Recent development of bio-integrated wearable electronics that provide continuous information,1,2 entertainment,14 help in carrying out routine activities3 are a result of our insatiable desire to develop technologies that make lives easy. The nascent field of body-bound electronics is still in its infancy and there exists several challenges that ought to be addressed for successful adaptation of the technology by various market segments.6–8 Identifying suitable wearable energy sources is one of the biggest omnipresent challenge that cuts across almost all wearable electronics fields.10 The situation is getting further exacerbated as the field of wearable electronics advances toward developing tiny, yet complex, multi-tasking wearable devices that continuously require high levels of energy supply for optimal performance. Research efforts to overcome this issue can be broadly classified into developing low-energy electronics,11 adaptive algorithms for intelligent, low-power consuming electronics12 and high energy density power sources.13 Of these, development of efficient power sources has attained the greatest attention. Usage of conventional power sources, such as, lithium ion and alkaline batteries result in increased bulkiness and rigidity of the wearable electronics wherein just a fraction of the device weight is due to electronics while the rest is because of the battery. Such integration of conventional power sources with wearable electronics thus vitiates the overall attractiveness of the wearable system. Hence, there has been a genuine effort within the scientific community toward developing new formats of power sources for wearable applications. One of the most obvious and widely explored avenues is the development of thin, flexible and even stretchable batteries and supercapacitors that can be easily mated with the human body.15,16 Such body-compliant energy storage systems are quite attractive, nevertheless, low energy capacity, poor discharge current and limited charge-discharge cycles dramatically lower their appeal for wearable applications. These limitations of the wearable energy storage systems have piqued researchers to explore other routes to power wearable devices. In this regard, energy harvesters that exploit the surroundings for various applications. Several reviews discuss the underlying work- ing principle and recent advances in the field of enzymatic biofuel cells.23–25 However, there has been limited discussion on the applications of enzymatic biofuel cells for wearable applications.26 The present perspective article will therefore briefly focus on the recent developments in the wearable biofuel cells field before providing a detailed discussion on major bottlenecks impeding further progress of the field and how these could be addressed.

Recent Advances in Body-Integrated Biofuel Cells: Where Do We Stand Today?

Implantable bio-fuel cells.—Devices, such as pacemakers and implantable cardioverter defibrillators are perfect embodiments of implantable devices that are closely mated with biological tissues for augmenting the quality of human lives. However, at present, lithium batteries are utilized for powering such devices wherein the concern related to battery leakage and the concomitant poisoning is real.29 Bio-compatible biofuel cells that can harvest chemicals naturally present in the human body which transforms chemical energy into usable energy harvesters, batteries and supercapacitors rely on toxic chemicals which pose serious health concerns if directly exposed to the body in an acute or chronic manner. Therefore, a power source constructed out of bio-friendly materials would be ideal for wearable applications. Nature is full of such bio-powerhouses. A very good example would be the human body which transforms chemical energy into usable mechanical energy via complex, multi-step biological processes. Of course, at present, it is impossible to mimic complex biological systems. However, one could exploit simple biomolecules and microbes toward developing energy generating systems. Indeed, such routes have been explored for decades wherein researchers have utilized microbes and enzymes for developing microbial22,23 and enzymatic,24–26 biofuel cells respectively. The anode and cathode of such systems are constructed out of biological entities that help consume a chemical, via natural processes, to generate electricity. Microbial fuel cells have several advantages, such as, multiple oxidoreductase enzymes for complete oxidation of a wide variety of fuels and long-term stability. However, there are several inherent issues with microbial fuel cells that render them unattractive for wearable applications. For example, the active sites of enzymes are buried underneath the thick cell walls of the microbes. This obstructs easy access of the fuel to the enzyme and restricts electron shuttling between the enzyme’s active site and the electrode. Moreover, cytotoxicity of microbes poses health concerns during potential wearable applications. On the other hand, enzymatic bio-fuels are capable to overcome these issues. Therefore, enzyme-based power generating platforms have been widely explored for various applications. Several reviews discuss the underlying working principle and recent advances in the field of enzymatic biofuel cells.25–27 However, there has been limited discussion on the applications of enzymatic biofuel cells for wearable applications.28 The present perspective article will therefore briefly focus on the recent developments in the wearable biofuel cells field before providing a detailed discussion on major bottlenecks impeding further progress of the field and how these could be addressed.
surrounding biofluids to power implantable electronics have the potential to address this issue. Motivation for developing such implantable biofuel cells have been around for decades as detailed in Ref. 22. However, its only recently the field has demonstrated its true potential thanks to the advances in materials science, nano-bioelectronics with promising examples of implantable biofuel cells in rats,31,32 snails,33 cockroaches,34,35 lobsters36 by various groups (Figures 1A–1F). Indeed, with consistent improvements, such systems may one day be used for powering implantable devices in humans. Surgical intervention is a major drawback of implantable systems and hence there is a push toward developing wearable electronics that can be easily worn by the user with minimal or no training. For such wearable applications, the biofuel cells should also be on the same wearable platform for easy integration of the power source with the rest of the system. Keeping this in view, Ramirez et al developed a minimally invasive micro-needle based glucose biofuel cell for harnessing electrical energy from the skin interstitial fluid (Figure 1G). Unlike implantable biofuel cells, these microneedle-based systems can be easily mounted by the user without the need for surgery.

