royal Society of Chemistry, American Association for the Advancement of Science, and World Academy of Materials and Manufacturing Engineering. He received the university-wide (one per year) Outstanding Graduate Teaching Award in 2012, Battery Division Research Award from The Electrochemical Society in 2014, Distinguished Alumnus Award of the Indian Institute of Technology Madras in 2015, Billy and Claude R. Hocott Distinguished Centennial Engineering Research Award in 2016, and Da Vinci Award in 2017. He is an elected member of the World Academy of Ceramics. He was a Web of Science Highly Cited Researcher in 2017 and 2018. He served as the chair of the ECS Battery Division from 2010-2012. He founded the UT Austin Student Chapter of ECS in 2006 and continues to serve as the faculty advisor.

Vittorio de Nora Award

Hubert Gasteiger received his PhD in chemical engineering from UC Berkeley (1993), working with Elton Cairns, Phil Ross, and Nenad Marković. After postdoctoral studies at the Lawrence Berkeley National Laboratory with Phil Ross and Nenad Marković (1994–1995) and at Ulm University with Jürgen Behm (1996–1998), he joined the GM/Opel fuel cell program (Honeoye Falls, NY) as technical manager (1999–2007), leading the development of catalysts and membrane electrode assemblies. In 2009, he was visiting professor at MIT with Prof. Yang Shao-Horn, and in 2010 was appointed chair of technical electrochemistry at the Technical University of Munich (www.tec.ch.tum.de), where his group is developing materials, electrode designs, and diagnostics for PEM fuel cells/electrolyzers and for lithium ion batteries. He has published 202 refereed articles (h-index 74 from Web of Science), 15 book chapters, 38 patent applications/patents, and served as editor-in-chief for Wiley's *Handbook of Fuel Cells* (2003, 2009).

In 2004, he received the Klaus-Jürgen Vetter Award of the International Society of Electrochemistry and was promoted to technical fellow at General Motors. He became an ECS Fellow in 2011, and in 2012, he received the Grove Award. More recently, he received the ECS Grahame Award (2015) and the ECS Energy Technology Division Research Award (2017), and he delivered the 2018 Jacobus van 't Hoff Lecture of the Process Technology Institute at Delft University of Technology. Since 2017, he has been serving on the scientific committee of The Fuel Cells and Hydrogen Joint Undertaking of the European Union.

Division Awards

Electronics and Photonics Division Award

Andrew Steckl is Ohio Eminent Scholar, Gieringer Professor, and Distinguished University Research Professor at the University of Cincinnati in the departments of electrical engineering and computer science, as well as materials science and engineering. Dr. Steckl obtained his BS degree from Princeton University and his MS and PhD degrees from University of Rochester. He is a life fellow of the Institute of Electrical and Electronic Engineering, fellow of the National Academy of Inventors, and fellow of the American Association for the Advancement of Science *"for distinguished contributions to optoelectronics*."

After several years in industrial research and development, Dr. Steckl joined Rensselaer Polytechnic Institute in 1976 as a faculty member in the electrical and computer engineering department, where he founded the Center for Integrated Electronics. At the University of Cincinnati since 1988, Steckl's current research interests are in biosensors, microfluidic lab-on-chip devices, and electrospinning of complex nanofibers and related membrane chem/bio/med applications. To date, Prof. Steckl has graduated 47 PhD students and has supervised 13 postdoctoral fellows. Together with his students, he has published ~ 440 papers, which have received over 13,000 citations to date. This has resulted in a current citation h-index of 61. Steckl also has obtained 26 patents on various electronic materials and devices.

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Energy Technology Division Research Award

Paul J. A. Kenis is the Elio E. Tarika endowed chair and a professor of chemical and biomolecular engineering at the University of Illinois at Urbana-Champaign, and an investigator of the International Institute for Carbon-Neutral Energy Research between Kyushu University in Japan and UIUC.

Kenis, a native of the Netherlands, received his BS degree in chemistry from Nijmegen Radboud University, where he worked on model systems for metalloproteins with Roeland Nolte, and his PhD degree in chemical engineering at the University of Twente, working with David Reinhoudt on films for nonlinear optical applications. As a postdoc with George Whitesides at Harvard, he explored the then-emerging area of microfluidics.

At the University of Illinois, Kenis develops microchemical systems with a range of applications: fuel cells, radiolabeling of biomolecules, protein/pharmaceutical crystallization, and platforms for cell biology studies. His recent efforts on CO_2 electroreduction pursue suitable catalysts, electrodes, electrolyzer designs, determining suitable operation conditions, and performing techno-economic analysis as a guide towards more energy efficient systems.

Kenis has authored over 200 publications and holds 14 patents. He was elected an ECS Fellow in 2019. Kenis previously has been recognized with a 3M Young Faculty Award, a NSF CAREER award, a Xerox award, and best paper awards from AICHE and SEBM. He also is a co-author of reports on the prospects of CO_2 utilization at scale issued by the National Academies, as well as the global Mission Innovation consortium.

Energy Technology Division Supramaniam Srinivasan Young Investigator Award

Christopher Hahn completed his doctorate in chemistry at the University of California Berkeley in 2012, where he studied bandgap engineering of 1-dimensional nitride and oxynitride materials for solar water splitting. After receiving his PhD, he conducted his postdoctoral research on catalyst discovery for electrochemical CO_2 reduction at Stanford University within the SUNCAT Center for Interface Science and Catalysis. He began his current position as an associate staff scientist at SLAC National Accelerator Laboratory in 2015, where he is conducting research on the intersection between the fields of heterogeneous catalysis and organic electrosynthesis.

Nanocarbons Division Robert C. Haddon Research Award

Andreas Hirsch received his PhD in 1990 from the University of Tübingen. From 1990 to 1991, he was a postdoctoral fellow at the Institute for Polymers and Organic Solids in Santa Barbara, CA in the group of Prof. Wudl. He subsequently returned to Tübingen as a research associate at the Institute for Organic Chemistry. Upon receiving his Dr Habilitus in 1994, for which he was honored with a variety of prizes and awards, he joined the chemistry faculty at the University of Karlsruhe as a professor of organic chemistry. Since October 1995, he has been chairing full professor of organic chemistry at the University of Erlangen-Nürnberg. He is coordinator of the Graduate School Molecular Science, the Interdisciplinary Center for Molecular Materials, and the Collaborative Research Center "Synthetic Carbon Allotropes" (SFB 953) in Erlangen. In 2006, he received the Elhuyar-Goldschmidt-Prize of the Spanish and German Chemical Societies. In 2010, he received an ERC Advanced Grant. In 2017, he became an elected member of the "Bayerische Akademie der Wissenschaften" and received a second ERC Advanced Grant. Hirsch's laboratory has been pioneering and is at the forefront of carbon allotrope chemistry and is well known for the investigations of basic principles for the functionalization of the 0-dimensional fullerenes, the 1-dimensional carbon nanotubes and the 2-dimensional graphene, which lead to synthesis of numerous examples of derivatives with tailor made structural, electronic, photophysical, and biomedical properties. These studies are also extended to new 2D-materials, including black phosphorus and transition metal dichalcogenides.

Nanocarbons SES Research Young Investigator Award

Markita Landry is an assistant professor in the department of chemical and biomolecular engineering at the University of California, Berkeley. She received a BS in chemistry, and a BA in physics from the University of North Carolina at Chapel Hill, a PhD in chemical physics, and a Certificate in Business Administration from the University of Illinois at Urbana-Champaign, and completed an NSF postdoctoral fellowship in chemical engineering at the Massachusetts Institute of Technology.

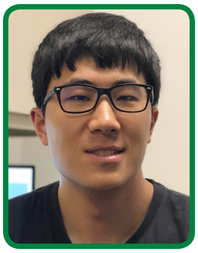
Her current research centers on the development of synthetic nanoparticle-polymer conjugates for imaging neuromodulation in the brain, and for the delivery of genetic materials into plants for plant biotechnology applications. The Landry lab exploits the highly tunable chemical and physical properties of nanomaterials for the creation of bio-mimetic structures, molecular imaging, and plant genome editing. She also is on the scientific advisory board of Terramera, Inc. She is a recent recipient of early career awards from the Brain and Behavior Research Foundation, the Burroughs Wellcome Fund, The Parkinson's Disease Foundation, the DARPA Young Investigator program, the Beckman Young Investigator program, the Howard Hughes Medical Institute, is a Sloan Research Fellow, an FFAR New Innovator, and is a Chan-Zuckerberg Biohub Investigator.

Student Awards

Energy Technology Division Graduate Student Award sponsored by Bio-Logic

Lisa M. Housel is currently a fifth year PhD candidate in chemistry at Stony Brook University, under the mentorship of Dr. Esther S. Takeuchi, Dr. Kenneth J. Takeuchi, and Dr. Amy C. Marschilok. She received her BS in chemistry and economics at Muhlenberg College. Housel's graduate research aims to understand the impact of charge transport properties on the structural change and electrochemistry of different battery materials. Specifically, synchrotron-based operando methods have enabled Housel to probe structural and chemical changes of battery materials during electrochemical reduction and oxidation. Housel's graduate work has resulted in over 20 publications, many of which are in the *Journal of The Electrochemical Society*.

Industrial Electrochemistry and Electrochemical Engineering Division H. H. Dow Memorial Student Achievement Award



Zhongyang Wang earned his doctorate degree from the energy, environmental, and chemical engineering department at Washington University (St. Louis, MO) in 2019. In his research, he focuses on understanding and improving the alkaline stability of anion exchange membranes with applications in flow batteries, alkaline membrane fuel cells, and direct borohydride fuel cells.

He has led the development of direct borohydride fuel cells by devising a bipolar junction with an anion-exchange-membrane-containing electrode placed adjacent to a cation exchange membrane separator. Using this architecture, Zhongyang was able to perform the respective electrochemical reactions at their ideal (significantly disparate) pH. He demonstrated (through fundamental electrochemical and morphological studies) that the bipolar junction was capable of maintaining a very sharp pH gradient of about 0.82 pH unit/nm. This work was published in *Nature Energy* and has had significant impact with multiple offers of collaboration based on this paper from groups worldwide.

