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ENERGY HARVESTING FROM ROADS

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ABSTRACT

Energy demand has been steadily increasing worldwide, and with fossil fuel stocks decreasing, it is becoming increasingly important to create new ways to extract energy from non-conventional sources. Roads have recently been identified as a possible energy harvest. Recent advances in the field of energy recovery from roads utilizing solar panels, piezoelectric, thermoelectric, and electromagnetic harvesters, as well as their efficiency, cost, and field application, are described in this review study. This study presents a review of technologies being developed worldwide for energy harvest from pavements, efficiencies, and prospects to fulfil future energy demand. It conjointly presents case studies of significant projects undertaken globally to reap energy from pavements. This review paper will also highlight the three Green Roadway Concepts that were influenced, proposed, and put into action.

Keywords: Electricity, Energy, Harvesters, Kinetic Energy, Mechanical, Photovoltaic.

I. INTRODUCTION

Harvesting of energy has recently been introduced on a micro-scale, where we can generate electricity from slight energy variations such as temperature fluctuations, pressure, pulsation and vibrations, radio-frequency, and even EM radiation, in addition to the significant renewable energy sources such as hydro, wind, solar, and waves. The surface of roads is constantly subjected to two phenomena: solar radiation and the load of vehicles, and it is remarkable that energy can be extracted from both of them, which may then be converted into electrical energy using specialized technology. Highways transport cars, which are the significant means of transit in cities. Vehicles use energy to run their engines and then release it in a variety of ways through various components. The road surface absorbs some of the energy generated by automobiles. Approximately 15–21% of the energy is transmitted to the wheels of the vehicle. Due to the massive number of cars present in all cities in industrialized nations, a significant quantity of energy gets transmitted to road pavements without being consumed. The roadways are also exposed to sun radiation, which creates temperature gradients between their layers, which can help to generate usable energy. Overall, road pavements offer a significant source of energy that may be captured and transformed into usable forms such as electrical energy, decreasing the need to 'import' energy from far away.

NEED FOR ROADS AND MOTORWAYS TO GENERATE ELECTRICITY

We've been decentralizing large-scale electricity use into hundreds of micro-consumption sites. And it's here that sustainable development, highway infrastructure, and the concept of energy-generating roads (all of which are critical components of future living quality) come into play.

In order to light up a bulb 15 kilometres from the nearest town, a 15-kilometre power line is required, which requires the installation of a continuous line of cable with associated posts every 10, 12, or 20 metres, as well as all expenses involved with line installation, servicing, and operation, as well as losses due to inefficiency.

The more energy you need to pump into a power line to reach the needed quantity at the other end, the thicker the copper cable must be to handle this increased power, and the amount of insulating material needed increases as well, all of which results in higher costs and a bigger environmental effect.

Furthermore, the necessity for intermediary transformer sites decreases the overall system's efficiency. A huge portion of these costs would be eliminated if each and every lamp post, traffic light, or emergency point on the highway had its own generator, driven and fed by the actual cars using the roads. It would be easier to fix, installation and maintenance expenses would be lower, and everything would be better for the environment.

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II. ROAD PAVEMENT ENERGY HARVESTING TECHNOLOGIES

INTRODUCTION

Energy gathering is an idea where energy is reaped, handled, put away, and utilized from several fuel sources. In other terms, energy harvesting is converting ambient energy into different valuable types of energy, such as electrical energy. Micro-energy harvesting and macro-energy harvesting are the two basic types of energy harvesting. Fuel hotspots for miniature energy collecting incorporate electromagnetic, electrostatic, heat, warm changes, mechanical vibrations, acoustic, and human body movement. In contrast, full-scale energy gathering includes sun-powered, wind, hydro, and sea energy. Large-scale energy harvesting, commonly measured in kilojoules or more significant, is akin to macro-energy harvesting. Energy harvesting on a small scale, usually on the order of a joule or less, is referred to as micro-energy harvesting. Different advances and frameworks have been made and tried as of late, considering these fuel sources. As shown in the figure below: the leading energy collecting technologies used on road pavement can be split into two categories:

The first category is concerned with technological advancements that take advantage of the sun's rays on the road's surface. Sun based radiation can be straightforwardly caught and changed into electrical energy by photovoltaic cells; it can likewise cause heat inclinations between the layers of the street asphalt, which can be used to create power or fuel thermoelectric generators (TEGs). Sun based energy can likewise be gathered using black-top sun-powered authorities (ASC), which separate the amassed warmth out and about the surface.