Skin-worn biofuel cells.—Minimally invasive biofuel cells are quite promising, yet the need for the needles to be pierced into the skin increases the possibility of biofouling and skin irritation. These limitations are the underlying motivation for the emerging field of skin-worn biofuel cells. Such skin-worn biofuel cells can be stuck to the human skin, just like a skin patch and unlike microneedles, do not have any protruding features that pierce the skin. These "sit-on-top" biofuel cells are thus very attractive as they minimize skin irritation and biofouling. The field of skin-worn biofuel cells is in its infancy and thus only a handful of demonstrations have been reported.38 One of the most important requirement to successfully use a biofuel cell is to select a fuel that can be provided in sufficient abundance. For skin-worn biofuel cells, the human sweat is an interesting fuel, since it contains a milieu of a rich variety of chemicals that can be potentially used for biofuel cells. Of all the potential candidates, aconitase and lactate dehydrogenase). Wang’s group has been prominently working toward exploiting sweat lactate for generating usable electricity to power wearable systems. In their first demonstration, the group developed a temporary tattoo-based system comprising of carbon nanotubes and lactate oxidase based anode (for sweat lactate oxidation) and platinum black-functionalized cathode (for oxygen reduction).38 The authors reported that their thin tattoo-based biofuel system could easily withstand repeated mechanical deformations without compromising on its performance. Ultimately, the authors applied the tattoo biofuel cells to perspiring human subjects and recorded the power generated by the wearable biofuel cells. The power generated was dependent on subject’s fitness level and the authors reported a power density of up to 70 μW/cm² (Figures 2A, 2B).

An inherent issue with any energy harvesting technique, including biofuel cells, is that the instant energy generated depends on the fuel concentration. However, electronic devices require a constant current supply at a fixed voltage. In addition to this, biofuel cells generate current at much lower voltages than what is required to power commercially available devices. Thus, there is a need for integrating energy management electronics with biofuel cells. In their follow-up work, the Wang group considered these limitations and developed a textile-based biofuel cell which was integrated with a DC/DC converter to boost the output voltage and supply a constant flow of current.39 Using such a device, the researchers demonstrated that wearable biofuel cells could scavenge sweat lactate to power low-energy device, such as, wrist-watch and LED (Figures 2C–2E). Although, such demonstrations highlight the potential of biofuel cells to power wearable electronics, there are several technological challenges that ought to be addressed, as will be discussed in later sections. In addition to skin-worn biofuel cells that harvest energy from their surroundings, some researchers have also devoted their attention toward developing bio-batteries — wherein high concentrations of fuels are sealed within an electrochemical cell comprising of enzyme-based anodes and cathodes (Figures 2F–2I).40–43