Zhongyang now is a postdoctoral scholar at the University of Chicago under the supervision of Prof. Paul Nealey from Pritzker School of Molecular Engineering. He is working on phase behavior and electronic transport in self-assembling conjugated copolymers.

Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Award

Saket Bhargava graduated with his BE (Hons) in chemical engineering from the Birla Institute of Technology and Science (Pilani) in May 2015. After completing his undergraduate studies, he worked for two years with Royal Dutch Shell at their technology center in India as a process technologist for propylene oxide derivatives. In fall 2017, Saket started his graduate studies at the University of Illinois at Urbana-Champaign and joined Prof. Kenis's research group, where he works on using flow electrolyzers to develop system-level process intensification approaches and study the effects of intensified process conditions on the activity, selectivity, and energy efficiency for CO_2 electroreduction to value-added chemicals.

NEW MEMBERS

Member Spotlight

Dominik P. J. Barz

Associate Professor
Department of Chemical Engineering
Queen's University
Kingston, Ontario, Canada

"A logical sequence of my new research in electrochemical engineering was to become an ECS member. I felt it was the most important professional association representing the interests of researchers in electrochemical science and technology. I think the main advantage as an ECS member is access to the large network of people sharing similar backgrounds and interests. There is a great opportunity to connect and exchange ideas and to learn about new developments."

Daniel A. McCurry

Assistant Professor of Chemistry
Department of Chemistry and Biochemistry
Bloomsburg University of Pennsylvania
Bloomsburg, PA, USA

"I joined ECS to become a part of the greater electrochemical community. There are many networking and funding opportunities available within ECS that are specific to my area of research. The most valuable member benefit is access to the ECS Digital Library. As a professor at a primarily undergraduate institution, we don't have the ability to subscribe to as many journals as much larger, research-oriented institutions."

ECS is proud to announce the following new members for October, November, and December 2019.
(Members are listed alphabetically by family/last name.)

Members

A

Ahn, Hyo-Jun, Jinju, Gyeongsangnam-do, South Korea
Almalki, Hind, Makkah, Mekka, Saudi Arabia
Andrew, Trisha, Amherst, MA, USA
Ankeney, Scott, Ann Arbor, MI, USA

B

Barz, Dominik, Kingston, ON, Canada
Battochio, Brock, Ottawa, ON, Canada
Belletti, Andrew, Vancouver, BC, Canada
Bose, Ranjith, Abu Dhabi, Abu Dhabi, UAE
Brick, Chad, Morrisville, PA, USA
Buratti, Marco, San Giuliano Milanese, Milano, Italy
Burger, Daniel, Cartersville, GA, USA

C

Cabaniss, Joseph, Bessemer City, NC, USA
Cao, Ben, Boston, MA, USA
Cao, Yu, Allen, TX, USA
Cheng, Mark Ming-Cheng, Tuscaloosa, AL, USA

D

Daly, Ronan, Cambridge, Cambridgeshire, UK
Deshpande, Mandar, Somerset, NJ, USA
Dick, Jeffrey, Chapel Hill, NC, USA
Dinh, Cao Thang, Kingston, ON, Canada

E

Efstathiadis, Harry, Albany, NY, USA

F

Foulger, Stephen, Anderson, SC, USA

G

Godin, Antoine, Quebec, QC, Canada
Goodwin, Brandon, Atlanta, GA, USA
Grau, Gerd, North York, ON, Canada
Gunji, Takao, Yokohama, Kanagawa, Japan

H

Hatton, Peter, Warrington, Cheshire, UK
Hauser, Adam, Tuscaloosa, AL, USA
He, Jie, Storrs Mansfield, CT, USA
Heist, Christopher, Atlanta, GA, USA
Henry, Charles, Fort Collins, CO, USA
Hilty, Robert, Walpole, MA, USA
Ho, YunLung, Taoyuan, Taoyuan City, Taiwan
Hodgen, Scott, Somerville, AL, USA
Hwa, Yoon, Walnut Creek, CA, USA

I

Isaev, Alexander, Vienna, Vienna, Austria

J

Jang, Ji-Hyun, Ulsan, Gyeonggi Province, South Korea
Janyasupab, Metini, Ladkrabang, Bangkok, Thailand
Jeong, Kyeong-Min, Ulsan, South Gyeongsang Province, South Korea

K

Keithley, Richard, Salem, VA, USA
Kim, SangBum, Seoul, Gyeonggi Province, South Korea
Kim, Sangil, Chicago, IL, USA
Klinkova, Anna, Waterloo, ON, Canada
Kodama, Manabu, Meguro-ku, Tokyo, Japan
Kubicsko, Michael, Medford, NY, USA

L

Lee, Jack, Wuhan, Hubei, China
Lee, Jiyoul, Busan, South Gyeongsang Province, South Korea
Li, Deyang, Eau Claire, WI, USA
Li, Weiyang, Bow, NH, USA
Liu, Anmin, Panjin, Liaoning, China
Liu, Tianbiao, Logan, UT, USA
Liu, Xiaohua, Mountain View, CA, USA
Lu, Jingyu, Cambridge, Cambridge, UK
Luo, Jiye, Guangzhou, Guangdong, China

M

Majumdar, Diptarka, Cumming, GA, USA
McCurry, Daniel, Bloomsburg, PA, USA
McGuire, Tim, Long Beach, CA, USA
McPeak, Kevin, Baton Rouge, LA, USA
Merl, Norbert, Meerbusch, Nordheim Westfale, Germany
Micek, Robert, Buffalo Grove, IL, USA
Morgan, Eman, El-Mokattam, Cairo, Egypt
Mul, Guido, Enschede, Overijssel, Netherlands
Musgrave, Charles, Boulder, CO, USA
Muy, Sokseiha, Cambridge, MA, USA

NEW MEMBERS

N

Nale, Angeloclaudio, Padova, Veneto, Italy
Neagu, Dragos, Newcastle, UK, UK
Nestoridi, Maria, Noordwijk, South Holland, Netherlands
Ngo, Ken, Golden, CO, USA
Nilsson, Bruno, Vero Beach, FL, USA
Nonnenmann, Stephen, Amherst, MA, USA

P

Patnaik, Sai, Toulouse, Auvergne-Rhone-Alpes, France
Pederson, Stephen, Columbia, MO, USA
Perez, Tzayam, Guanajuato, Guanajuato, Mexico
Peters, Vanessa, Livermore, CA, USA

R

Raty, Jean-Yves, Sart-Tilman, Liege, Belgium
Ren, Xuefeng, Dalian, Liaoning, China

S

Sakaue, Tomohiro, Otsu, Shiga, Japan
Sanhueza Chavez, Carlos, Jamaica, NY, USA
Sathrum, Aaron, San Diego, CA, USA
Schindelholz, Mara, Albuquerque, NM, USA
Suram, Santosh, Los Altos, CA, USA
Susantyoko, Rahmat Agung, Dubai, AD, UAE
Svoboda, Vojtech, Atlanta, GA, USA

T

Takayama, Tsutomu, Chiyoda-ku, Tokyo, Japan
Thomas, Joshua, Independence, OH, USA
Tomioka, Katsuhiro, Sapporo, Hokkaido, Japan

V

Vasiliev, Igor, Las Cruces, NM, USA
Vepsalainen, Mikko, Clayton South, Victoria, Australia

W

Wang, Yuxing, Dayton, OH, USA
Wetterman, TL, Woodside, CA, USA
Wong, Danny, Sydney, New South Wales, Australia

Y

Yang, Chenhui, Xi'an, Shaanxi Province, China
Yang, Li, Morrisville, PA, USA
Yoo, Seung, Gwangju, South Jeolia Province, South Korea
Young, Sheng-Joue, Yunlin, Hsinchu County, Taiwan
Yuwono, Jodie, Maroubra, New South Wales, Australia

Z

Zago, Matteo, Milano, Lombardia, Italy
Zhang, Minghao, San Diego, CA, USA

Student Members

A

Adamu, Mohammed, Leeds, West Yorkshire, UK
Aghili, Mohammad, Montréal, QC, Canada
Alofari, Karrar, Houghton, MI, USA
Alvarez-Hernandez, Jose, Rochester, NY, USA
Anari, Zahra, Fayetteville, AR, USA
Andrews, Justin, College Station, TX, USA
Ante, Mirko, Bamberg, Bavaria, Germany

B

Balaghi, S. Esmael, Zurich, ZH, Switzerland
Baumer, Christoph, Steinbach-Hallenberg, Thuringia, Germany
Bell, Crystal, Atlanta, GA, USA
Benavente, Fabian, Stockholm, Stockholm, Sweden
Bhardwaj, Abhishek, New Delhi, DL, India
Bimashofer, Gesara, Villigen PSI, AG, Switzerland
Boryczka, Jennifer, Morgantown, WV, USA
Bozal-Ginesta, Carlota, London, London, UK
Bublitz, Raphaela, Muenchen, Bavaria, Germany

C

Charry, Simon, Tallahassee, FL, USA
Chauhan, Piyush, Villigen-PSI, AG, Switzerland
Chen, Weikun, Potsdam, NY, USA
Chen, Zhaoyang, Houston, TX, USA
Chiquero Ovejero, Andrees, Madid, Madrid, Spain
Chubachi, Satoshi, Yonezawa, Yamagata, Japan
Cleary, Timothy, State College, PA, USA
Cornwell, Casey, Los Angeles, CA, USA
Culum, Nina, London, ON, Canada
Cumberbatch, Helen, Los Angeles, CA, USA
Czachor, MIchal, Pontypridd, Wales, UK

D

Dailey, Daniel, Paris, KY, USA
Darbar, Devendrasinh, Oak Ridge, TN, USA
Das, Ashis, Ecublens, VD, Switzerland
De Wild, Tym, Villigen, Aargau, Switzerland
Deich, Tobias, Munich, Bavaria, Germany
Diklic, Natasa, Villigen PSI, AG, Switzerland
Duchene, Leo, Zürich, ZH, Switzerland

E

Ebner, Kathrin, Villigen-PSI, Aargau, Switzerland
Esen, Ekin, Munster, Nordheim Westfale, Germany

