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Biosensors for supporting the Green Economy

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ABSTRACT

This paper describes how the numerous forms of biosensors perform necessary functions in research, medicine and industrial uses. It describes recent developments that allow biosensors to be used to reduce resources in power, materials and costs while improving our quality of life.

Keywords: Biosensors, wearables, nanosensors, biofuel cells

I. INTRODUCTION

The term biosensor is short for "biological sensor" and is generally defined as an analytical device that uses a biological recognition component in combination with a transducer (detector) to provide a qualitative or quantitative indication. The history of biosensors dates back as far as the early 1900's while the first true biosensor was developed by Leland Clark in the 1950's, known as the Clark electrode, a device for measuring oxygen in blood. FIGURE 1 contains a list of traditional recognition elements and corresponding transducers which comprise many of the biosensor types utilized today. For much of the past 20 years, the word biosensor implied two basic types of devices, either benchtop instruments or the Lateral Flow Biosensor (LFB) type. The most common form of commercialized benchtop biosensors has traditionally been based upon Label-Free technologies[1], such as Surface Plasmon Resonance (SPR), Bio-Layer Interferometry (BLI), Nuclear Magnetic Resonance (NMR) or Iso-Thermal Calorimetry (ITC). Label-Free technologies do not require chemical or some other form of modification of the target molecule/analyte and therefore are more suitable for monitoring biomolecular affinity and kinetic properties than "labeled" technologies, such as fluorescence. Common forms of LFBs utilize gold nanoparticles to create a point-of-care detector. Other LFBs utilize additional forms of nanoparticles for applications in environmental contaminant detection.

II. COMMERCIAL EXPANSION OF BIOSENSORS

A. WEARABLE BIOSENSORS

The commercial success of "wearable" biosensors has dramatically increased in the past ten years, Wearables are defined as biosensors that can be worn on the body in some form, such as a wrist watch, patch, eye-glasses, mouthguard, contact lens, foot sensor or other device attached to skin or body part. Among the most common wearables are "smart watches" that can monitor blood pressure, heart rate, body temperature, activity (steps taken and sleep), and simultaneously receive email and text message via Bluetooth to either Android or iPhone devices.

B. OTHER TYPES OF BIOSENSORS

Another market space that has expanded the definition of the term biosensor are "nanosensors". Nanosensors are devices ranging from just a few nanometers to approximately 100 nanometers in size. These devices are typically configured to detect the presence of nanomaterials, toxins, contaminants, or biomolecules. Nanosensors can be utilized in a wide range of applications, from lateral flow strips in environmental detection of toxins to medical applications. In medical or biomedical applications, the nanosensor may be used in vivo for treatment or monitoring of a health condition, or as an *in vitro* device to provide a qualitative or qualitative diagnostic result. Fortunately, biosensors have broad applicability and can be utilized to address even the modern challenges of a changing climate, as described below.

III. BIOSENSOR APPLICATIONS FOR A GREEN ECONOMY

A. ELIMINATION/REDUCTION OF TRAVEL

The rise of wearable biosensors has enabled the potential for a significant reduction in travel costs associated with trips to the primary care physician (PCP) as well as clinics where initial testing and diagnosis have traditionally occurred. Wearable biosensors are now commercially available for remote real-time monitoring of blood pressure, heart rate, body temp, glucose, cortisol, and other parameters, while results can typically be transmitted to the PCP for review, as needed. An example of this wearable biosensor technology is the Apple Watch 7, which is able to detect sinus arrhythmia, atrial fibrillation (AFib) and unusually low or high heart rates. A similar product suitable for portable use is the Alivecor KardiaMobile 6L, which can detect afib, bradycardia, tachycardia, Premature Ventricular Contractions (PVCs), sinus rhythm, wide waveforms (known as wide QRS) and Superventricular Ectopy (SVEs). Numerous similar products are on the market that monitor vital signs in real-time, thus enabling patients to be better informed and potentially reducing or eliminating visits related to a lack of monitored medical conditions.

B. PLANT GROWTH OPTIMIZATION

Biosensors are being developed to monitor plant growth in real time. By monitoring parameters such as sugar levels in plant tissue in real-time, researchers can determine whether a species is able to thrive in a changing climate. Through genetic manipulation, the plant species could then be modified to better adapt to its environment. An example of this particular