Ocular biofuel cells.—There has been a growing interest in developing smart contact lens-based sensors and other ocular devices.44–47 The eye is one of the most complex and delicate organs in the human body. It’s soft nature, spherical shape and confined structure makes the development of contact lens based devices quite difficult. Integrating a reliable power source thus becomes even more challenging for such ocular devices as compared to their epidermal counterparts.
Some groups have demonstrated the viability of RF-based wireless powering of ocular devices.\textsuperscript{3,48,49} Although attractive, the need for a RF receiver to be in close vicinity of the ocular device diminishes the appeal of such an approach. Standalone ocular devices with completely integrated power source would be ideal. In this regard, biofuel cells offer engaging features that can be exploited for powering low-power ocular devices in a bio-friendly manner. Shleev's group recognized the need for such ocular based biofuel cells and were among the first to demonstrate the viability of such systems.\textsuperscript{44} In their works, the researchers have employed enzyme-tethered gold microwires for realizing bioanodes and biocathodes to generate electricity from glucose\textsuperscript{50} and ascorbic acid (Figures 3A, 3B)\textsuperscript{51} present in the tears. Detailed characterization of these systems reveal that biofuel cells generate stable power for several hours in fuel concentrations commonly encountered in tears. The small size of the eye coupled with the low levels of fuels in tears are two major reasons for low power output by ocular biofuel cells. Minteer’s group recently attempted to address this issue by developing a contact lens based biofuel cell that relied on high surface area buckypaper electrodes for generating energy from lactate in tears.\textsuperscript{52} The authors were able to
generate a maximum current and power density of 61.3 mA/cm² and 8.01 μW/cm², respectively with an open circuit voltage of 0.413 V (Figures 3C–3E).

Bottlenecks in Wearable Biofuel Cells Field: Grand Challenges and How to Overcome Them

Akin to any new emerging technology, the field of wearable biofuel cells too is fraught with multiple challenges and the success of the field will ultimately depend on successfully resolving these issues. The major challenges faced by the field can be broadly classified into four domains and the present perspective article will give an overview of these along with possible routes to address them in the following sub-sections.

Biofuel cell stability.—Enzymes are one of the most important components of a biofuel cell. Unfortunately, these are also the most labile constituents. Enzymes easily and rapidly degenerate when exposed to environments with conditions mildly differing from ideal settings. Numerous earlier works have unequivocally reported that factors such as local ionic strength, presence or absence of certain chemicals, humidity, temperature, pH and pressure greatly affect these biomolecules. Denaturation of enzymes deeply affect their biocatalytic ability to consume fuels and generate electricity. High stability of enzymes become increasingly crucial for wearable applications since wearable devices are regularly present in settings characterized by varying temperature, pH, ionic strength, humidity, or pressure. Presently, enzymes are unable to perform optimally in fast changing environments for long durations. For decades, researchers have attempted to develop strategies that can augment the stability of enzymes under harsh conditions. Approaches such as, providing bio-compatible environments by judiciously selecting the enzyme immobilization strategy (Figure 4A),53 incorporating enzyme stabilizers54 (Figure 4B) and even protein engineering55 have been employed to enhance enzyme stability. Researchers could look into such techniques for developing highly stable enzymes for long-lasting wearable biofuel cells. Instead of identifying paths of stabilizing naturally occurring enzymes, researchers could also venture into exploring synthetic enzymes that mimic their natural counterparts sans the stability issues.56 However, it must be pointed out that, at present, the turnover number for such synthetic enzymes is much lower than that of naturally occurring enzymes and much work needs to be undertaken to overcome this limitation.

In addition to the stability of enzymes, stability of mediators, that shuttle electrons between enzyme’s active sites and electrode, also have significant effect on biofuel cell performance. Several redox mediators are environment sensitive and gradually decompose thus leading to poor biofuel performance.58 Apart from natural decomposition, inefficient redox mediator immobilization can lead to its leaching thus further reducing power output of biofuel cells. One could rely on judicious mediator immobilization processes59 or polymeric redox species60 to address this issue. Researchers could also look into completely obviating the need for using mediators by developing biofuel cells that rely on direct electron transfer reactions between the enzyme’s redox site and electrode surface.58,61 This has been possible thanks to the advances in the field of nanotechnology which have resulted in the development of nanomaterials that are small enough to easily reach the active sites of enzymes and provide efficient electrical nano-pathways between the site and electrode. By depending on biofuel cells that permit direct electron transfer one can also circumvent other issues associated with mediators, such as, toxicity and reduction in open circuit voltage. However, it must be pointed out that direct electron transfer based biofuel cells usually generate lower power densities as compared to their mediator-based counterparts, mainly due to slower electron transfer kinetics. Thus, efforts must be directed toward developing new class of electrode materials that permit direct electron transfer without diminishing power output.