F

Fakhruddin, Siti Masturah, Sendai Taihaku, Miyagi, Japan
Fathi Tovini, Mohammad, Munich, Bavaria, Germany
Frascatore, Dominic, Potsdam, NY, USA

G

G, Tamilselvi, Chennai, TN, India
Gainza Martin, Javier, Madrid, Madrid, Spain
Garbe, Steffen, Villigen-PSI, Aargau, Switzerland
Garcia-Miranda, Alejandro, Manchester, Greater Manchester, UK
Garg, Sahil, St Lucia, Queensland, Australia
Gautam, Prakalp, Hsinchu City, Hsinchu County, Taiwan
Gonzalez, Miguel, Atlanta, GA, USA
Graham, Mackenzie, Tallahassee, FL, USA
Grohmann, Lukas, Landshut, Bavaria, Germany
Gunasekera, Disni, Detroit, MI, USA
Gutierrez-Portocarrero, Salvador, Sparks, NV, USA

H

Hano, Yuta, Takamatsu, Kagawa, Japan
Hansen, Henrik, Trondheim, Trondelag, Norway
Hasdin, Ornapsorn, London, England, UK
Hewa Rahinduwage, **Chathuranga Chinthana**, Detroit, MI, USA
Hogrefe, Christin, Ulm, Baden-Wuerttemberg, Germany
Hsueh, Wu, Hsinchu City, Hsinchu County, Taiwan
Hu, Jie, Lowell, MA, USA
Huang, Hung Wen, New Taipei City, Taipei, Taiwan
Hussein, Walaa, Cairo, Cairo, Egypt

I

Ighodalo, Kester, Hefei, Anhui, China
Indrizzi, Luca, Villigen PSI, AG, Switzerland
Ingelsson, Markus, Calgary, AB, Canada

J

Jabbari, Vahid, Chicago, IL, USA
Jess, Alexander, Gainesville, FL, USA
Jha, Sauraj, Richardson, TX, USA
John, Elsa, Crissier, VD, Switzerland
Josifovska, Katarina, Karlsruhe, Baden-Wuerttemberg, Germany

K

Kabbinahithlu, Gautham, Hsinchu, Hsinchu County, Taiwan
Kaiwa, Haruka, Yonezawa, Yamagata, Japan
Kakar, Akshay, Houston, TX, USA
Kim, Samuel, Atlanta, GA, USA

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NEW MEMBERS

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Kimura, Junya, Yonezawa, Yamagata, Japan
Kirtania, Sharadindu Gopal, Vancouver, WA, USA
Koprek, Miriam, Memmingen, Bavaria, Germany
Kornherr, Matthias, Garching, Bavaria, Germany
Kothalawala, Nadeesha, Lexington, KY, USA
Kudo, Hana, Yonezawa, Yamagata, Japan

L

Lai, Hoong Lien, Hsinchu City, Hsinchu County, Taiwan
Lai, Yi-Fong, Hsinchu, Hsinchu County, Taiwan
Lawandi, Hashim, Jalingo, Taraba, Nigeria
Lee, Bong Han, Fort Worth, TX, USA
Lei, Huai-Yu, Hsinchu, Hsinchu County, Taiwan
Lei, Qi, Baton Rouge, LA, USA
Lewis, Tyra, Peterborough, ON, Canada
Li, Changlong, Clemson, SC, USA
Li, Ke, Baton Rouge, LA, USA
Li, Zhenglong, Newark, NJ, USA
Licini, Andrew, Albuquerque, NM, USA
Lin, Po-En, Hsinchu City, Hsinchu County, Taiwan
Liu, Daohua, Detroit, MI, USA
Liu, Rongli, Los Angeles, CA, USA
Lopez, Edgar Clyde, Manila, Metro Man, Philippines
Lucero, Gisella, Ilmenau, Thuringia, Germany

M

Macko, Rastislav, Humenne, Presov Region, Slovakia
Mankovsky, Denis, Montréal, QC, Canada
Marquis, Scott, Oxford, Oxfordshire, UK
Mauth, Dario, Unterführing, Bavaria, Germany
Mazzetti, Joe, Los Angeles, CA, USA
Mirolo, Marta, Villigen - PSI, Aargau, Switzerland
Mosquera, Nerly, Medellin, Antioquia, Colombia
Mukaiyama, Daisaku, Nagoya, Aichi, Japan

N

Naik, Keerti, Kumta, KA, India
Narita, Kai, Pasadena, CA, USA
Nguyen, Dieu, Houston, TX, USA
Nißler, Robert, Goettingen, Lower Saxony, Germany

O

Obute, James, Lexington, KY, USA
Okada, Shiyori, Yonezawa, Yamagata, Japan
Okuno, Ryota, Ikoma, Nara, Japan
Ortiz, Axel, Canovanas, PR, USA
Overhoff, Gerrit, Munster, Nordheim Westfale, Germany

P

Park, Junsung, Troy, NY, USA
Patel, Mahendra, Sion, VS, Switzerland
Pena, Armando, San Juan, PR, USA
Perner, Verena, Muenster, Nordheim Westfale, Germany

Q

Qian, Simon, Hirschaid, Bavaria, Germany
Qiang, Zhe, Hattiesburg, MS, USA

R

Raciti, David, Gaithersburg, MD, USA
Radloff, Sonja, Ulm, Badem-Wuerttemberg, Germany
Ranweera, Ruchiranga, Detroit, MI, USA
Rehman, Abd Ur, Potsdam, NY, USA
Reta, Tadesse Billo, Taipei, Taiwan, Taiwan
Rivas, Jerome, Tallahassee, FL, USA
Rodrigo, Sachini, Detroit, MI, USA
Rodrigo, Undugodage Nuwanthi, Kingston, RI, USA

S

Sagar, Anand, Faridabad, HR, India
Salamat, Charlene, Los Angeles, CA, USA
Sanchez Ahijon, Elena, Alcorca, Madrid, Spain
Saraswat, Mohit, Stillwater, OK, USA
Schroeter, Jonas, Ulm, Badem-Wuerttemberg, Germany
Schuler, Tobias, Villigen, AG, Switzerland
Shaji, Ishamol, Muenster, Nordheim Westfale, Germany
Sharma, Gyan, Kanpur, UP, India
Siddiqui, Muhammad, Shenyang, Liaoning, China
Singh, Mayanglambam, Vidya Vihar, RJ, India
Sipowicz, Robert, Houston, TX, USA
Spittle, Stephanie, Knoxville, TN, USA
Sultana, Ruhi, Fayetteville, AR, USA
Sundaramoorthy, Santhoshkumar, Rolla, MO, USA
Sung, Cheng-Han, Hsinchu City, Hsinchu County, Taiwan
Suthar, Gajendra Madanlal, Hsinchu City, Hsinchu County, Taiwan
Suzuki, Toru, Yonezawa, Yamagata, Japan

T

Talebkeikhah, Farzaneh, Lausanne, Vaud, Switzerland
Tani, Yurika, Yonezawa, Kanagawa, Japan
Tavakoli, Elham, Lincoln, NE, USA
Turcheniuk, Kostiantyn, Atlanta, GA, USA

U

Usman, Bashir, Manchester, Greater Manchester, UK
Usubelli, Camille, San Jose, CA, USA

V

Vema, Sundeep, Cambridge, Cambridgeshire, UK

W

Wallace, William, Peterborough, ON, Canada
Wang, Chenxiang, Los Angeles, CA, USA
Wang, Yuchen, Philadelphia, PA, USA
Whiddon, Elizabeth, Baton Rouge, LA, USA
Wilson, Evan, Atlanta, GA, USA
Winter, Eric, Untersiggenthal, Aargau, Switzerland
Wizner, Agnieszka, Miñano, Álava, Spain
Workman, Maniell, Lexington, KY, USA

X

Xiao, Albert, Oxford, Oxfordshire, UK
Xie, Shun-Yu, Hsinchu, Hsinchu County, Taiwan
Xin, Huang, Yonezawa, Yamagata, Japan
Xiu, Zhaohong, Shanghai, Shanghai, China
Xu, Zed, Atlanta, GA, USA

Y

Yamaguchi, Hiroto, Yonezawa, Yamagata, Japan
Yang, Ren-Yung, Miaoli City, Miaoli County, Taiwan
Yang, Yung Fang, Hsinchu, Hsinchu County, Taiwan
Yeu, Tsai, Hsinchu City, Hsinchu County, Taiwan
Yu, Weilai, Pasadena, CA, USA

Z

Zhang, Manlin, Montréal, QC, Canada
Zhao, Rui, Ottawa, ON, Canada
Zheng, Hongzhi, Houston, TX, USA
Zheng, Zhaohan, Verdun, QC, Canada
Zimmermann, Pauline, Trondheim, Trondelag, Norway
Zlobinski, Mateusz, Villigen, Aargau, Switzerland

American University in Cairo Student Chapter

The second workshop of the **ECS American University in Cairo (AUC) Student Chapter**, "Energy Conversion and Storage in Our Daily Life: Research and Technology," took place on Sunday, January 12, 2020, at the AUC campus. ECS American University in Cairo Student Chapter President Taher El-Najjar introduced the ECS organization and student chapter board members to the audience. Under the supervision of Ehab El-Sawy, Department of Chemistry at AUC, the board members invited six speakers from various research institutes with different electrochemistry-based specialties.

The first two talks were given by Aiat Hegazy, Department of Solar Energy, and Hala Handal, Department of Inorganic Chemistry, at the National Research Center on dye-sensitized solar cells and solid oxide fuel cells.

The talks were then followed by Ahmed Abdelmoneim, Basic and Applied Sciences Institute in Egypt-Japan University of Science and Technology, who spoke about the use of graphene in supercapacitors, electrochemical sensors, and capacitive deionization. El-Sawy discussed catalysis in low-temperature fuel cells. Nageh Allam, Department of Physics at AUC, delivered an interesting talk on water splitting. Lastly, Mostafa Youssef, Department of Mechanical Engineering at AUC, expanded the audience's theoretical background in computational chemistry by presenting his work on charged defects in metal oxides and their application in water splitting.

