PIEZOELECTRIC MATERIALS FOR ENVIRONMENT SUSTAINABILTY

Soma Mukherjee

Department of Applied Science & Humanities(Physics)

Guru Nanak Institute of Technology, 157/F Nilgunj Road, Panihati, Kolkata 700114
Email Id: soma.mukherjee@gnit.ac.in,
Susinjan Bhattacharya
School of Agriculture and Allied Science, The Neotia University, Sarisa, D.H. Road, West Bengal
Diprit Turul
Department of Computer Science &Engineering
Guru Nanak Institute of Technology, 157/F Nilgunj Road, Panihati, Kolkata 700114
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ABSTRACT

Piezoelectric materials can be used as an unconventional sustainable source of green energy, an urgent need at present. The present paper reviews the potential of these smart materials to sustain the environment. Applications are based on the energy extracted from our day to day life events like vibrations from cars on highways, bridges or footballs on floors. Piezoelectric energy harvesting process with its minimal maintenance requirement, clean operation, scalability and renewable nature are emphasized in this paper. Its potential for green energy future in the renewable energy market is also discussed here.

Keywords: Piezoelectric materials, green energy, renewable energy, sustainability

INTRODUCTION

An energy crisis is now coupled with the unprecedented and accelerating impacts of climate change. Global population growth and increases in urbanization and industrialization have spurred the demand for energy across multiple sectors like transport, manufacturing and household consumption. Unfortunately, a large part of this demand is still supplied by fossil fuels - coal, oil and gas - which are environmentally harmful, finite and ever-more costly [1], [2]. The generation of huge carbon dioxide and other greenhouse gases from the burning of fossil fuels creates global warming, extreme weather, and rising seas. The carbon emissions produced from energy generation is the largest and most harmful pollutant leaving the sector in a technological, social, and ecological crisis that endangers public health, climate, and the whole of living biodiversity on the planet [3].

The immediate transition to renewable and sustainable forms of energy is now a global imperative. [4].The renewable sources of energy like solar, wind, hydro and biomass are all developing, but have limitations that include intermittency, geographic dependence, and expensive storage and infrastructure. Therefore, the unconventional exploration of other energy alternatives that can complement existing renewable systems is critical.

Promising new technologies such as Mechan synthesis and especially, piezoelectric energy harvesting technologies have the capacity to convert the wasted mechanical energies of human and environmental activities into usable electrical energies.

The term 'piezoelectricity,' has its roots in the Greek words for press (piezein) and amber (elektron), was first explained in 1880 by the Curies. They noticed that certain crystals like quartz would build up a charge when mechanical stress was applied [5].This curious effect is not one way: applying stress mechanically and obtaining a charge is reversible, and applying a charge mechanically deforms the body. For decades, this effect has been used in devices like sensors, actuators, and oscillators. The integration of materials science and nanotechnology into the field of piezoelectricity has begun to allow the harvesting of piezoelectric energy, making piezoelectricity a candidate for decentralized, sustainable energy generation [6].

The ability to convert even small vibrations and movements to energy makes piezoelectric materials crucial to contemporary sustainability efforts. Many everyday activities, including chalking a score, dribbling a football, and even foot traffic, can be tapped into to generate electrical energy. Piezoelectric devices can therefore be used as part of “smart” infrastructures, along with self-chargeable electronics and wearable tech, to form a key part of future smart cities and the IoT. Unlike piezoelectric systems, which can be localized to street lights, sensors, and even biomedical devices to power them, renewable energy systems are large and offer little flexibility [6].

Piezoelectric materials provide a novel way to enhance traditional forms of renewable energy [5]. They also assist in the environmental goals of energy conservation and sustainability. Piezoelectric energy harvesting presents opportunities to decentralized power generation while diminishing reliance on fossil fuels. This paper discusses principles, applications, and prospects of piezoelectric materials, especially on their potential to resolve the climate change issue and energy crisis.

Piezoelectric Effect and Material Basis

Some crystalline materials have the unusual feature of producing an electric charge when under mechanical pressure. They also change shape when a mechanical pressure is electrically charged. The converse of this pressure is also able to be achieved in electricity. A crystal lattice is able to maintain this feature when they are non-centrosymmetric. In the most common terminology, when piezoelectric crystals are subjected to stress, the pressure generates an electric potential difference, or polarization. This is caused by the separation of charges. The most common applications of this unusual coupling of electromechanical features are in crystals, but they also in sensors, and energy harvesting [5].