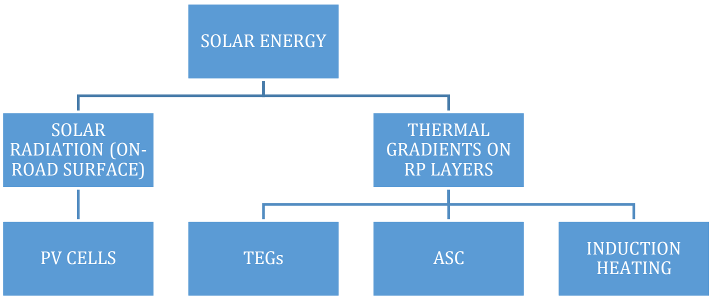

FIGURE -1: Solar energy (RP energy harvesting)

The second set of technologies is concerned with the use of mechanical energy delivered from automobiles to the road surface. This can be directly harvested using piezoelectric harvesters, which produce electricity. Hydraulic, pneumatic, electromechanical, and micro-electromechanical systems can all collect energy (MEMS) that send the gathered energy to electromagnetic generators, generating electricity. When it comes to MEMS, they can also use the energy accumulated to power piezoelectric devices generators.

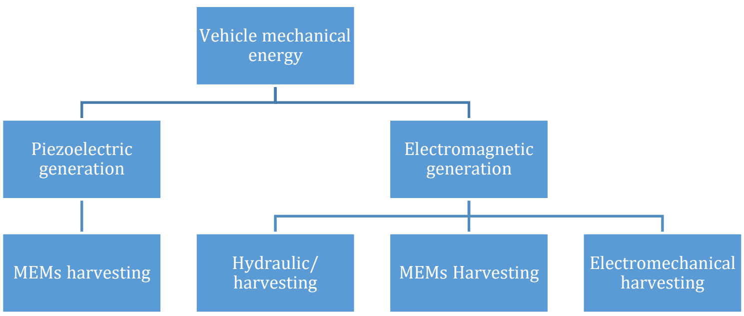

FIGURE -2: Mechanical energy (RP energy harvesting)

A. SOLAR ENERGY HARVESTING ON THE ROAD SURFACE

[1] THERMOELECTRIC TECHNOLOGY

The Seebeck impact, characterized by Schreier et al. (2013) [1]as a voltage distinction on a material brought about by a temperature angle forced across its surfaces, produces electrical energy in TEGs. The more energy is delivered, the more noteworthy the temperature inclines.

Hasebe et al. (2006) [2] made an asphalt cooling framework that incorporated a TEG inserted in the asphalt. A water funnelling framework inserted in the street surface gathers sunlight-based warmth, which is then cooled by stream water.

The water goes first through the hot side of the TEG, then through the cold side of the TEG, which is installed beneath the road. TEGs on the surface of pavements were investigated by Wu and Yu (2012) [3]. They propose using highly thermal-conductive materials to connect the lower half of the module to the subgrade soil in order to promote heat conduction and hence increase electrical energy output. They found that employing Quantum Well Structured (QW) materials instead of Bi-Te cells increased maximum efficiency by 4%; however, the storage of these materials was a concern.

[2] ASC TECHNOLOGY

A different option to take advantage of the temperature gradients between road pavement layers is to turn the pavement into a solar collector, with pipes and pumps strategically placed to gather solar energy and convert it to thermal energy. ASC is a methodology that has been explored by various creators lately (Bobes-Jesus et al., 2013) [4].

Sullivan et al. (2007) [5] proposed utilizing the warmth engrossing property of black-top cement applied to the structure of adaptable asphalts to make an ASC framework for warming and cooling street asphalts and different foundations. The ASC framework consists of a layer of black-top asphalt with water pipes inserted in it. The ASC system is related to two underground storehouses for water-storing, one for cold water and the other for warm water (RES, 2007) [6], which are utilized for occasional capacity. The temperature of the street surface rises because of sunlight based radiation, which is consumed by the street asphalt materials and passed on to a water pipe framework introduced underneath the street surface, where it is put away in the dirt or other stockpiling tanks.

[3] PHOTOVOLTAIC TECHNOLOGY

Researchers from around the world investigated how solar energy may be captured from road pavements by inserting solar cells into the infrastructure. They came to the conclusion that present thin-film solar cells are difficult to employ on surfaces that are subjected to mechanical loads and that environmental factors can lead to premature corrosion and wear. As a result, the researchers are working on new thin-film solar cells that will be suitable for use on road surfaces.