Attendees included doctors, early career researchers, and undergraduate students from AUC and other universities in Cairo. Discussions were informative and encouraging, as attendees were able to ask questions, receive feedback, and exchange ideas.

Overall, the diversity of the talks, interactive discussions, and networking opportunities led to a successful workshop, made possible with the help of volunteers and ECS student members.

A group picture of the day's event, including the ECS American University in Cairo Student Chapter committee, volunteers, and some of the invited speakers and attendees.
Photo: Abdelrahman Khalid

Clarkson University Student Chapter

Founded in 2019, the **ECS Clarkson University Student Chapter** has an interdisciplinary, enthusiastic group of chemistry, physics, chemical engineering, materials science engineering, civil engineering, and environmental engineering students and faculty members.

Wanting to initiate an ECS student chapter at Clarkson University, ECS Clarkson University Student Chapter President Farideh H. Narouei and ECS Clarkson University Student Chapter Vice President Cheng Wang held a social event in June of 2019 to introduce fellow students and supportive faculty to the idea. More

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ECS Clarkson University Student Chapter members and advisors with **Prof. Zamborini.**

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than 20 people from various departments attended the introductory meeting to discuss the chapter's goal to bring together a diverse group of students, faculty, and research groups from Clarkson University and other universities in the northern New York region. The chapter received support and encouragement from faculty in the field of electrochemistry at Clarkson University, including Evgeny Katz, Silvana Andreescu, and Elizabeth Podlaha-Murphy.

At its first event, the ECS Clarkson University Student Chapter introduced and organized an electrochemistry component of Clarkson University's annual Research and Project Showcase (RAPS) conference in August 2019. Students from several departments presented talks covering a wide range of electrochemistry topics, including metal-organic frameworks, electrochemical biosensors, and lithium-ion batteries. They also exchanged ideas on the latest research developments. This electrochemistry session was chaired by Narouei and judged by one of ECS Clarkson University Student Chapter faculty advisors, Taeyoung Kim. An information table was made available during the poster sessions to introduce their student chapter to a broader audience. The benefits and career opportunities available to members of The Electrochemical Society were highlighted, and games with prizes were held to attract interest and attention. At the end of the RAPS conference, Narouei delivered a talk introducing the chapter to the Clarkson University community, encouraging membership, and announcing game winners.

During the fall semester of 2019, the chapter organized two invited talks. The first talk held on October 4, 2019 was presented by Francis Zamborini from the University of Louisville. He discussed "Measuring the Size, Size Stability, Aggregation, and Unique Reactivity of Metal Nanoparticles by Anodic Stripping Voltammetry." The invited talk fostered connections across many areas of research. An audience of over 30 students and faculty members participated in Zamborini's presentation and raised interesting questions, which led to a fruitful discussion before the close of the seminar. The second talk, "Electrochemical Detection and Monitoring of Bacterial Infections," presented by Edgar D. Goluch of Northeastern University, was held on October 24, 2019. After the seminar, Goluch enjoyed lunch with student chapter members. The students discussed their research, and each received useful suggestions and feedback from Goluch. Finally, he met with student chapter advisors from the Departments of Chemical Engineering and Chemistry for discussion and sharing of research.

ECS Clarkson University Student Chapter members and advisors with **Prof. Goluch.**
Photo: Steve Jacobs/Clarkson University

Complutense University of Madrid Student Chapter

The **ECS Complutense University of Madrid Student Chapter** organized the second edition of the annual competition "Brain Wars: The Future is in Your Hands." This event was held on October 18, 2019 at Complutense University of Madrid, Spain. More than 30 young scientists presented their research results with oral and poster contributions and explained how their investigations contribute to science and society. Taking into account that the United Nations General Assembly proclaimed 2019 as the International Year of the Periodic Table of Chemical Elements, the conferences and posters presented in the contest emphasized the periodic table of chemical elements as one of the major achievements in science.

Professor Bernardo Herradón, president of the Madrid Section of the Spanish Royal Society of Chemistry, and Mónica Peñas Caballero, winner of the first edition of this contest, gave invited talks, titled "Priorities' Wars in the Discovery of Chemical Elements: The Role of Women in the Development of Periodic Table" and "Current Development in the Field of Self-Healing Polymer Systems," respectively. Tanja Holzknecht and Elisabet Alfonso were awarded with the best oral presentations. In the poster section, the winners were Amira Ben Hassine and Jaime Dolado.

The ECS student chapter also commemorated the International Year of the Periodic Table of Chemical Elements with the celebration of a Chocolate Xmas meeting, taking place in the faculty of chemistry sciences of the university, where a sculpture of the three elements—V, W, and Pt—discovered by Spanish scientists, were inaugurated. In this event, the members of our student chapter discussed science while enjoying a typical Spanish breakfast: chocolate and churros. The success of these events has attracted new members to the student chapter.

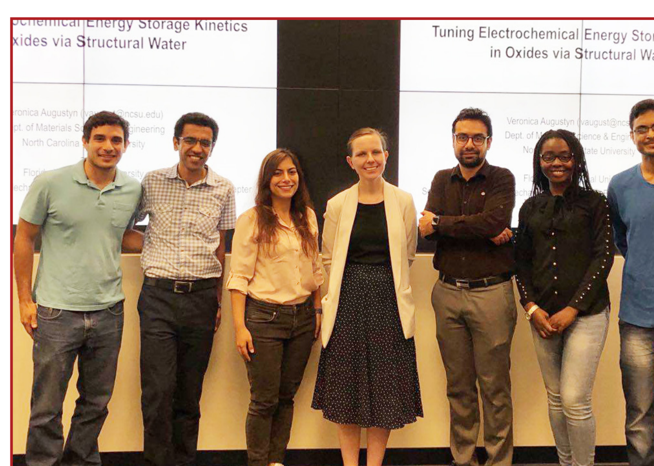
The prize ceremony for "Brain Wars: The Future is in Your Hands."
Photo: Elena Sanchez Ahijon

Florida International University Student Chapter

The **ECS Florida International University (FIU) Student Chapter** participated in several electrochemistry-related activities during the 2019 year, the second year since its founding.

In March 2019, the chapter held a guest speaker seminar featuring Prof. John Rogers from Northwestern University. Rogers visited the campus on March 29, and gave a seminar on "Soft Electronic and Microfluidic Systems for the Skin." Rogers, one of the pioneering people in the field of bio-integrated electronics, discussed the latest results in the field of electrochemistry. The event was attended by faculty members and students from the College of Engineering and Applied Science at FIU.

In April, the ECS Florida International University Student Chapter hosted one more seminar with the Department of Mechanical and Materials Engineering at FIU. Veronica Augustyn from North Carolina State University visited FIU. Her seminar discussed "Tuning Electrochemical Energy Storage Kinetics in Oxides via Structural Water." During her visit, members of the student chapter had a friendly meeting with her to discuss possible future activities for the student chapter. In May, five members of the ECS student chapter presented their research at the 235th ECS Meeting in Dallas, Texas. Before the end of 2019, the chapter also hosted Prof. Akahiro Kushima from the University of Central Florida. He discussed the latest method of in-situ TEM analysis of energy storage devices.



Attendees and members of the ECS Florida International University (FIU) Student Chapter. Left to right: **Carlos Vargas, Iman Khakpour, Shahrzad Forouzanfar, Prof. Veronica Augustyn, Amin Rabiei Baboukani, Chiamaka Okafor,** and **Santanu Mondal.**
Photos: Amin Rabiei

Attendees and members of the ECS Florida International University (FIU) Student Chapter. Left to right: **Ahmed Jalal, Fahmida Alam, Shervin Tashakori, Prof. Charlie Lin, Iman Khakpour, Shahrzad Forouzanfar, Omena Okpowe, Amin Rabiei Baboukani, Prof. John Rogers, Prof. Chunlei Wang, Elnaz Mirtaheri, Maedeh Mozneb,** *and* **Lin Tong.**

Georgia Institute of Technology Student Chapter

On August 19, 2019, the **ECS Georgia Institute of Technology Student Chapter** led a group of students and hosted an exhibit table at Saint Philip's career resource ministry's 12th Annual Science, Technology, Engineering, Mathematics, and Service (STEMS) Career Fair for lower, middle, and high school students, with a particular focus on underrepresented and minority students in the Atlanta metropolitan area. The event hosted 50 exhibitors and 300-plus students in all grades. The focus was on hands-on activities. The team provided STEMS related educational information and products for STEMS career information to share with parents.

During the engagement day tabling fair at Georgia Institute of Technology on September 3, 2019—hosted by the student government association and the center for student engagement—the ECS student chapter had the opportunity to reach out to students about the events and services the chapter provides throughout the year.

On September 27, 2019, the ECS student chapter held a kickoff event to learn about their new members and their exciting electrochemistry-related work, as well as revisit their current members. The kickoff event brought in approximately 13 people. This included graduate and undergraduate students from various schools within, including chemical and biomolecular engineering, biology, chemistry, and mechanical engineering. Attendees introduced themselves, discussed their diverse research interests, and the labs in which they work. The event lasted for approximately one hour.

On September 27, 2019, the ECS Georgia Section and the ECS Georgia Institute of Technology Student Chapter co-hosted the local conference at the Georgia Institute of Technology. The meeting

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Undergraduate, graduate students, postdocs, and faculty participated at the 2019 ECS Georgia local conference co-hosted by the ECS Georgia Section and ECS Georgia Institute of Technology Student Chapter.
Photo: Mohammadreza Nazemi

was organized by Mohammadreza Nazemi, Paul Kohl, and Seung Woo Lee. The event was initiated with a reception and an invited seminar entitled "Opportunities and Fundamental Challenges for the Development and Deployment of Anion Exchange Membrane Fuel Cells" given by William E. Mustain, Department of Chemical Engineering professor at the University of South Carolina. It was followed by a group lunch and a student poster session. Three student poster awards were presented at the award ceremony: in first place Jung (Zhengyuan) Fang, Georgia Tech; in second place Garrett Huang, Georgia Tech; and in third place Marc R. Papakyriakou, Georgia Tech.