The explanation of the piezoelectric effect can be approached from the macro and micro perspectives. Crystals piezoelectric at the atomic level do not have centre of symmetry which means the arrangement of the constituent ions and the structure will not be the same when inverted. Hence, any deformation caused by applied stress results in an imbalance which can be turned into a measurable voltage. On the macro level, embedding such materials into functioning mechanical systems which vibrate, compress, or bend, results in the generation of an alternating current which can then be harvested, rectified, and stored [5]. This is one of the reasons piezoelectricity is so useful for harvesting renewable energy as it can collect mechanical energy that would otherwise be wasted [7].

Classes of Piezoelectric Materials

Several natural and synthetic materials exhibit piezoelectric properties, each of which shows unique advantages in terms of performance, durability, and processability. The most notable classes include [8]:

- Quartz (SiO_2): Quartz is one of the oldest natural piezoelectric materials, and is still one of the most widely used in oscillator, resonators, and time keeping devices. Despite the low piezoelectric coefficient, materials thermal stability and availability in the market, quartz remains a usable for many electronic devices.
- Lead Zirconate Titanate (PZT): As a ferroelectric ceramic material, PZT is one of the most widely used synthetic piezoelectric materials due to its high piezoelectric coefficients, strength, and low cost. It is heavily used in actuators, ultrasonic transducers and energy harvesting devices. However, its environmental impacts due to the lead content in PZT have sparked the search for lead-free PZT.
- The Flexible Piezoelectric Polymer - PVDF. PVDF is effortless to manufacture and lightweight. PVDF is not as rigid as ceramic and thus is incorporated in wearable technology, biomedical sensors, and lightweight electronics. PVDF is adaptable to conform to surfaces or under body movement [9].
- Barium Titanate ($BaTiO_3$). This is a ferroelectric-piezoelectric ceramic. $BaTiO_3$ is used in capacitors, sensors, and actuators. Also because $BaTiO_3$ does not contain lead, and is therefore less harmful to the environment than PZT, it is becoming more popular.
- Gallium Orthophosphate ($GaPO_4$): Because of its strong piezoelectricity and outstanding thermal stability as a synthetic crystal, $GaPO_4$ is excellent for use in Acoustic sensors, and ultrasonic transducers for high frequency and high temperature applications.
- Rochelle Salt: Although less commonly used today due to stability issues, Rochelle salt historically played a significant role in the early development of piezoelectric devices.

Characteristics Enabling Energy Harvesting

The energy harvesting capabilities of piezoelectric materials is derived from specific physical and electrical characteristics of the materials. Materials having high piezoelectric coefficients (d_{33} and g_{33} values) show significant conversion efficiencies from mechanical stress to electric charge. For long term cyclic loading applications in transportation or industrial machines, mechanical robustness and fatigue resistance are critical. For wearable and biomedical devices, flexibility of materials such as polymers (e.g. PVDF) is invaluable rather than the rigid ceramics. The ability to develop advanced nanocomposites and the fabrication of piezoelectric thin films has allowed significant downsizing of piezoelectric harvesters for incorporation into micro electromechanical systems (MEMS) and IoT devices.

Additionally, piezoelectric materials can be incorporated into various structures from big projects like bridges and highways to little portable electronics. Their low maintenance demand and functionality in different environments strengthen their status as energy harvesters ready for sustainable energy harvesting.

Energy Harvesting Mechanisms

Piezoelectric energy harvesting depends on the piezoelectric effect and the conversion of mechanical stimuli into electrical energy [5],[10]. Because there is a multitude of natural and anthropogenic environments composed of vibrations, movements, and impacts, energy can be captured through piezoelectric materials. Piezoelectric systems are highly versatile, ranging from the large scale of highway vehicle vibrations to the small scale of oscillating biomedical devices.

Sources of Piezoelectric Energy Harvesting

Vibration-Based Harvesting:

Vibrations are one of the most common sources of mechanical energy. Practically every automobile, train, bridge, industrial machine, and even household appliance produces some ambient vibration. Piezoelectric energy harvesters can be tuned to the frequency of these vibrations for optimized energy conversion [9],[11]. For instance, piezoelectric transducers can be embedded in roadways to capture the vibrational energy of traffic to power roadside sensors and even street lights [1].