Julie and Scott Brusaw proposed Solar Roadway, a sunlight-based gatherer framework that would supplant the top layer of the street surface (SR, 2015) [7]. The Solar Roadway consists of a set of structurally built solar panels that are placed to the road surface and convert solar radiation into electrical energy. They have a design patent on the upper layer of the (Brusaw and Brusaw, 2014) [8]. Simultaneously, the upper layer should guarantee that sun-oriented radiation is sent to the photovoltaic cells underneath it to accomplish a high transformation proficiency.

Toegepast Natuurwetenschappelijk Onderzoek (TNO)[9] and other mechanical accomplices in the Netherlands have fostered a model venture considered SolaRoad that comprises a particular cycleway framework (SolaRoad, 2014; TNO, 2014)[10]. The cycleway consists of substantial pieces with a ten-centimetre-thick glass top layer. Precious stone silicon sun-based cells are put behind this glass layer, though the introduced force and energy transformation productivity are not shown. The modules are implanted in concrete slabs and laid on top of the pavement's base layer. The next stage, according to the project's designers, will be to adapt the technology for use on roads (SolaRoad, 2014) [10].

B. VEHICLE MECHANICAL ENERGY HARVESTING ON STREET ASPHALTS

[1] ELECTROMAGNETIC TECHNOLOGY

Electromagnetic generators work on the principle of EM induction, also known as Faraday's law, which states that when an electric conductor moves in relation to a magnetic field, an electric current is induced in the conductor (Beeby et al., 2006) [11]. These generators are typically found in large power facilities that utilize both non-renewable and renewable energy sources. More modest electromagnetic generators have been made in energy collecting in the course of the last decade to change ecological fuel sources (for the most part mechanical vibrations) into electrical energy.

Rather than piezoelectric gadgets, electromagnetic generators are not set off straight by the mechanical energy of vehicles. At the point when reaper units depend on water-powered or pneumatic frameworks, electromechanical frameworks, or MEMS, interfaces are utilized, as clarified in the accompanying segments.

1. PRESSURE DRIVEN AND PNEUMATIC ENERGY HARVESTING SYSTEMS

A water-powered framework includes a drive or transmission framework that sends powers and electric machines utilizing a compressed water-powered liquid.

The difference with pneumatic systems is the working fluid; instead of liquid, air is used (Parr, 2011) [12]. Hydraulic systems can be employed in the other direction on road pavements, delivering mechanical energy from automobiles to operate electric equipment.

2. ELECTROMECHANICAL HARVESTING SYSTEMS

Electrical devices are controlled by mechanical components in electromechanical systems or vice versa. Mechanical energy is utilized to incite an electrical machine, making electrical energy in electromechanical energy gathering frameworks.

The electromechanical frameworks utilized in street asphalt energy reaping can be parted into four classes.

- Decay Rot is the way toward changing over the pivoting movement of a surface into the rotational motion of an electric generator.
- Another way is converting a surface's linear motion into an electric generator's rotational motion (Lin–Rot).
- Next is converting a surface's linear motion into an electric generator's linear motion (Lin–Lin).
- Further, converting a surface's rotating motion into an electric generator's linear motion (Rot–Lin).

3. MEMS Harvesting Systems

MEMS is a technology that uses microfabrication techniques to manufacture tiny mechanical and electromechanical components. MEMS can range from relatively simple structures with no moving parts to extremely complex electromechanical systems with multiple moving parts, all of which are usually controlled by integrated microelectronics. The use of MEMS to gather energy from ambient vibration and convert it into electrical energy has sparked much interest recently (Stephen, 2006) [13].

Vibrations are used to trigger piezoelectric materials to generate electrical energy in a system consisting of a microstructure for application under the road surface. Because the technology is still in development, no commercial applications have been established, and no technical findings of trials have been published.

[2] PIEZOELECTRIC TECHNOLOGY

Piezoelectric materials gather strong state materials that can make electrical energy when pressing factors or vibrations are applied (Beeby et al., 2006) [11]. If we desire to change mechanical energy into electrical power, both vehicle pressing elements and beats made out and about asphalt can be utilized to work piezoelectric transducers (Xiang et al., 2013) [14]. Zhao and associates (2010) proposed and examined the utilization of cymbal piezoelectric transducers on street asphalts. For one vehicle passing, 12 mW of energy was made at a recurrence of 20 Hz; this compared to 006 J for each vehicle section, demonstrating transformation effectiveness of under 15%.