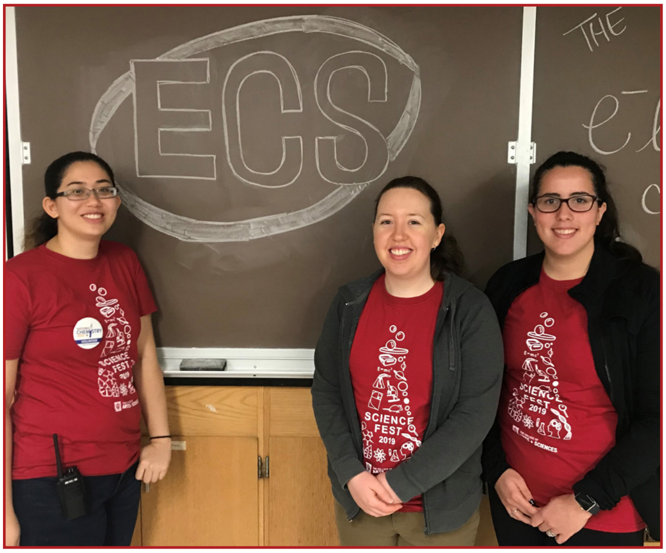
The ECS Georgia Institute of Technology Student Chapter participated as a demonstration team for the Hands On Future Tech 2019 (Future Tech) middle school STEM outreach event, which was held on Saturday, October 26, 2019, at Georgia Tech's Molecular Science & Engineering (MoSE) building. Future Tech was open to all middle school students, and the program was targeted toward underserved and underrepresented middle school students. The event for student participants included laboratory tours, demonstrations in engineering, chemistry, biology, robotics, and other related areas.

On December 13, 2019, the ECS student chapter held an end of the year social. Both current members and interested students at Georgia Tech attended and enjoyed pizza after finals. Students were able to connect with members of other labs on campus and share the exciting research they have been working on this year, while relaxing after finishing their academic semester. Students were particularly interested in the events planned for next year, which include Electrochemistry Jeopardy and visiting Oak Ridge National Laboratory in Oak Ridge, Tennessee.

Indiana University Student Chapter

Students of the **ECS Indiana University (IU) Student Chapter** have continued to promote The Electrochemical Society this year on the Bloomington campus. On October 26, 2019, the student chapter led a chemistry room to demonstrate electrochemical science at the largest outreach event at Indiana University, Science Fest. Demonstrations and hands-on experiments followed the theme "Marvelous Metals." Members set up a demonstration of oxidation state and color change through reduction and oxidation of the complex nickel(II)/nickel(I) salen. This well studied complex is often used as a catalyst for the reduction of halogenated organic compounds. In its oxidized state, a solution of nickel(II) salen is orange, but when the complex gets reduced, the solution changes to a distinct green color. Other experiments conducted at Science Fest included electroplating of copper metal onto a nickel rod, cathodic protection of iron nails with magnesium strips, and galvanic cells.

In addition to community outreach, on October 21, the student chapter had its annual officer election, which brought in new members and new officers to the group. On December 13, the chapter hosted a breakfast at the department of chemistry to celebrate the end of another successful semester and promote our student chapter and its mission. The chapter is grateful for the opportunities that ECS provides in meeting with accomplished and enthusiastic speakers, and is eagerly looking forward to planning future events.



Indiana University student chapter members (left to right) **Kelly Rudman, Natasha Siepser,** *and* **Ana Flávia Petro** *help to organize an electrochemistry-themed room at Science Fest 2019.*
Photo: Benjamin Petro

Norwegian University of Science and Technology Student Chapter

On September 13, 2019, the **ECS Norwegian University of Science and Technology Student Chapter** held its annual election for the new student chapter officers. The elected chapter officers consist of Frode Håskjold Fagerli as president, Faranak Foroughi as vice president, Yash Dharmendra Raka as treasurer, and Henrik Erring Hansen as secretary. Since then, the officers have had several meetings where they have planned various events, as well as discussed possible ways to expand the student chapter at the given university.

On November 7, 2019, a kickoff meeting took place, where student chapter members gathered. At the meeting, Foroughi informed attendees of what the ECS student chapter has to offer and presented some of the work being done at the university. After the presentation, pizza was served, and participants were encouraged to discuss the best ways to reach out to other electrochemistry related groups at the university and how to recruit more students to the chapter. Several inputs and ideas were given by the participants, which was later followed up by the officers.

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Newly elected student chapter officers (from left to right): **Henrik Erring Hansen**, *secretary;* **Faranak Foroughi**, *vice president;* **Frode Håskjold Fagerli**, *president; and* **Yash Dharmendra Raka**, *treasurer.*
Photo: Frode Håskjold Fagerli

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Student chapter officers have made it their goal to reach out to more students at the university and expand its relatively small student chapter throughout the upcoming year. Together, with better promotion within their own groups as well, student chapter officers hope to make the annual electrochemistry group seminar in the spring an event with more participants than ever before. The student chapter looks forward to an exciting year in 2020.

Ulm Student Chapter

The 2019 year was a busy and successful one for the young **ECS Ulm Student Chapter**. The chapter kicked off the year with a fireplace chat alongside former faculty advisor Werner Tillmetz. Tillmetz told members and several guests about his career and his personal experiences working on the development of the fuel cell—from aerospace to automobile application in industry and applied research. He also offered attendees some personal insight to the question, "What makes innovations successful?"

In July, the ECS student chapter co-hosted a summer BBQ at the Helmholtz Institute Ulm to further increase the chapter's high profile at the three main institutes in the field of electrochemistry in Ulm: Center for Solar Energy and Hydrogen Research (ZSW), Helmholtz Institute Ulm (HIU), and Ulm University. After a presentation by Rolf Schäfer, managing director of WBZU, on knowledge transfer between science and handicraft, ECS Ulm Student Chapter President Nicola Jobst introduced the chapter to the audience. This presentation was followed by a talk by Sylvain Brimaud, postdoc at ZSW, on surface techniques for the determination of the structural and electronic effects in electrocatalysis on an atomic level. After the talks, guests gathered for BBQ and drinks and engaged in conversation.

In September, a delegation of the student chapter attended the symposium "Interdisciplinarity in Electrochemistry" hosted by the ECS Munich Student Chapter. The symposium covered inspiring talks regarding fuel cells, electrolyzers, and batteries. The event also served as a networking platform between fellow students and presenters.

In October, the elite of battery research met in Ulm for the Advanced Lithium Batteries for Automobile Applications – ABAA 12 conference. On the arrival day of the conference, the Ulm student chapter organized lab tours through the labs of HIU, the pilot production line at ZSW, and the safety testing at ZSW, consisting of approximately 70 participants. With this in mind, guests gathered in the hotel for a social evening event. Equipped with food and drinks, attendees grouped together to answer and discuss some semi-serious questions of the Ulm student chapter's battery quiz. During the intense discussions, the attendees bonded, making the event a successful kickoff to the ABAA 12 conference.

As a highlight of the conference, the announcement of 2019 Nobel Chemistry Prize Laureates coincided with the plenary lecture given by Stanley Whittingham. The announcement by Professor Petr Novak and the standing ovations for Professor Stanley Whittingham were a moment to remember.

In November, the student chapter visited the fuel cell group of the Bosch Corporate Research Center in Renningen, Germany. After a kind introduction to the organization and activities of the corporate research at Bosch, student chapter members were able

2019 Nobel Chemistry Prize Laureate **Stanley Whittingham** *poses with a few members of the ECS Ulm Student Chapter at the ABAA 12 conference. From left to right:* **Marilena Mancini**, **Christin Hogrefe**, **Thomas Waldmann**, **Nina Zensen**, **Lukas Schick**, **Verena Müller**, **Stanley Whittingham**, **Lea Kremer**, **Karsten Richter**, *and* **Sonja Radloff**.
Photo: Lukas Schick

to see the testing and development labs of solid oxide fuel cells and polymer electrolyte membrane fuel cells, as well as the large materials surface labs.

In December, parts of the student chapter followed an invitation by Jörg Huslage and his group, Volkswagen AG, to visit the new Center of Excellence for battery research in Salzgitter, Germany. During a tour through the battery pilot line, student chapter members were able to witness the impressive push towards the development and production of electric vehicles in Germany by Volkswagen AG. After the tour, student chapter members were able to introduce the ECS student chapter and present some of their scientific work to Jörg Huslage and his team. The day was topped off by a tour through the component production site of Volkswagen in Salzgitter.