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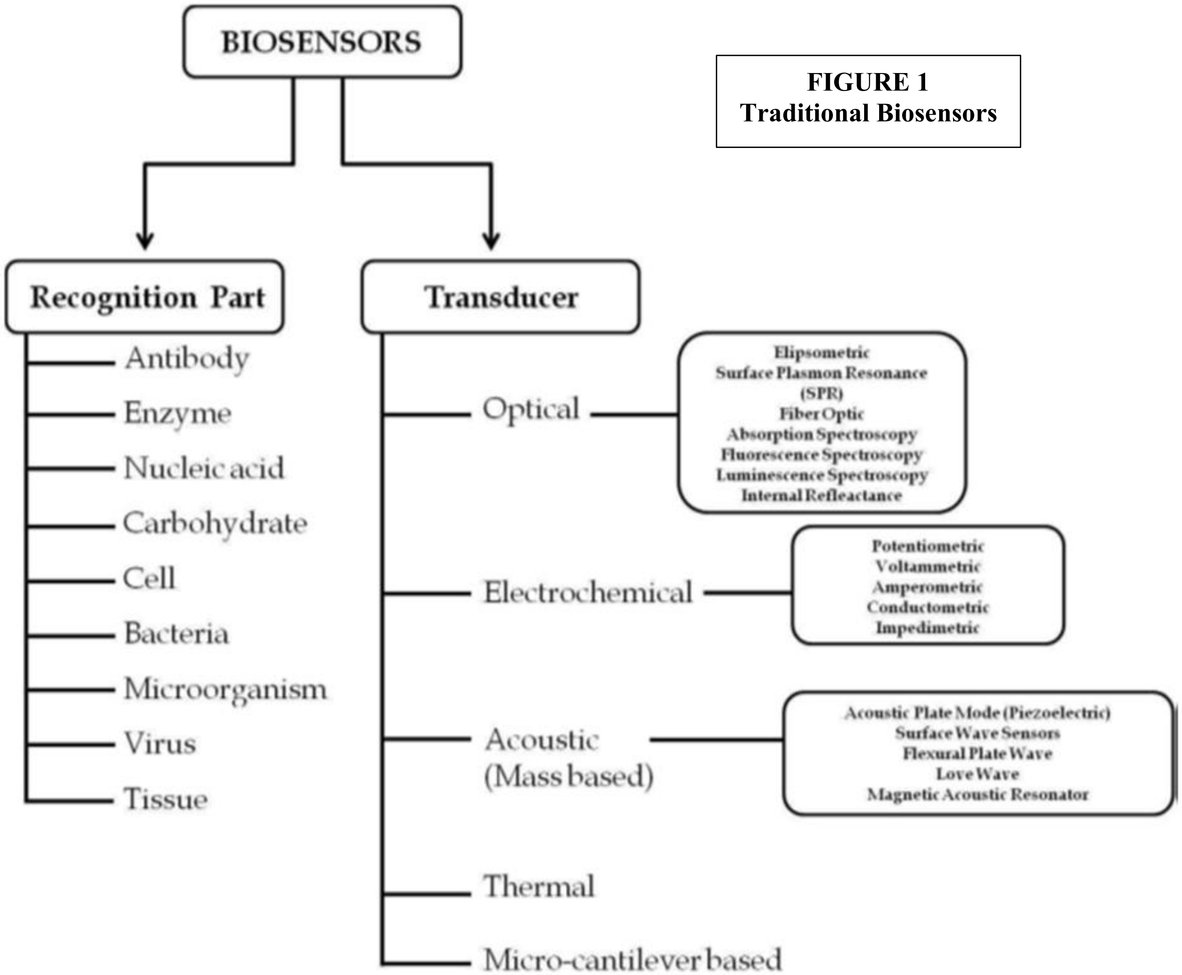
methodology is the research being performed at the Linkoping University in Sweden (Diacci et al., 2021) . Innovations such as this may eventually allow crops to be growth-optimized even in the face of significantly changing environmental conditions.

FIGURE 1
Traditional Biosensors



C. REDUCTION OF COSTLY MEDICAL IMAGING SCANS

Magnetic Resonance Imaging (MRI), Positron Emisson Tomography (PET), and Computer-Aided Tomograhy (CAT) scans are among the most commonly used medical imaging scans for screening of tumors. However, nanosensors have the potential to be a more cost-effective alternative to these standard imaging and scanning technologies. As an example, researchers at MIT have created an *in vitro* diagnosic test using nanoparticles to detect lung cancer biomarkers in urine.The paper *Urinary detection of lung cancer in mice via noninvasive pilmonary protease profiling* (Kirkpatrick et al., 2020) concluded that this method has the potential to be more effective than PET imaging as it detects signals in the lung that PET imaging can miss. In the paper *Nanotechnology in Bladder Cancer: Diagnosis and Treatment. Cancers,* (Barani et al., 2021) researchers developed biomarkers for the detection of bladder cancer in urine samples. This paper describes several nanoscale biosensors, including quantum dots and inorganic nanoparticles that have been used to create biomarkers for the detection of bladder cancer in urine. These nanoparticle-based biosensors demonstrate the promise of nanosensors to displace or augment imaging methods in the future, reducing cost for the patient and insurance companies alike and potentially reducing the footprint or perhaps the number of of large clinical diagnostic facilities.