Slope et al. (2014) utilized information given by the organizations to look at the items created by Innowattech and Genziko. They present an energy age for every module, per vehicle, of 576 J from Innowattech; in any case, Genziko has introduced an energy age for each module, per vehicle, of 40 J, more than seven times Innowattech. However, the study's authors determined that none of the companies has enough real-world environmental validations to back up the reported energy generation figures.

III. COMPARISON OF TECHNOLOGIES DESCRIBED ABOVE

The parameter on which we can spot differences between the energy collecting systems mentioned in the preceding sections is their power output. Aside from their medium, electromagnetic harvesters often have a large power output, varying from almost 15 W to 600 W in various references. This amount of electricity is adequate for street lights, amenities, and wireless connectivity. However, because this technology affects traffic flow, requires maintenance, and is still relatively new, its usage on highways is limited.

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Another way to capture energy from roadways is with piezoelectric energy harvesters. They have a lesser power output than electromagnetic systems, and their manufacturing and maintenance are more costly than the usual cost. They may, however, be installed directly in the pavement structure (in a protective container), and, unlike other techniques, their efficiency or performance is not affected by the weather. They can be used in distant sensors and systems that demand micro-level power despite their modest power output.

Harvesters of thermoelectric and PV cells can also be put in civil constructions, such as road pavements, for harvesting energy. Both of them rely on local weather and climate, which restricts their use. In comparison to electromagnetic systems, they likewise have a modest power output. Both are often simple to install and incorporate into the road construction, as well as being less expensive than piezoelectric harvesters. However, like piezoelectric harvesters, these harvesters have a low power output, making them ideal for low-power sensors and devices.

IV. GREEN ROADS

INTRODUCTION

This concept is projected to serve a dual purpose: extracting energy that would otherwise be squandered by automobiles, radiations, and people or pedestrians, and extending the pavement's service life by increasing its thermal and mechanical qualities. This design might be a sustainable road that consumes the least amount of natural resources, emits the least amount of greenhouse gases, prevents air, noise or water pollution, and ensures medical and traffic safety. Whatever the goal of applied technology in a future sustainable roadway system, optimizing the thermophysical properties of road pavement materials should be a top priority. This can be accomplished through two ways: either by using light- or dense weight and ordinary aggregates to produce concrete, such as quartzite, limestone (calcium carbonate), normal sand, pulverized (sintered) fuel ash lightweight aggregate, copper fibres, and so on, or by substituting phase change materials for a specific asphalt mixture (PCMs). Both of them seem to have the capacity to improve incident solar power absorption and storage throughout the pavement's layers, as well as mitigate the UHI impact by controlling the temperature on the pavement's surface, therefore extending the pavement's service life and decreasing ravelling/rutting occurrences. Also, instead of PCMs or simple asphalt changes, Nanomaterials may be included in the pavement infrastructure; however, their rising costs raise numerous issues due to their production.

[1] GREEN ROAD-TYPE1

PV sound barriers and induction charging processes can be used in the same configuration, depending on their location and readiness for use. PVSBs, on the other hand, combine the needs of renewable energy production and traffic noise abatement in a single device.

They can be grid-connected, which eliminate the need for batteries, especially when used near industrialized urban cities where sound mitigation and energy demand are high.

Induction charging, on the other hand, theoretically enables the self-healing process of the pavement structure by incorporating conductive additives such as steel wool or cooper fibres into the asphalt mixture to make it electrically conductive. In general, the asphalt mixtures containing cooper fibre or steel wool have shown improved fatigue resistance, and the connectivity behaviour of copper fibres could improve heat conductivity even more.

However, given the normal cost of copper fibres, it is certainly unlikely to provide a major economic benefit.

PV sound barriers provide a variety of purposes in these types of green roads: they are grid-connected, reducing noise levels while also providing the electricity required for the induction healing process. When micro-fractures appear in porous asphalt, induction heating could be used to increase the temperature of the material.

To put it another way, the propagation of PV power to the inner structure of the pavement in order to raise the temperature is the interface between these technologies in terms of energy flow. Part of the electricity generated is leaked to the pavement, while the remainder is put into the grid, thanks to photovoltaic phenomena and the required mechanical links (regulators, inverters, batteries). The sealing of micro-fissures avoids the growth of macro cracks by preventing ravelling through.