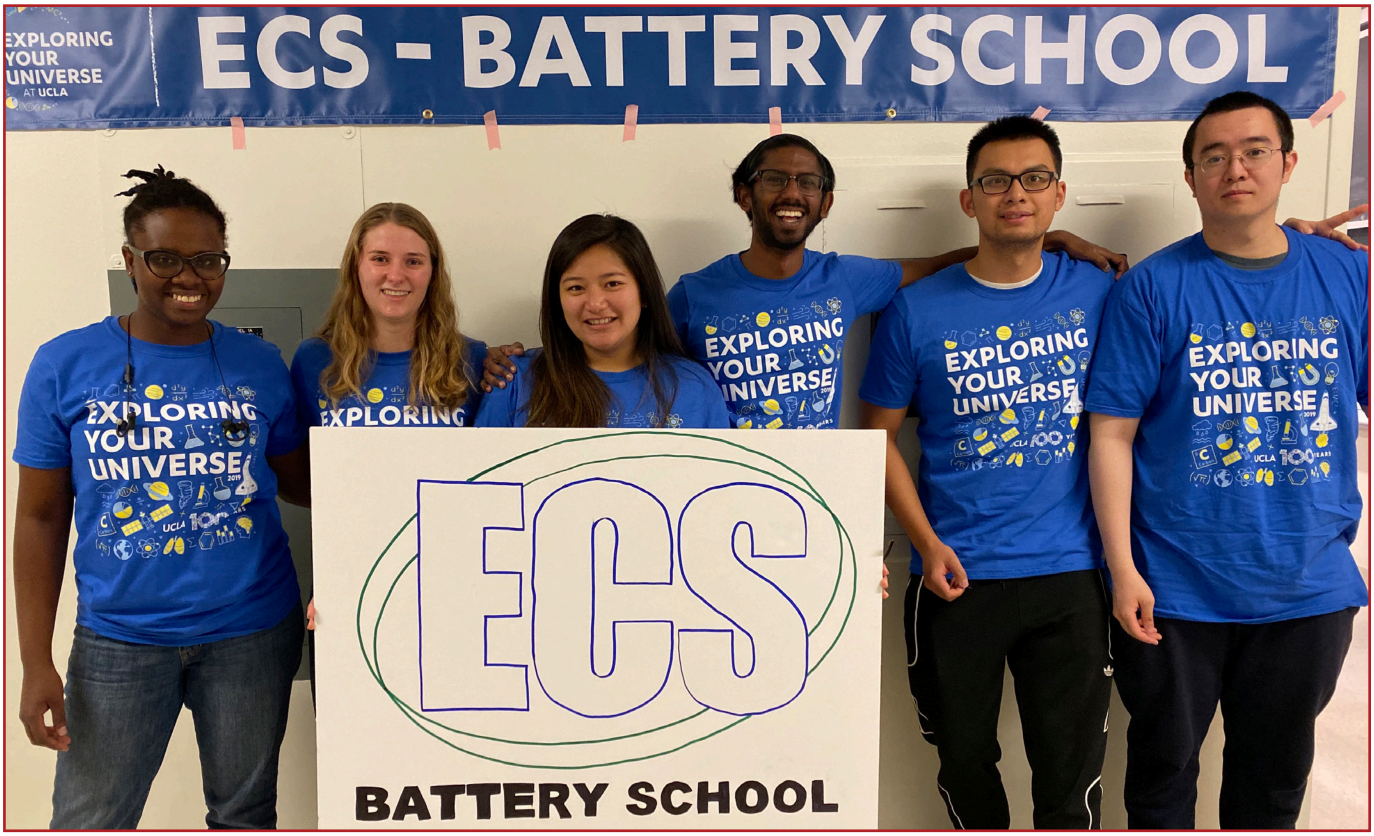
During the 2019 year, the ECS Ulm Student Chapter grew from eight to 15 members, representing all three main institutions in Ulm working in the field of electrochemistry, and therefore, continuing to connect young researchers in the area of Ulm to one another.

For the 2020 year, the student chapter will continue to organize events and get-togethers for colleagues and followers to increase their impact on the science of electrochemistry and society.

University of California Los Angeles (UCLA) Student Chapter

The **ECS University of California Los Angeles (UCLA) Student Chapter** held its annual Exploring Your Universe event, the largest science outreach event on campus. Thousands of children and parents from the Los Angeles community participated in a fun, interactive day full of hands-on science experiments and presentations from all subfields of science.

At the event, the UCLA student chapter held its annual ECS Battery School Booth where children were shown how to build batteries using common household items—vinegar, paper towels, pennies, and aluminum foil—and how to integrate their homemade battery into a complete light-emitting diode (LED) circuit using graphite pencils as an electron conductor.



Members of the ECS UCLA Student Chapter attend the Exploring Your Universe event. Left to right: **Sophia King, Tori Basile, Charlene Salamat, Andrew Dawson, Guangyan Zhong,** *and* **Dan Zhu**.
Photo: Grace Wang

University of Maryland (UMD) Student Chapter

The **ECS University of Maryland (UMD) Student Chapter** held several events throughout the fall semester, hosting interactive sessions with visiting speakers at the university and engaging with the community through K-12 outreach.

On October 18, 2019, the chapter hosted a breakfast with Arumugam Manthiram from the University of Texas at Austin. Members of the chapter discussed their research with Manthiram, exchanging ideas on a wide range of topics, such as multivalent batteries and phase transitions in oxide cathodes during cycling. Students were excited to learn Manthiram's perspective on careers in academia and his take on how to pursue high-impact research.

The chapter hosted a meet-and-greet lunch with senior scientist Nancy Dudney from Oak Ridge National Laboratory (ORNL) on November 22, 2019. Students asked Dudney several questions in the meeting, including the process of her discovery and further investigation of the solid electrolyte LiPON, and her viewpoint on the future of solid state batteries. Dudney also discussed her experience as a senior scientist and her life at ORNL.

Both events were a huge success. The chapter is grateful to ECS, the Department of Materials Science and Engineering, and the Clark School of Engineering at UMD for making the events possible.

Finally, the chapter continued its ongoing collaboration with Adventure in Science (AIS), a weekend STEM outreach program partnered with the National Institute of Standards and Technology. Chapter member Adelaide Nolan led a discussion on batteries and electrochemistry concepts with local sixth and seventh grade students at an AIS event on December 7, 2019. Students built lemon batteries using Zn and Cu foil and connected several batteries in series to light a light emitting diode (LED). The chapter plans to present another lesson and demonstration on electroplating in February 2020.

Members of the ECS University of Maryland Student Chapter at the discussion with **Arumugam Manthiram** *(seated at center table).*

University of South Carolina Student Chapter

The **ECS University of South Carolina Student Chapter** had a busy fall 2019 semester. The chapter hosted its first annual University of South Carolina Electrochemical Student Symposium. The chapter also launched the University of South Carolina ECS Speaker Series. Moreover, the chapter hosted industry and national lab visitors that offered students a new perspective on various career paths. The new programs have significantly increased the visibility of the ECS student chapter, which added over 10 students and representation from two more University of South Carolina departments.

The University of South Carolina Electrochemical Student Symposium was hosted on October 4, 2019. The multidisciplinary nature of the symposium brought a wide variety of topics in the form of both poster and oral presentations. Mike Brizes and Pongsarun Satjaritanun presented their computational fluid dynamics (CFD) model-based research to understand porous structures used in electrochemical systems. Mitch Sepe showed the development of an experimental apparatus to measure the Macmullin Number of electrochemical porous structures. Brenna Parke and Colby Witt shared their research based on in-situ electrochemical measurements of Serotonin and Dopamine. Hailey Boyer and Kris Likit-Anurak presented a CFD model of a solid oxide electrolyzer cell and the effects of catalysts on oxidation of HCl in an electrolyzer, respectively. Ehsan Faegh illustrated his investigation of corrosion and charge/discharge behavior of preferentially faceted zinc particles for battery applications. In addition, Laura Murdock provided a summary of her research and development of enhanced polybenzimidazoles for use in electrochemical devices.

The symposium-improved awareness of electrochemical research being conducted all around the University of South Carolina campus and helped to draw more connections between departments. The symposium also proved to be an excellent setting for constructive criticism before the 236th ECS Meeting in Atlanta, Georgia. Professors and students in attendance were able to learn from and contribute to an effort for better research and communication within the chapter.

The University of South Carolina ECS Speaker Series ran through the fall semester of 2019 and included several field-leading electrochemistry professionals from academia, the Department of Energy, and industry. The speaker series focused on sharing research, as well as experiences and opinions on varying career paths. Julie Renner of Case Western Reserve University presented her recent work on engineered proteins for use as ionomer control in electrode engineering and engaged the ECS student chapter to discuss her experience as a young faculty member. After the ECS conference, John Newman visited the campus to present his recent work developing a new theory of turbulence and joined the University of South Carolina Chapter for lunch. Paul Kohl also visited and presented his recent work on membrane engineering to increase the mobility of conductive ions—with application to both Li-ion batteries and ionic exchange membrane fuel cells.

The ECS student chapter also hosted brief career-based seminars with a Q&A portion with Mohan Karulkar from Sandia National Lab and Julie Renner. The focus of these sessions were job prospects in industry and in the national labs and to compare and contrast those experiences with academia. They were also able to provide new points of reference for strengthening resumes and the best ways to engage with their organizations as students move towards graduation—including the possibility for on-site research experiences during a PhD.

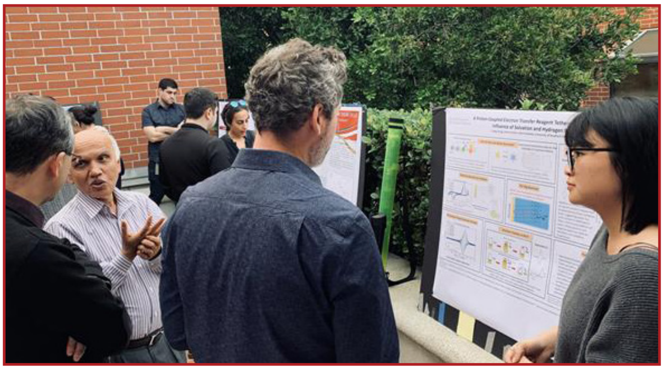
Mohan Karulkar *from Sandia National Lab discusses his experiences at Ford Motor Company and Sandia National Laboratory with the ECS University of South Carolina Student Chapter.*
Photos: William E. Mustain/Drew Pereira

Members of the ECS University of South Carolina Student Chapter and Faculty Advisor **William Mustain** *gather for a photo at the University of South Carolina Electrochemical Student Symposium.*

University of Southern California (USC) Student Chapter

The **ECS University of Southern California (USC) Student Chapter** hosted their first poster competition on Friday, December 13, 2019. Students from various departments engaged in conversations with each other and judges about their research on energy storage, batteries, spectroelectrochemistry, and materials improvement.

Earlier in the semester, the student chapter voted on events to host in the upcoming year, including an Electrochemistry Journal Club and E-waste Competition. Members of the chapter are looking forward to hosting more events in 2020.



*Poster presenter **Cindy Tseng** shares research on organic batteries to invited professors. Left to right: **Jahan Dawlaty**, **Surya Prakash**, and **Michael Inkpen**.*
Photo: Billal Zayat

University of Washington (UW) Student Chapter

The **ECS University of Washington (UW) Student Chapter** had a fruitful year filled with outreach and educational and professional development activities. They continued the tradition of a summer book series with students, taking turns to lead weekly coffee-fueled discussions based on chapters from the book *Electrochemical Engineering* by Thomas F. Fuller and John N. Harb. Throughout the school year, the chapter also held biweekly journal club meetings where students read and reviewed selected editor's choice *Journal of The Electrochemical Society* articles.