Impact or Shock-Based Harvesting:

Sharp shocks or impacts, including the sound of footsteps on a pavement, the bounce of a football, or the stamping operations in an industry, lead to rapid and intense mechanical stress. This energy type is well suited to piezoelectric harvesters since quick and intense mechanical deformations lead to high electrical output in quick intervals [12].

Structural Stress and Oscillations:

Huge constructions like buildings, towers, and bridges bear persistent pressure and vibrations from heavy traffic, wind, and earthquakes. Using piezoelectric materials in these constructions makes it possible to do energy harvesting and monitor structural health at the same time. The energy captured can operate battery-free wireless sensors for real time monitoring [13].

Human Motion-Based Harvesting:

Industrial Monitoring: Predictive maintenance can be improved and downtime reduced by using piezoelectric harvesters embedded in machinery to power condition-monitoring sensors [10].

Environmental Sensing: For sustainable environmental management, remote weather stations or devices used to monitor wildlife can operate using harvested vibration energy [10].

Incorporating piezoelectric materials with energy-efficient circuitry and smart algorithms for wireless transmission systems and advanced algorithms makes it possible to optimize and effectively use the harvested energy. This will enhance sustainable energy development and optionally reinforce the vision of self-sufficient intelligent infrastructures.

Fluid Flow Harvesting:

Every time there is liquid or gas flow, there are pressure changes and possible turbulence. These fluctuations can be captured and transformed [9]. Electrical energy can be created when inserting piezoelectric films or composites into pipelines or channels. These materials generate power when fluid moves and forces them to change shape. This is the case when there is smart water distribution or during other processes where there is industries [14],[15].

Environmental Vibrations:

There are energies, in the form mechanical energy, in our natural surroundings. The pressure fluctuations caused by the wind blows, the action of waves in the ocean, or the impact of falling rain are all potential sources of energy. Piezoelectric harvesters can be deployed to remote areas in these situations and provide localized power to small sensors, weather monitors, or environmental IoT systems, where there is no conventional power supply [16], [17].

Energy Conversion and Storage Process

Piezoelectric materials initially emit an alternating current (AC) which has to be processed further to be useful. The energy harvesting cycle typically following steps:

Rectification:

Piezoelectric devices produce AC signals which have to be converted to DC to store or power most electronic devices. This is achieved through the use of rectifier circuits which are usually designed with diodes.

Voltage Regulation:

The output voltage generated by piezoelectric harvesters might be unstable and reliant on the level of stress applied. Damage can occur to downstream components or storage devices, so voltage regulation circuitry is essential to ensure that output is stabilized and contained within a safe and usable range.

Energy Storage Devices:

Rechargeable Batteries: The rectified DC output can be stored in advanced batteries like lithium-ion or other rechargeable batteries. They facilitate long-term storage with controlled discharge to power portable electronics, lighting, or wireless systems.

Supercapacitors or ultracapacitors are incorporated for use cases that need fast charging and discharging capabilities. These devices are appropriate for powering sensors, actuators, and circuits that need quick bursts of energy since, while they are less energy dense than batteries, they have a much greater power density.

Charge Control and Management:

To improve system efficiency, overcharging may be avoided, charging cycles may be regulated, and additional circuitry may be incorporated, including charge controllers. This guarantees that the rechargeable piezoelectric harvesters and the batteries or piezoelectric devices are safeguarded.

Integration with Electronics and IoT

A significant advantage of piezoelectric energy harvesting is the ease with which it can be combined with today's electronics and the Internet of Things (IoT) ecosystem. Self-powered IoT devices can function independently in remote locations where batteries cannot be replaced [15],[17],[18]. For example:

- Smart Cities: Piezoelectric surfaces can energize smart illumination, surveillance, and traffic control systems.
- Healthcare: Body-worn biomedical monitors, like heart-rate sensors and glucose monitors, can harvest energy from movements to power the devices, which minimizes the need to replace the batteries often
- Industrial Monitoring: Predictive maintenance can be improved and downtime reduced by using piezoelectric harvesters embedded in machinery to power condition-monitoring sensors.
- Environmental Sensing: For sustainable environmental management, remote weather stations or devices used to monitor wildlife can operate using harvested vibrational energy.

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APPLICATIONS ACROSS SECTORS

Initially, piezoelectric materials were considered functional materials for niche applications [2]. With the ability to convert vibrations and mechanical stress within the environment to usable electric energy, the scope for functional integration of these materials and technologies to capture energy grew considerably. Now, piezoelectric materials and technologies are integrated within the systems of numerous high energy consuming and unsustainable applications. Their integration within systems that span from civil and transportation infrastructure to biomedical engineering and devices improves not only their performance but also their energy use and overall environmental impact [19].