D. MONITORING FOR ENVIRONMENTAL POLLUTANTS/CONTAMINANTS

Biosensors have been utilized in the field of environmental monitoring for a number of years. Commercialized biosensors are available to monitor genotoxic compounds, soil contaminants (ie heavy metals and pesticides) and water pollutants such as organic compounds, hormones and oil. The book "*New trends in biosensor development for pesticide detection*" (Shrikrishna, Mahari, Abbineni, Eremin, Gandhi, 2021) is a comprehensive review of trends in the development of biosensors for agricultural-related applications. The paper "*Aptamer-based biosensors for environmental monitoring*" (McConnell et al., 2020) is another excellent review of "aptasensor" applications, focusing on water-based biological contaminants such as S. aureus and E.coli. The various commercialized versions of these biosensor configurations provide a broad base of environmental testing for the future protection of our changing climate.

E. REDUCTIONS IN ENERGY CONSUMPTION

Among some of the most "green" applications of biosensors are those devices that require no external power. The innovation of ultrathin solar cells has made possible the development of self-powered biosensors. In a noteworthy example of both a self-powered ultrathin biosensor, researchers were able to combine a biosensor with a biomimetic material to test urine for a cancer biomarker . This work paves the way for the potential of self-powered devices in the point-of-care arena. In addition, research into the development of biofuel cells (BFCs) continues towards the commercialization of self-powered wearable & implantable devices. BFCs generally fall into two categories, enzymatic or microbial fuel cells (MFCs). Enzymatic fuel cells use enzymes as a catalyst to oxidize its fuel, whereas microbial fuel cells utilize microorganisms in a chemical reaction to oxidize and reduce organic molecules to produce electricity. In the paper "*Self-powered and reusable microbial fuel cell biosensor for toxicity detection in heavy metal polluted water*" (Naik et al., 2021) the researchers utilized a MFC to provide power for a biosensor capable of detecting four types of heavy metals in industrial wastewater. These examples show the potential for self-powered biosensors to be used not only to eliminate an external power source but also to enable environmental and biomedical monitoring to be implementable on scales small enough for point-of-care and portable/field use.

F. AIDING IN THE PRODUCTION OF BIOFUELS

Biofuels comprised approximately 7% of blended gasoline, diesel and jet fuel in the US during 2019. It is expected to grow to approximately 9% in the next few decades. Biosensors play an important part in the production of biofuels, specifically in the monitoring of water content and toxic chemical contaminants. As an example, the paper "*Surface plasmon resonance sensor to detect n-hexane in palm kernel oil using polypyrrole nanoparticles reduced graphene oxide layer*" (Sadrolholhosseini et al., 2021) describes how the label-free biosensor technology , SPR, is used to detect the level of the hazard-air-pollutant n-Hexane in extracted oil from palm kernel. In the paper " *Application of surface plasmon resonance sensor in detection of water in palm-oil based biodiesel and biodiesel blend*" (Sudrolsosseini et al., 2010) , an SPR-based biosensor is utilized to quantify the water content of biodiesel mixtures. As the momentum for fossil fuels alternatives grows, these examples illustrate the utility of biosensors to enable the path towards a greener economy.

IV. FUTURE RESEARCH AND COMMERCIALIZATION EFFORTS

The paper "*Sensing the future of bio-informational engineering*" (Dixon et al., 2021) summarizes many of the potential future outcomes for biosensors, nanosensors, BFCs and MFCs. Among the notable projections is the concept of "*smart greenhouses, where plant physiology is adjusted according to biosensor reported intracellular conditions using light, light-controlled microbial patterning and biomaterial production*, *or even to provide precise control over mammalian cells for smart-phone mediated insulin release*". Another projection is the concept of the "*Internet of Biological Things",* where synthetic biology will connect directly to both optoelectronic and digital components to comprise new forms of biosensors. In the meantime, nanosensors, BGCs and MFCs will continue to enable advancements such as real-time *in vivo* patient monitoring and eventually result in devices that can release pharmaceuticals *in situ,* as illustrated in the referenced paper.

These futuristic families of biosensors will greatly enhance our ability to (1) maximize the production of crops under changing environmental conditions, (2) reduce our dependency on regionalized medical facilities and physicians, thus reducing the carbon footprint for travel, (3) provide direct monitoring of health and environmental hazards in real-time and (4) produce self-powered biosensors based upon biofuel cells to reduce or eliminate power needed from the grid.

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