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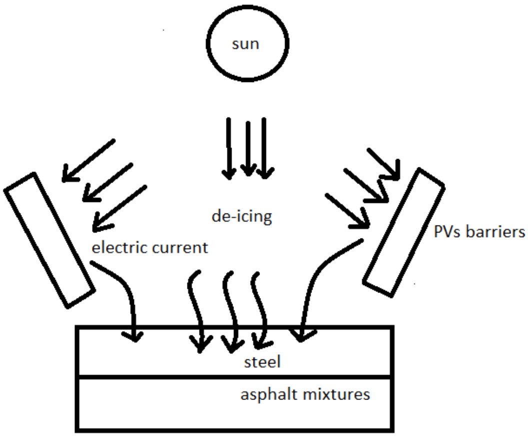

FIGURE -3: Energy Flow for Green Road Type-1

[2] GREEN ROAD-TYPE 2

A popular explored configuration is to equip the pavement structure with fluid pipes as well as the necessary materials. The fluid-working pipes are at the heart of the system, providing a conduit for the stored thermal energy to be harnessed.

Because of their lower thermal conductivity (1.8kW/mK) and huge heat capacity (1200J/kgK), asphalt pavements absorb a lot of heat and hence suffer temperature increase in hot weather. Convection then transfers the thermal energy to the fluid, raising the temperature of the fluid while lowering the temperature of the pavement.

By having a dual function that is determined by climate circumstances, this harvesting device can be used for de-icing and heating/cooling purposes on its own.

- During summers, cold water after being pumped up from an underground storage tank/medium is delivered to the upper asphalt layer of pavements via pipes. The water warms up as a result of the sun, and the thermal energy is transferred to another underground reservoir via a heat exchanger and stored there until it is needed.
- The mechanism operates in the other direction throughout the winter. The water which was previously heated is pumped out of the hot storage reservoir and is used to heat neighbouring facilities or to de-ice the asphalt pavement

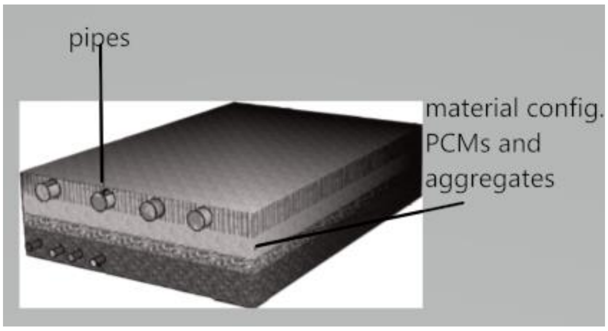

FIGURE -3: Model for Green Road Type-2

[3] GREEN ROAD TYPE -3

Piezoelectric materials, also known as piezoceramics, have been shown to gather kinetic power in the form of vibrations, which can be utilized to drive wireless connectivity of compact systems and computer peripherals, as well as sensors for healthcare applications and fracture detection.

Moreover, piezoelectric materials could be employed as actuators because when a voltage is placed across the pole axis of their poles, they can be stretched or moved. The force due to the vibrations strains PZTs, causing a voltage difference which can be dissipated via a resistive circuit.

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This technology could be utilized in conjunction with an asphalt solar collector system (ASC) in full-time inhabited areas such as parking lots or minimal traffic roads near malls or residential areas after materials adjustments (PCMs or modified asphalt mixtures).

The implemented piezoelectric sensors are used to monitor the pavement conditions in real-time as they are affected by the coupled thermomechanical stresses from the temperature difference and vehicular loads, as well as the stresses owing to the positioning of pipes. The ASC system can also be used for hydronic, district heating or cooling, or even as feedwater.

Using the ASC approach in conjunction with piezoelectric cantilevers can be a powerful combination for noise reduction. On second thought, the existence of PV panels may be able to compensate for the electricity generation shortfall. As a result, the need for lighting traffic lights and signals, road advertising, handheld devices, and enhancing sensor system performance can all be met.

V. SMART ROAD TECHNOLOGY

Roadways are continuously changing due to maintenance and development. Companies and research organizations have been trying to design ways to make these roadways safer and more driver-friendly as a result of new and rising advancements in smart technology, allowing the utilization of innovations from the automotive sector. Here, we'll look at a wide range of these technologies and how they'll progress in the near future.

[1] ROADS THAT HONK

HP Lubricants and Leo Burnett India established the world's first anti-collision vehicle management system at a hairpin bend along the Jammu-Srinagar route, which includes a pole with an incorporated incoming vehicle alarm mechanism.