Supply of constant power for long durations.—Almost all electronic devices require a supply of constant current at fixed voltage for

Figure 3. Ocular biofuel cells. (A) Schematic illustrating the potential use of biofuel cells to power contact-lens based glucose sensor. (B) Typical power density plots for miniature BFC operating in a microcell containing (1) human basal tears, (2) buffer with 0.5 mM ascorbate, and (3) buffer. (C) Image and (D) scheme showing components and electrode reactions for a lactate-based ocular biofuel cell. (E) Biofuel cell polarization and power curves scanned at 1 mV/s in tear solution at 35 °C. (Reproduced with permission from Refs. 51, 52.)
optimal performance. Satisfying these conditions by biofuel cells is challenging since the power output of the biofuel cells depends on the presence of the fuel. The concentration of commonly present fuels, such as, lactate, glucose, ascorbic acid etc in biofluids, for example, tears, sweat, blood depend on several physiological parameters and thus keep constantly changing. Such transient fuel concentrations have deleterious effect on the ability of wearable biofuel cells to generate constant power. Furthermore, for almost all the reported biofuel cells, the voltage at which usable power can be extracted is much lower than what is required to power routine electronic items. Thus, efforts must be made toward developing innovative techniques that address the issue of constant power supply.

Researchers could look into different possible strategies to overcome the challenge of constant fuel supply for the wearable biofuel cells. One possible route could be the reliance on wearable microfluidic systems that can store biofluids and regulate constant flow of fuel to the biofuel cells. Researchers could also explore the development of bio-batteries that get regularly replenished by biofluids. Several groups have demonstrated refuelable (Figure 5A) and rechargeable (Figure 5B) bio-batteries. One could take inspiration from such works toward addressing the issue of constant power supply. It is important that researchers do not limit themselves to only wearable biofuel cells to power wearable electronics. In several scenarios, the fuel concentration can be extremely low to produce any significant levels of power. Such cases would mandate researchers to combine wearable biofuel cells with other forms of energy harvesting platforms to supply constant power to electronic devices. In addition to this, researchers would have to integrate energy storage systems, such as wearable supercapacitors, to store the power generated by various energy harvesting systems and then supply the desired power to energize electronics. Such integration of energy harvesting and storage techniques is crucial for real-life applications of wearable biofuel cells. Although such seamless integration is necessary, not much has been done in this regard and researchers must pay utmost importance to this. Apart from constant current supply, there is also a need to improve the current levels generated by biofuel cells. Innovations in the field of nano-materials for developing new genres of catalytic surfaces must be exploited toward developing high power biofuel cells.

Conformability and mechanical resiliency.—A requirement that is unique to wearable biofuel cells is conformability and mechanical resiliency. Biological tissues are soft, delicate, have complex three dimensional morphologies and exhibit unique stress-strain curve. However, conventional biofuel cells are fabricated using rigid electrode materials which possess mechanical properties quite different from biological tissues. Such mismatch between the device material and target biological tissue has deleterious effect on the performance of the biofuel cell as well as cause irritation to the tissues. It thus becomes imperative that the wearable biofuel cells too possess mechanical properties similar to the target biological species. This is crucial for achieving conformal device contact and for minimizing somatosensory response by the target tissue. Furthermore, the human tissues, such as skin, regularly undergo complex, three dimensional deformations during routine body movements. Wearable biofuel cells must be able to withstand such deformations without letting such harsh mechanical stress affect their performance.