Beyond UW, the student chapter also engaged the greater Seattle and Washington state community in several outreach activities. Enginearrings is the highlight of the year where they highlight a titanium anodization experiment to create a rainbow effect on titanium wire. Student member show their creative side by crafting 600 pairs of earrings out of the wire to give to fourth through eighth grade students at the UW Discovery Days. Other organized activities included a hand battery demo at the Interactive Enumclaw Expo and a classroom visit to a local high school AP chemistry class, where the students learned about applications of electrochemistry.

To help students develop their professional skills and connections, the chapter also organized a Clean Energy Industry Panel in collaboration with the student organization Diversity in Clean Energy (DICE). They invited six speakers with backgrounds in cleantech, public utilities, and energy storage. The event was split into two panels focused on starting cleantech careers and energy infrastructures, with plenty of networking time after for the undergraduate, graduate, and postdoc attendees.

The Clean Energy Industry Panel at the University of Washington.

University of Western Ontario Student Chapter

The **ECS University of Western Ontario Student Chapter** hosted its third annual student research symposium. The symposium, designed to give young researchers a platform to discuss new research findings and problems, as well as to connect them to local companies performing similar research, was an overwhelming success. In addition to the support provided by The Electrochemical Society, the symposium was supported by the Chemical Institute of Canada, Surface Science Division.

Over 45 students attended the symposium with presentation topics, including Li-ion batteries, light-emitting devices, long-term disposal of nuclear waste, and the corrosion of different commercial alloys. This included 14 presentations given by student chapter members. Between talks, as well as during the provided coffee and lunch breaks, members engaged in discussion and connected with other student researchers from around campus.

In addition to student speakers, the symposium featured two invited lectures, one from Sridhar Ramamurthy, a senior research scientist at Surface Science Western (SSW), and the other from Erin Azzopardi, a director of business development at Mitacs.

Ramamurthy discussed the recent upgrades SSW has received and how they can be applied to members' research in a talk titled "Surface Science 2.0." The new capabilities of SSW's instruments were presented, including confocal laser scanning microscopy (CSLM), X-ray micro computed tomography (micro-CT), field effect scanning electron microscopy (FESEM), Auger electron spectroscopy (AES), and laser Raman spectroscopy. Additionally, Ramamurthy discussed real-world solutions to research problems encountered, including some examples of work conducted at SSW by chapter members. SSW continues to play an integral role in research problems across Southwestern Ontario. Following Ramamurthy's lecture, students had the chance to engage in discussion with Ramamurthy during an extended question period, as well as during the coffee break.

To further highlight opportunities for professional connections, Erin Azzopardi presented "Mitacs: Delivering Innovation Through Research, Development and Training." Azzopardi discussed how Mitacs fosters connections between academia and industry through financially supporting industry-related research endeavors. She examined how ECS members can be incorporated into industrial research solutions to provide members with professional connections and skills for their future.

Overall, the symposium provided members a chance to engage with scientists across campus, opportunities for their professional development, as well as analytical solutions to their research problems. The chapter looks forward to the continued development of this symposium in the years to come.

The chapter's executive team would like to acknowledge Chemical Institute of Canada, Surface Science Division for their financial support; SSW and Sridhar Ramamurthy for his lecture; Mitacs and Erin Azzopardi for her lecture; Shannon Reed at ECS for his continued support; and Jamie Noël at the University of Western Ontario for his guidance.

Attendees of the third annual ECS student research symposium.
Photo: Jeffrey Daniel Henderson

Yamagata University Student Chapter

The **ECS Yamagata University Student Chapter** successfully held their seventh ECS Yamagata University Student Chapter Symposium on December 17, 2019, at Yamagata University. The student chapter invited three guest speakers: Klaus Meerholz from The University of Cologne, Germany; Xia Long from Peking University, Shenzhen Graduate School, China; and Lina Sun of the Innovation Center for Organic Electronics (INOEL) of Yamagata University, Japan.

Meerholz presented "Solution-Processed Organic Semiconductors and their Applications." Student chapter members learned about organic semiconductors from their basics to applications. An especially new and interesting topic covered was "organic memories" employing photochemical isomerization to achieve write/erase by wavelength of light.

Long's presented "Rational Design and Synthesis of Efficient Transition Metals Based Catalysts for Hydrogen Production via Water Splitting." Various strategies were developed and tested to obtain highly efficient catalysts for water splitting and also CO_2 reduction, by combination of transition metal compounds.

Sun's presented "Photochemical Solution Processing of High Performance Thin Film Encapsulation for OLED." Low-temperature solution processing of multi-layered, high-performance thin film encapsulation was achieved by using vacuum ultraviolet photochemical sol-gel reaction for realization of low cost, air-stable flexible organic light-emitting diodes.

ECS student chapter members found it helpful that each speaker spoke in English and explained the basics of the study so that they could understand the matters well. Many students asked questions and a lively discussion was held.

The ECS Yamagata University Student Chapter is planning a joint symposium with the ECS Montréal Student Chapter for the occasion of the 237th ECS Meeting with the 18th International Meeting on Chemical Sensors (IMCS 2020) in Montréal, Canada. The international symposium between two ECS students chapters of the two different countries is the first for the ECS Yamagata University Student Chapter. They hope to establish a friendship and partnership by presenting each other's research work.

The upcoming eighth symposium is planned for June 5, 2020. The chapter will invite Matthew White of the University of Vermont, USA, whose work entails investigating nonlinear processes in optoelectronic devices and exploring materials physics for low-cost and high-performance photovoltaics. Several students will also be coming to Yamagata University from the United States as interns for the International Research Experience for Students (IRES) summer program—taking place from June to August 2020—supported by NSF. They also will be talking about their research experiences and introducing themselves at the meeting.

The seventh ECS Yamagata University Student Chapter Symposium.

2019 Division Travel Grants

ECS Biannual Meeting Travel Grants provide funds for undergraduate, graduate, postdoc students, and young professionals and faculty to travel to ECS biannual meetings to present their research. Travel grants are materially important—making it financially possible for some applicants to attend who could not otherwise afford the travel. They also demonstrate to early career scientists that their work is important, and their presence at ECS meetings is valued.

In 2019, 13 ECS divisions received almost 350 applications to attend the 235th and 236th ECS Meetings. A total of $70,510 was awarded to 149 applicants.

Battery Division

Battery Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	43	11	26
236th ECS Meeting	48	13	27
TOTAL	**91**	**24**	**26**

"The most beneficial part of the 236th ECS Meeting was talking to other researchers since that helped me get job interviews. I met two researchers who work for two different companies and interviewed with each of the companies after that. I did get offers as a result."

Rochelle Weber
Dalhousie University
Traveled from Halifax, NS, Canada

"Having the chance to present my work at the 236th ECS Meeting, represent my institution, and meet experts and peers from my field was surely an exciting experience. I met a few significant people in my field, Nobel Laureate Stanley Whittingham for one."

Khryslyn Guzman Arano
Deakin University
Traveled from Melbourne, Australia

Corrosion Division

Corrosion Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	4	1	25
236th ECS Meeting	6	3	50
TOTAL	**10**	**4**	**40**

"As a PhD student at the 235th ECS Meeting, exchanging ideas and studying the latest research results with experts and scholars broadened my horizons. It benefited me a lot, giving new direction to my work and research."

Tongming Cui
Shanghai University
Traveled from Shanghai, China

"Financial support for graduate student travel at my university is limited. Students have to be selective about which venues to visit. My work is related to the electrochemistry of corrosion, and it was very useful to learn at the 236th ECS Meeting how research is progressing worldwide."

Samanbar Permeh
Florida International University
Traveled from Miami, FL, USA

Dielectric Science and Technology Division

Dielectric Science and Technology Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	2	2	100
236th ECS Meeting	3	3	100
TOTAL	**5**	**5**	**100**

"While I could have attended without the grant, it helped a lot in a motivational way. I traveled from Slovenia, and this, the 236th ECS Meeting, was my first large international meeting. I met new people, learned new things at various lectures, and gained new experiences."

Martin Košiček
Josef Stefan International Post Graduate School
Traveled from Ljubljana, Slovenia

Electrodeposition Division

Electrodeposition Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	3	3	100
236th ECS Meeting	12	7	58
TOTAL	**15**	**10**	**67**

"Without the financial support of ECS, I would not have been able to attend the meeting. It opened up new perspectives on the topic and gave me the opportunity to exchange ideas with other researchers who are working on this or similar topics."

Steffen Link
Technische Universität Ilmenau
Traveled from Ilmenau, Germany

Electronics and Photonics Division

Electronics and Photonics Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	20	19	95
236th ECS Meeting	8	6	75
TOTAL	**28**	**25**	**89**

"The travel grant allowed me to attend the 236th ECS Meeting without having to worry about finances and see the varying research areas performed around the world. I loved getting the chance to meet new friends and collaborators. It also gave me many ideas about future projects and collaborations."

Chaker Fares
University of Florida
Traveled from Gainesville, FL, USA

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Energy Technology Division

Energy Technology Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	37	6	16
236th ECS Meeting	26	6	23
TOTAL	**63**	**12**	**19**

"I was invited to the Energy Technology Division luncheon with other grant recipients and active members of the field. This was a truly remarkable experience as I met some of the biggest names which I have always been exposed to in my young research career."

Ruben Govinarajan
University of British Columbia
Traveled from Vancouver, BC, Canada

"It was a natural choice for me to apply to the ECS Energy Technology Division as much of my work deals with the development and improvement of electrochemical engineering mathematical models for electrochemical energy sources. Participating in the 236th ECS Meeting, presenting my research for the first time to the ECS community, and interacting with scholars working in the same domain was a wonderful opportunity. I would not have been able to attend without this grant."

Mayur Bonkile
Indian Institute of Technology Bombay
Traveled from Mumbai, India
Photo: Akshaykumar Desai

High-Temperature Energy, Materials, & Processes

High Temperature Energy, Materials, & Processes Metals Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	7	7	100
236th ECS Meeting	5	4	80
TOTAL	**12**	**11**	**91**

"Attending the 235th ECS Meeting opened my eyes to many new strands of electrochemistry research. I was inspired to learn more about the field beyond my research and read papers on a variety of different electrochemical subjects. It taught me how to develop a positive research environment, which can lead to higher quality work. Without this grant, going to the meeting would have been a significant financial burden."