Transportation and Infrastructure

Transportation systems create a great deal of mechanical vibrations and dynamic stresses, making them perfect candidates for piezoelectric integration. The constant flow of vehicles and trains offers an opportunity for energy harvesting. for energy harvesting. By embedding piezoelectric transducers into highways, bridges, and railway tracks, this energy can be used to power street lights, traffic signals, toll gates, and wireless monitoring systems, thus reducing dependence on the conventional power grid. In addition, piezoelectric sensors can be used to monitor the structural health of a bridge or pavement and help track the formation of cracks, stress, and fatigue to improve safety and decrease maintenance costs. Projects in Israel and in Japan, for example, have demonstrated piezoelectric roads and street lighting to help model smart transportation networks [17],[20]

Public Utilities

The city life offers numerous possibilities for the use of piezoelectric technology as a result of human activity. Floors that harvest energy from footsteps can be put in places with a lot of foot traffic like train stations, airports, shopping malls, and stadiums. The energy produced from millions of footsteps every day can be used to power ambient lights, security cameras, and advertising billboards. Besides energy generation, these tools also amplify public engagement. People can visualize the power generation from their foot movements, making them understand the concept of energy movement in a more practical way and use it as a tool to educate people on the value of renewable energy. Airports and sports arenas around the globe use piezoelectric tiles made by Pavegen [21],[22].

Industrial Sector

Industries involve the use of heavy equipment, machines, and vehicles which produce consistent operational vibrations. Normally, these vibrations are lost as heat or sound, but with the use of piezoelectric harvesters, they can be converted into electricity. The electricity produced can be used to power the monitoring system, remote sensors, actuators, and other devices used for predictive maintenance that are also powered by electricity like piezoelectric knock sensors which are used in the automotive industry. Ultrasonic cleaning systems are other examples which use piezoelectric transducers. Other industries also use piezoelectric actuators for advanced robotics, automated assembly lines, and additive manufacturing for precise position, control, and system to improve the overall efficiency and reliability of the system [21].

Medical Field

Given the increasing need for miniaturized, self-powered, and non-invasive devices, the medical sector is one of the most promising fields for the applications of piezoelectric. For instance, piezoelectric materials are used in ultrasound imaging systems, which generate detailed images of internal organs by converting electrical pulses into sound waves and back. Furthermore, piezoelectric implants and wearable biomedical devices are able to capture the infinite energy provided by the body during movements such as walking, breathing, and even the heartbeat, which removes the hassle of battery replacements. Examples are chest powered pacemakers and hearing aids using piezoelectric bone conduction. In addition, the integration of piezoelectric actuators on drug delivery systems will enhance the effectiveness of treatment using controlled and precise release of medication [23],[24].

Consumer Electronics

Analysis of consumer electronics show

how piezoelectric devices are incorporated into everyday licensed electronics items [21]. Every piezoelectric models, toys, smart phones, timepieces, and appliances have sound generating components that use piezoelectric devices [6]. Piezoelectric devices gain a unique role with the piezoelectric actuators as they become a part of the advanced inkjet printers which have a precise control over the ejection of ink droplets. Piezoelectric materials are also advanced as they provide nano-positioning capabilities within the AFM and STM devices which are advanced research devices. Small dimensions of these devices, reliability, and low operational power are some of the reasons for its applicability to power contemporary consumer electronics [6].

Defence and Aerospace

In the sectors of defence and aerospace, piezoelectric materials play an important role in applications that are high-performance and critical to the mission. These materials are implemented in solar systems, used for submarines detection, aircraft vibration sensor systems, and aerospace engine actuators. The piezoelectric materials in micro-robotics and adaptive munitions that are emerging in defence technologies assist self-powered sensors and precision motion control. As an example, the piezoelectric actuators in bullets that can change course assist in micro-adjustments during the bullets flight. Also, energy-harvesting systems in communication and sensor devices incorporated into military boots and gear assist compressed powered bulky mission batteries [6],[25].

Indian Scenario

India, one of the world's fastest growing economies, is dealing with two challenges at the same time - escalating energy needs and the decreasing environmental impacts of reliance on fossil fuels. Around 70% of the power generated in India is from coal, and the coal energy sector supplied India's power for many decades, while also, the greenhouse gases, air pollution and land degradation caused predominantly by coal energy. India's power needs will continue to grow fast with the rate of urbanisation, industrialisation and growing middle- class making the diversification of energy sources and the adoption of sustainable energies extremely crucial to India [26],[27].