Presently reported wearable biofuel cells have addressed this issue by developing the energy harvesters on thin flexible tattoo paper, textiles and polymeric substrates. The flexible nature of these biofuel cells is certainly more acceptable than using conventional rigid electrodes. However, the mechanical properties of these flexible substrates still don’t perfectly match with that of the human tissues. In this regard, soft, stretchable elastomers could be of great use. Phenomenal developments have been reported in the realization of soft stretchable bio-integrated electronics in the recent past. Broadly, these skin-like devices have been fabricated by routes that either rely on deterministically stretchable (Figures 6A, 6B) or random composite (Figures 6C–6E) systems. Recently, Wang’s group demonstrated...
Figure 5. Refuelable and rechargeable bio-batteries. (A) Schematic showing an example of refuelable bio-battery and galvanostatic measurements at the anode with fuel exchanged every 5 min. (B) Pictorial illustration of a rechargeable bio-battery. (Reproduced with permission from Refs. 62, 63.)

Figure 6. Stretchable electronics. (A, B) Images of deterministic stretchable epidermal devices. (C, D and E) Images of random composite based stretchable systems. Power curves obtained after repeated stretching of biofuel cell (Panel E; right). (Reproduced with permission from Refs. 71–75.)

highly stretchable all-printed electrochemical devices that can be potentially used for wearable biofuel cells. The authors reported that their biofuel cells could be repeatedly stretched by 300% without much effect on their power generating ability (Figure 6E). Separately, Ogawa et al. demonstrated a stretchable textile-based biofuel cell using a stretchable pantyhose that could be repeatedly stretched by 50% with inconsequential impact on the power output. Researchers could look into these initial developments for realizing wearable biofuel cells that have mechanical properties perfectly matching to that of the target biological tissues.

It should however be pointed out that, stretchable devices fail if the strain exceeds a particular limit. Nature has cunningly addressed this issue by incorporating remarkable self-healing properties in biological systems. Dysfunctioning of wearable systems is imminent thanks to the daily wear and tear caused due to body movements. Thus, developing self-healing systems could be quite pertinent to address the issue of deformation-induced malfunctioning of wearable biofuel cells. Researchers have attempted to mimic Nature by developing man-made self-healing materials. Such systems have been employed for diverse electronics, healthcare, construction applications. Recently, Wang’s group demonstrated the first example of a self-healing electrochemical system that can be easily adapted toward developing self-healing biofuel cells. Researchers could build up upon these advances for realizing truly self-healing wearable biofuel cells that immediately recover their functioning after experiencing complete damage without any external trigger to initiate the healing process. Such Nature-mimicking smart biofuel cell systems will have much higher lifespan for uninterrupted powering of wearable devices.

Aesthetics and visual appearance.—As scientists and researchers, one has a tendency to focus solely on the technical challenges experienced in a field while underappreciating the importance of a device’s
aesthetics for its mass-scale adaptation. Upon addressing the technological challenges faced by wearable biofuel cells, such devices are expected to be introduced in the markets. However, the market penetration of such devices will not only depend on their performance but also on their aesthetics and fashionable appeal. Researchers thus must give appropriate importance toward developing wearable biofuel cells that provide high performance while being visually appealing to various market segments. Wearable devices, by their very nature, will be worn by users and therefore these will be regularly displayed by the users to surrounding people. Such devices thus will reflect the wearer’s persona and it is therefore essential that these devices are carefully designed to cater to a wide range of customer taste. Researchers must therefore work together with visual arts and product design experts to develop wearable biofuel cells that look aesthetically pleasing without compromising on the devices’ performance.

Privacy is a major concern for many people these days. In several scenarios, the wearer would like the wearable biofuel cells to be as discreet as possible or even invisible to others. Researchers could work toward developing invisible wearable biofuel cells that rely on transparent nano-electronic components. Such transparent biofuel cells could be quite attractive for many users who would like to take advantage of the wearable biofuel cell technology without the need to draw attention from nearby persons. Several independent groups have demonstrated the fabrication of transparent devices. One could build over such developments for realizing transparent wearable biofuel cells.