Yvonne Chart
Northwestern University
Traveled from Evanston, IL, USA

"The progress of my work improved greatly after the meeting. I got to know many professors in my field and learned many new things. I could not have attended without the division's support."

Nengneng Xu
University of Louisiana at Lafayette
Traveled from Lafayette, LA, USA

Industrial Electrochemistry and Electrochemical Engineering

Industrial Electrochemistry and Electrochemical Engineering Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	11	5	45
236th ECS Meeting	16	5	31
TOTAL	**27**	**10**	**37**

"Early career scientists like me from outside the U.S. often do not have the budget to attend international conferences annually. Receiving the grant made it possible for me to attend the 236th ECS Meeting in Atlanta. It was very important for me to access a group of well-known scientists in my area and get 'sparks' from their talks. Moreover, I attended many presentations in other areas and got a bigger and general picture of the development of electrochemical engineering and electrochemistry. Thank you!"

Yang Wang, PhD, Assistant Professor
School of Chemical Engineering and Technology
Tianjin University
Traveled from Tianjin, China

Luminescence and Display Materials Division

Luminescence and Display Materials Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	N/A	N/A	N/A
236th ECS Meeting	4	2	50
TOTAL	**4**	**2**	**50**

"I am from Xi'an Jiaotong University in Shaanxi, China, and am currently a visiting scholar at Texas A&M University. Without your assistance, I could not attend the ECS meeting. I benefitted greatly from the meeting. Much research related to mine was presented, which inspired me with new ideas. After my talk, professors gave me advice on how to improve my research. The 235th ECS Meeting was a great experience in my life."

Lingguang Liu
Texas A&M University
Traveled from College Station, TX, USA

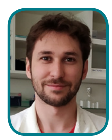
"As a student and first-time attendee, it was both encouraging and exciting to hear from experts in the field of solid state science from all across the globe. The most rewarding part of the meeting was attending the keynote talk by Chemistry Nobel Prize Laureate, M. Stanley Whittingham. I would like to thank ECS again for this wonderful learning opportunity. It would not have been possible had I not received the travel grant."

Abhinav Shukla
Texas A&M University
Traveled from College Station, TX, USA

Nanocarbons Division

Nanocarbons Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	12	11	92
236th ECS Meeting	2	2	100
TOTAL	**14**	**13**	**93**

"The 235th ECS Meeting was a very interesting opportunity to learn about the latest research in my field and the field of nanotechnologies in general and to meet with experts in the field. There were many opportunities for networking, for example, at the opening reception, the student mixer event, and the Nanocarbons Division reception. Some interesting questions during the talks and the poster presentations helped me consider new directions for my research."

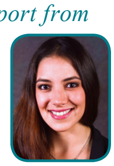


Benjamin Lambert
École polytechnique fédérale de Lausanne
Traveled from Lausanne, Switzerland

"Attending the 236th ECS Meeting at this phase in my graduate career was immensely beneficial—more than I would have predicted. The question and discussion period after talks were valuable because people were very frank about their thought processes. It helps me better frame and critique some of my own research questions."

Lynne LaRochelle Richard
Northeastern University
Traveled from Boston, MA, USA

"I traveled to the 236th ECS Meeting as an undergraduate student. The presentation I gave provided invaluable experience for improving my communication skills. My research work has surely benefited from the insight offered by other attendees and collaborations that were made with other research groups. I could not have attended the conference without financial support from The Electrochemical Society. I am continuing my studies as a graduate student in electrochemistry."



Mariana Martinez Pacheco
Universidad de las Americas Puebla (UDLAP)
Traveled from Puebla, Mexico

Organic and Biological Electrochemistry Division

Organic and Biological Electrochemistry Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	14	7	50
236th ECS Meeting	4	2	50
TOTAL	**18**	**9**	**50**

"Attending the meeting was a truly wonderful experience and invaluable to my research and professional growth. Between going to seminars, poster presentations, and social gatherings, I learned a lot about electrochemistry, electrochemical applications, and met many great people. I was also able to attend the amazing seminar delivered by Prof. Héctor Abruña, in recognition for his Society award."

Ana Flavia Couto Petro
Indiana University
Traveled from Bloomington, IN, USA

"The 235th ECS Meeting was very engaging and informative. I had chances to network with many professionals and learn more about other areas at the seminars. Since the meeting, I am more open to other fields, which helps me to be more creative in my research. While I had the funds to attend the meeting without the travel grant, I might not have been able to attend a short course in electrochemistry and other social networking events."

Natalie (Nuttanit) Pramounmat
Case Western Reserve University
Traveled from Cleveland, OH, USA

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Physical and Analytical Electrochemistry Division

Physical and Analytical Electrochemistry Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	16	7	44
236th ECS Meeting	13	6	46
TOTAL	**29**	**13**	**45**

"The ECS travel grant lifted the burden of financing the trip from my advisor and allowed more of my lab members to attend the conference. In my first talk at a major society conference, I presented my research to colleagues from all over the world. I acted as a session chair, networked with fellow PhD candidates, potential postdoc advisors, and made invaluable connections with my peers. Attending the Physical and Analytical Electrochemistry Division social hour was a fantastic experience."

Charlotte Flatebo
Rice University
Traveled from Houston, TX, USA

"At the 235th ECS Meeting, I saw firsthand the full breadth of electrochemistry beyond the systems I work with. The Physical and Analytical Electrochemistry Division meeting was a window into what a larger involvement in ECS would look like, and allowed me to meet more scientists than I would have normally. I made friends with the other student winners there and at the student social. I saw my direct peers' presentations, contextualizing and personalizing what I consider my subfield."

Travis Schmauss
Northwestern University
Traveled from Evanston, IL, USA

Sensor Division

Sensor Division	Total Applications	Approved	Percent Approved
235th ECS Meeting	18	7	39
236th ECS Meeting	12	4	33
TOTAL	**30**	**11**	**37**

"Without your support, I could only have attended my poster session. The grant allowed me to participate in a fabulous professional development course, the Electrochemistry in Space symposium, lectures, and network at the opening reception and student mixer. The meeting influenced how I think about my work. The people that I spoke to about my research gave me ideas and tips to consider, and it has helped my focus in my research. Thank you!"

Alana MacLachlan
Auburn University
Traveled from Auburn, AL, USA

"Thank you for the wonderful opportunity to join the 235th ECS Meeting, my first conference in the U.S. This was my first major international conference (and first time in Texas) as I am originally from Thailand. Attending this prestigious conference has shaped the future of my career and built up my network as a young professional entering the vast scientific and public communities. This network is an important tool that helps me solve problems and stimulates new thought-provoking questions in my field. This first, impressive conference has given me the opportunity and motivation to support me and my peers' endeavors toward the joint success of our scientific projects."

Itthipon Jeerapan
University of California San Diego
Traveled from San Diego, CA, USA

DID YOU KNOW?

Don't miss out!

The Electrochemical Society offers Section Travel Grants!

EUROPE SECTION

The **Europe Section (ES) of ECS** supports the travel of one or more students (up to four) to each biannual ECS meeting. Applicants for this award must be enrolled in a graduate or upper level undergraduate program at, or be recent (within 12 months) graduates from, an institution in Europe and must give at the meeting an oral or poster presentation. For the 235th ECS Meeting, there were 5 Europe Section applications, 3 of which were approved—a 60% approval rating. None were awarded for the 236th ECS Meeting.

TEXAS SECTION

The **Texas Section of ECS** supports the travel of one or more students to each biannual ECS meeting. Applicants for this award must be enrolled in a graduate or upper-level undergraduate program at an institution in Texas, or have graduated from such an institution within 12 months at the time of the meeting, and must give an oral or poster presentation at the meeting. For the 235th ECS Meeting, there were 6 Texas Section applications, 2 of which were approved—a 33% approval rating. None were awarded for the 236th ECS Meeting.

Those 5 travels grants from the Europe Section and Texas Section for the 235th ECS Meeting totaled $3,385. Don't miss out on these unique travel grants. The next biannual meeting travel grant submission deadline is June 29, 2020. Perhaps a travel grant from one of these sections can help you get to PRiME 2020 in Honolulu, Hawaii.

2019 ECS Institutional Members

The Electrochemical Society values the support of its institutional members. These organizations help ECS support scientific education, sustainability, and innovation. Through ongoing partnerships, ECS will continue to lead as the advocate, guardian, and facilitator of electrochemical and solid state science and technology.

Benefactor

AMETEK-Scientific Instruments (38)
Bio-Logic USA/Bio-Logic SAS (11)
Duracell (62)
Gamry Instruments (12)
Gelest, Inc. (10)
Hydro-Québec (12)
Pine Research Instrumentation (13)

Patron

3M (30)
Energizer (74)
Faraday Technology, Inc. (13)
GE Global Research Center (60)
Lawrence Berkeley National Laboratory (15)
Scribner Associates, Inc. (23)
Toyota Research Institute of North America (11)

Sponsoring

BASi (4)
Central Electrochemical Research Institute (26)
DLR-Institut für Vernetzte Energiesysteme e.V. (11)
EL-CELL GmbH (5)
Ford Motor Corporation (5)
GS Yuasa International Ltd. (39)
Honda R&D Co., Ltd. (12)
Medtronic Inc. (39)
Nissan Motor Co., Ltd. (12)
Panasonic Corporation, AIS Company (25)
Permascand AB (16)
Technic Inc. (23)
Teledyne Energy Systems, Inc. (20)
The Electrosynthesis Company, Inc. (23)
Tianjin Lishen Battery Joint-Stock Co., Ltd. (5)
Yeager Center for Electrochemical Sciences (21)
ZSW (15)

Sustaining

Axiall Corporation (24)
Battery Sciences LLC (1)
General Motors Holdings LLC (67)
Giner, Inc./GES (33)
Hydrogenics Corporation (1)
IBM Corporation Research Center (62)
Ion Power Inc. (5)
Kanto Chemical Co., Inc. (7)
Karlsruher Institut für Technologie (3)
Leclanché SA (34)
Los Alamos National Laboratory (11)
Microsoft Corporation (2)
Occidental Chemical Corporation (77)
Sandia National Laboratories (43)
SanDisk (5)

02/28/2020