At severe, sharp turns or hairpin bends, this technology uses Smart Life poles, which combine complex networked gadgets, wireless connectivity, radar systems, and an anti-collision warning system, all powered by solar photovoltaic modules.

Mechanism

The transmission of an EM wave in the 24-GHz frequency band (K-band) is used in this technique, and the frequency shift of the reflected electromagnetic wave is measured. Doppler effect of a moving object on an EM wave causes the frequency change. When the relative speed between the radar detector and the target rises, the observed shift in frequency increases, allowing for exact target speed measurement by the radar sensor.

FIGURE-4 Model of 'ROADSTHATHONK' Project

[2] ElectReon's ELECTRIC CHARGING LANE

ElectReon created the Electric Charging Lane: DWPT (Dynamic Wireless Power Transfer). It can share energy amongst all of the vehicles travelling along the road, together with direct wireless transmission.

Mechanism

The DWPT Technology's mechanism depends on an inductive coil infrastructure put beneath the surface of the road lanes. Furthermore, the working model of these devices has been optimized such that their magnetic field does not extend into the cab of vehicles, making this solution human-safe. A series of "smart" inverters, which

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basically are converters that can communicate information with one another, provides the electricity necessary to run these systems.

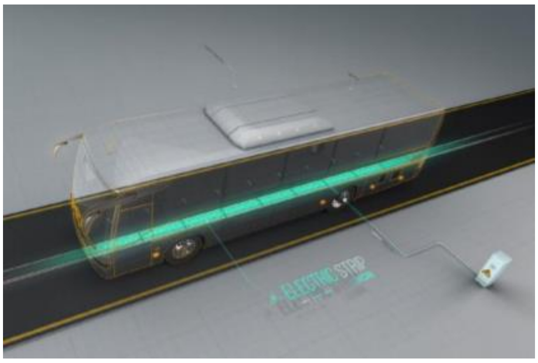

FIGURE-5 ElectReon's Electric Charging Lane model

[3] SOLAR PANEL BY WATTWAY

Wattway's pavement blends road building with photovoltaic technology to provide power that is clean and renewable. Wattway panels covering 20 square metres may provide the energy needs of a single home. In 2016, Colas put the first solar road to the test in a tiny hamlet in France, utilizing a 1-kilometre (0.62-mile) length of solar pavement to power the community's street lighting and service its 3,400 people.

Mechanism

Wattway's solar panels employ polycrystalline thin-film cells as their mechanism. Each module has 28 active cells with a total production area of 0.96 m2. Photovoltaic cells are placed in resin and are narrow or thin enough to not pull away from the road underneath them when the temperature changes.

FIGURE-6 Solar Panel by Wattway project Model

VI. METHODS TO MAKE THIS TECHNOLOGY BETTER IN FUTURE

[1] Newly designed hybrid piezo-pyroelectric materials with higher power generation efficiencies can be discovered.

[2] Experiments may be conducted to determine the best laying pattern for embedding the crystals beneath the surface of the pavements so as to achieve higher outputs while being cost-effective.

[3] Experiments can be conducted to establish the optimal distance from the surface at which various materials function best.

[4] More research into the endurance of such embedded layers is possible.

VII. CONCLUSIONS

Because traffic volume and wheel hundreds have been steadily growing, the energy that might be saved by using pyro- and piezoelectric technology is being squandered. One of the most practical and beautiful techniques of harvesting energy is to embed roads with electricity and pyroelectrical devices. The facility created by this approach is environmentally benign, has a low carbon footprint, and may be useful in reducing carbon emissions. This energy is frequently used to power street lights, toll collection stations, and other small-scale applications; previously, it was assumed that the energy generated by the pyroelectrical impact was far less than that created by electricity; thus, it was thought that investing in harnessing the waste energy generated by the pyroelectrical impact would be unprofitable; however, latest researches have shown that the electrical phenomenon produced as a result of temperature differences and thus malformations in piezo-pyro hybrid crystals is roughly equivalent to the energy produced by electricity, and thus it cannot be ignored. However, putting these technologies into practice in the real world is challenging since most of the techniques used in this space region unit are still in the research and analysis stages. Gathering energy using the integrated piezo-pyro electric pavement, on the other hand, adds a whole new dimension to energy production and has a lot of promise for highways and roads to function as both a powerful power generation system and a means of getting to places. Thus, collecting energy from roadways appears to be a viable option, but more research and development is required before it can be implemented properly in the future.

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