Conclusions and Future Prospects

The present perspective article outlined the attributes of enzymatic biofuel cells and how these are attractive for wearable applications wherein biocompatibility of devices is of utmost importance. The article also briefly discussed the advances that this nascent field has experienced in the recent past with examples of wearable tattoo and textile based biofuel cells for generating electricity from human sweat, ocular biofuel cells to harvest energy from human tears and also examples of wearable bio-batteries. These preliminary demonstrations expound the potential of using biofuel cell technology for wearable energy harvesting. However, through these examples, the article highlights the grand challenges wearable biofuel cells face. For example, as illustrated in Table I, the current biofuel systems cannot compete with widely used batteries. Major bottlenecks of the field include 1) developing innovative protein engineering and immobilization approaches to realize long-lasting biofuel cells that perform desirably under settings common to wearable devices, 2) fabricating wearable biofuel cells that can generate high levels of currents at desired voltages to power common wearable devices, 3) realizing wearable biofuel cells that can conformably mate with target human tissue while withstanding mechanical deformations caused due to routine body movements and 4) developing aesthetically pleasing wearable energy harvesters for easy acceptance of this new technology by the public. The success of the field will ultimately rely on overcoming all of these challenges. The perspective article also delineates possible routes to address these issues. A critical look at these paths reveals that resolving major issues involved in the wearable biofuel cells field will mandate a collaborative effort by experts from disparate technological and fine arts domains. Its only through innovative systems engineering solutions that these major challenges would be addressed.

The budding field of wearable biofuel cells thus offers exciting challenges to a wide range of research communities to apply their skills toward identifying innovative routes for the development of the field. With growing interest in using biofuel cells for various applications, it’s only a matter of time that major advances in the field of wearable biofuel cells will be reported.

### Table I. Comparison between biofuel cells and batteries.

| Characteristics       | Biofuel Cells                                                                 | Batteries                                                                 |
|-----------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Fuel dependency       | Functional as long as fresh fuel is supplied. Does not require re-charging.    | Requires re-charging.                                                     |
| Shelf-life            | Shelf-life mostly affected by enzyme stability.                               | Long shelf-life.                                                          |
| Power density         | Low power density.                                                            | High power density.                                                       |
| Fabrication materials | Relies on benign materials.                                                   | Relies on potentially harmful materials.                                  |
| Operational conditions| Affected by ambient conditions.                                               | Fairly stable at ambient conditions in most practical cases.              |