India's Government has been proactive in responding to these challenges with ambitious goals for the adoption of renewable energy. As per the NAPCC and the National Electricity Plan, India is targeting over 200 GW of solar, wind and hydropower renewable energy capacity by 2025. This is an integral part of the NAPCC and India's commitment to the world and the Paris agreement to ensuring India's energy sector with low carbon intensity. However, while mainstream renewable have made significant progress, there is still an urgent need to explore non-conventional and decentralized renewable sources, particularly for localized applications where large-scale installations are impractical.

In this scenario, piezoelectric energy harvesting can be used as an alternative solution. Consider an urban environment where the population density and daily human activity are enormous; footstep-powered systems are a potential source of clean electricity in places such as railway stations, airports, shopping malls, and stadiums. Piezoelectric tiles can be integrated into metro stations or public pathways and be used as power sources for LED lights, digital billboards, and wireless sensor networks. Likewise, piezoelectric harvesters can be embedded into roadways and used to capture energy from the constant vehicle vibrations to power street lighting. This approach can ease the pressure on the national grid while saving municipalities on operational costs [27],[28].

Multiple factors indicate that such systems could be market feasible in India. The first reason is urban public venues' high foot traffic creates a great deal of mechanical energy that can be captured economically. The second reason is that, in addition to sustaining smart city initiatives, the government is also providing support for the implementation of these projects, and citizens with an increasing awareness of sustainability. The third reason is that, due to the developing thin flexible piezoelectric ceramics, piezoelectric polymers and other policies strengthening the electronically controlled devices; these systems are much better economically feasible. Additionally, such systems have greater potential to provide decentralized remote power for semi-urban and rural regions where the expense of electricity is high and access to electricity is infrequent.

The adoption of piezoelectric technology in India will require demonstration of their functional reliability and real-world scenario cost effectiveness. As a proof of concept in the early stages of adoption, piezoelectric floors in busy transit hubs and harvesters in national highways can be installed. Over decades, with a reduced use of coal and cleaner energy to the India, piezoelectric energy harvesting will help with the goal of emission reduction and balance with the other renewable technology coming from solar and wind energy.

ADVANTAGES AND CHALLENGES

Incorporating piezoelectric materials into energy harvesting technologies highlights their significance during the current shift to renewable energy. These smart materials do present a number of unique benefits in comparison to traditional energy sources; however, the technical and economic issues will need to be resolved to allow greater integration, which should not be overlooked [29],[30].

Advantages

Eco-Friendly and Renewable:

Piezoelectric energy harvesting does not emit greenhouse gases, pollutants, or toxic byproducts during operation, and since it relies on mechanical energy, that would otherwise be wasted, it contributes directly to minimizing negative environmental consequences and upholding the sustainable energy continuum [30].

Decentralized Power Generation:

In contrast to solar farms or wind parks, renewable systems like piezoelectric harvesters can be integrated more freely on a smaller scale. This flexibility allows them to produce power on-site for immediate use, including roadways, public buildings, or even portable devices. Distributed energy generation can lessen reliance on centralized power systems, strengthening energy resilience [9].

Adaptability across Applications:

The different uses of piezoelectric materials include transportation, healthcare, personal electronics, and military applications. They can be used in large constructions like highways and bridges as well as small devices like sensors and medical implants [9],[10],[30],[31].

Low Maintenance Requirements:

After the initial installation, piezoelectric systems need little maintenance. Many systems have no moving parts, which means they have lower chances of mechanical deterioration and can run for long periods without incurring major maintenance expenses. This feature is especially advantageous for use in remote areas, where regular maintenance is impossible [32].

Integration with Smart Technologies:

In general, powering low-energy devices works in tandem with the expanding Internet of Things (IoT) and the development of smart cities directly. Piezoelectricity facilitates the provision of self-powered sensors and devices, unlocking real-time data capture, and environmental surveillance, and automating the smart infrastructure [33].

Challenges

Low Power Density:

Piezoelectric energy harvesting has yet to match the power output of more established renewables-- wind and solar. It works, however, to power sensors and small electronics, LEDs and other lightweight technologies. Unfortunately, the technology has yet to reach the scalability needed for high-demand uses, including home appliances and industrial plants [34].