### References

1. G. Matzeu, L. Florea, and D. Diamond, *Sens. Actuators B*, 211, 403 (2015).
2. S. R. Steinhubl, R. R. Mehta, G. S. Ebner, M. M. Ballesteros, J. Waalen, G. Steinberg, P. Van Cocker Jr, E. Felicone, C. T. Carter, S. Edmonds, J. P. Honcz, G. D. Miralles, D. Talatov, T. C. Sarich, and E. J. Topol, *Am. Heart J.*, 175, 77 (2016).
3. A. R. Lingley, M. Ali, Y. Liao, R. Mirjalili, M. Klonner, S. Suihkonen, T. Shen, B. P. Ous, H. Lipsanen, and B. A. Parviz, *J. Microchem. Microeng.*, 21, 1250 (2011).
4. R. Tajima, T. Miwa, T. Ogumi, A. Hitosuwayagi, H. Miyake, H. Katagiri, Y. Goto, Y. Saito, J. Goto, M. Kaneyasu, M. Hiroki, M. Takahashi, and S. Yamasaki, *J. Soc. Inf. Disp.*, 22, 237 (2014).
5. Z. Tang, J. Li, P. Fu, and H. Zhao, in *Healthcare Innovation Conference (HIC)*, 2014 IEEE, 2014, pp. 251.
6. A. J. Bandodkar, I. Jeerapan, and W. J. Choi, *ACS Sens.*, 1, 464 (2016).
7. S. Imani, P. P. Mercier, A. J. Bandodkar, J. Kim, and J. Wang, in *2016 IEEE International Symposium on Circuits and Systems (ISCAS)*, 2016, pp. 1122.
8. A. J. Casson, in *Signal Processing Conference (EUSIPCO)*, 2015 23rd European, 2015, pp. 424.
9. J. Williamson, L. Qi, L. Fenglong, W. Mohnr, L. Kun, R. Dick, and S. Li, in *The 28th Asia and South Pacific Design Automation Conference*, 2015, pp. 136.
10. R. Hahn and H. Reichl, in *Wearable Computers*, 1999, *Digest of Papers*, The 3rd International Symposium on, 1999, pp. 168.
11. C. Park, P. H. Yoo, Y. Bai, R. Matthews, and A. Hibbs, in *2006 IEEE Biomedical Circuits and Systems Conference*, 2006, pp. 241.
12. C. Moser, L. Thiele, D. Brunelli, and R. Benni, *IEEE Trans. Comput.*, 59, 478 (2010).
13. L. Dong, C. Xu, Y. Li, C. Wu, B. Jiang, Q. Yang, E. Zhou, F. Kang, and Q.-H. Yang, *Adv. Mater.*, 28, 1675 (2016).
14. R. E. Sousa, C. M. Costa, and S. Lanceros-Mendez, *ChemSusChem*, 8, 3535 (2015).
15. A. E. Ostfeld, A. M. Gaikwad, Y. Khan, and A. C. Arias, *Sci. Rep.*, 6, 26122 (2016).
16. L. Dong, C. Xu, Y. Li, Z.-H. Huang, F. Kang, Q.-H. Yang, and X. Zhao, *J. Mater. Chem. A*, 4, 4659 (2016).
17. J. Y. Oh, J. H. Lee, S. W. Han, S. S. Chae, E. J. Bae, Y. H. Kang, W. J. Choi, S. Y. Cho, J.-O. Lee, H. K. Baik, and T. I. Lee, *Energy Environ. Sci.*, 9, 1696 (2016).
18. M. Hyland, H. Hunter, J. Liu, E. Veety, and D. Vashae, *Appl. Energy*, 182, 518 (2016).
19. B. Li, F. Zhang, S. Guan, J. Zheng, and C. Xu, *J. Mater. Chem. C*, 4, 6988 (2016).
20. X. Ren, H. Fan, Y. Zhao, and Z. Liu, *ACS Appl. Mater. Inter.*.
21. T. E. O’Connor, A. V. Zaretski, S. Savagatrup, A. D. Printz, C. D. Wilkes, M. D. I. E. J. Sawyer, and D. J. Lipomi, *Sol. Energy Mat. Sol. Cells*, 144, 438 (2016).
22. E. Katz, In *Implantable biofuel cells operating in vivo: Providing sustainable power for bioelectronic devices: From biofuel cells to cyborgs, Advances in Sensors and Interfaces (IWAIS), 2015 6th IEEE International Workshop*; June 18–19, 2015; pp 2–13.
23. L. Su, W. Jia, C. Hou, and Y. Lei, *Biosens. Bioelectron.*, 26, 1788 (2011).
24. T. Chen, S. C. Barton, G. Binyamin, Z. Gao, Y. Zhang, H.-H. Kim, and A. Heller, *J. Am. Chem. Soc.*, 123, 8630 (2001).
25. S. D. Mintzer, B. Y. Lizaw, and M. J. Cooney, *Curr. Opin. Biotechnol.*, 18, 228 (2007).
26. M. Zhou and J. Wang, *Electroanal.*, 24, 197 (2012).
27. S. Calabrese Barton, J. Gallaway, and P. Atanassov, *Chem. Rev.*, 104, 4867 (2004).
28. A. J. Bandodkar and J. Wang, *Electroanal.*, 28, 1188 (2016).
29. D. C. Bock, A. C. Marschlik, K. J. Takeuchi, and S. E. Takeuchi, *Electrochim. Acta.*, 84, 155 (2012).
30. S. Cosnier, A. Le Goff, and M. Holzinger, *Electrochem. Commun.*, 38, 19 (2014).
31. A. Zebda, S. Cosnier, J.-P. Alcaraz, M. Holzinger, A. Le Goff, C. Gondran, F. Boucher, F. Giroud, K. Gory, H. Lamerouxi, and P. Cinquin, *Sci. Rep.*, 3, 1516 (2013).
32. J. A. Castroena-Gonzalez, C. Fuesto, K. MacVitie, J. Halamek, L. Halamkolow, L. A. Martinez-Lemus, and E. Katz, *Electroanal.*, 25, 1579 (2013).