High Installation Costs:

Integrating piezoelectric materials into roadways, pavements, or even industrial machinery can be a costly endeavour. This is even more pronounced in developing economies, where budget constraints can limit the integration of materials and energy storage components [34].

Durability and Reliability Issues:

Many piezoelectric harvesters have to withstand extreme temperatures and repetitive stress and strain and may even have to endure mechanical degradation over time. Assessing the efficiency and mechanical failure over time is most likely to remain a perpetual engineering challenge [33],[35].

Energy Storage and Integration Complexities:

Piezoelectric systems produce small amounts of energy in short bursts and, thus, require efficient energy rectification, voltage regulation, and storage. This increases system complexity and cost when integrated with batteries or supercapacitors, which inhibits the large-scale adoption of the technology.

FUTURE PROSPECTS

Unlocking and overcoming the current restrictions will determine the future of piezoelectric energy harvesting and characterizing it as a complementary and scalable reconciliation energy source. With current developments in materials science, electronics, and construction of sustainable infrastructure, piezoelectricity will occupy a prominent position in the energy spectrum of the future.

Development of Lead-Free Ceramics and Nanocomposites

The material choice is a big challenge in this field. The most popular material used is PZT (lead zirconate titanate). PZT is very piezoelectric and functional, but the use of lead poses environmental health dangers. The materials of focus in current research include lead-free barium titanate, potassium sodium niobate, and lithium niobate. These lead-free materials are more temperature stable, have fatigue resistance, and are more environmentally friendly. The research on polymer nanocomposites (specifically PVDF polymer and carbon nanotubes or graphene) showed significant promise [36],[37],[38]. The piezoelectric nanocomposites being lightweight and flexible form the basis of piezoelectric harvesters used in wearables.

Such materials expand the use of piezoelectric devices in biomedical implants and other more flexible and biocompatible devices.

Integration with IoT and Smart Cities

With the expansion of the Internet of Things (IoT), billions of self-powered sensors and devices will need dependable autonomous sources of power. For self-sustaining IoT nodes, piezoelectric harvesters are the best fit since they transform human activity and environmental vibrations into electric power. In smart cities, piezoelectric floors can lighten walkways, bridges with embedded sensors can autonomous monitor structural health, and roadside harvesters can fuel traffic management systems—all without dependence on centralized electrical grids. The move toward autonomous self-powered electronics perfectly matches the vision of sustainable data-driven urban development. This makes piezoelectricity essential for smart infrastructure [36].

Large-Scale Adoption in Infrastructure Projects

In the future, the potential for piezoelectric technologies, especially in infrastructure, is extraordinary. For example, the ‘smart highways’ of the future will have piezoelectric sensors that monitor real-time updates to road conditions and generate electricity from traffic. Airports, train stations, and sport facilities will use piezoelectric systems to capture and generate electricity from footsteps. Urban planners and the government are seeing the value in piezoelectric systems from an integrated design approach. This technology not only offers energy sustainability, but also real-time monitoring of the structure, leading to improved safety and operational efficiencies. Declining costs of materials and proven feasibility of initial projects will lead to piezoelectric technology becoming more widespread in road construction [22],[39],[40].

CONCLUSION

Piezoelectric materials provide new possibilities in providing alternative sources of green energy by capturing mechanical energy from vibrations, impacts, structural stresses, and even human activities. It avoids extracting energy from the environment. The wide range of applications, including, transportation, civil structures, biomedical devices, and consumer electronics demonstrate the versatility and flexibility of the technology. They also require little maintenance and work independently without centralized energy supply systems, thus, providing a sustainable energy source for smart cities and IoT devices.

However, the low power density of the piezoelectric harvesters challenges their use as primary energy sources. Small scale or auxiliary energy applications are the best uses for these technologies. Cost, limited life, and lead ceramic pollution are all big issues for its large scale use. The use of hybrid piezoelectric and other more used renewable systems, along with reasonable priced manufacturing systems will help in the final cost of the project.

The potential incorporation of piezoelectric energy harvesting into infrastructure, smart city initiatives, and wearable technology would form self-sustaining, self-powered ecosystems that would be sustainable. Piezoelectric systems harness energy that would otherwise be squandered, which builds an attitude of taking accountability towards the environment and diminishes the amount of carbon emissions. Piezoelectric systems strive towards global sustainable development and ensure that the planet remains healthy, green and robust for future generations.

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