Gemns: Innovations that Lead the Way in Energy Harvesting & IoT

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Executive Summary

As IoT sensors and devices increase, so does the need for sustainable and maintenance-free power solutions – the service costs of battery replacements are simply prohibitive and hinders mass deployment. WePower Technologies' advanced kinetic energy harvesting solutions replace conventional battery sources to enable reliable power generation for IoT and smart device applications that are truly maintenance and service free. WePower's novel energy harvesting targets wireless data transmitter applications across the IoT in industrial, automotive, smart home, smart buildings, and aerospace markets. Our mission – To engineer reliable, scalable, sustainable energy harvesting solutions that power the IoT, all while improving product performance, robustness, and eliminating wasteful batteries.

The next decade will see a sprawling IoT infrastructure with billions and even trillions of connected sensors and data transmitters coming online. These wireless devices need a power source, but batteries are expensive, wasteful, and endlessly tedious to replace - especially in remote, unattended sensors. Energy harvesting is a developing market, but advancements in generators and harvester circuits are enabling a wide variety of energy sources. Development of microelectronics and wireless chipsets with ultra-low power technology are allowing the IoT industry to do more advanced measurement and reporting with less energy, allowing an increasing number of applications to be powered by harvested energy and avoiding the challenges presented by batteries.

Introduction

In a world increasingly dependent on wireless technology, the biggest challenge remains the same: energy. Batteries require maintenance and service, hard-wired solutions limit design flexibility, and both create long-term waste. At WePower Technologies, we've developed a solution — Gemns™ energy harvesting technology. Gemns patented technology generates power on demand using nothing but motion. Capable of generating more than 30x more power than similar kinetic energy harvesting systems, Gemns is in a unique position to offer battery replacement solutions in devices that were previously unattainable by antiquated energy harvester offerings.

Traditional batteries require frequent maintenance and replacement, which impacts scalability and sustainability. Regulatory pressures and market demands, such as Europe's mandating user-friendly serviceability of batteries, drive the need for innovative battery-free power solutions.

WePower's Gemns technology is focused on applications where the source of energy - a mechanical event – is locally derived by the target application/device. For example, a wireless switch or button harvests energy from the mechanical interaction with the device to energize a transmitter that reports the intent of the interaction (on, off, dimmer, brighter, etc.). In another example, stored magnetic energy is released by a mechanical or chemical event (water leak dissolves a liquid-sensitive film strip) and the harvested electrical energy is used to report the leak. In a final example, mechanical energy from vibration is harvested and collected. Once the energy attains a sufficient threshold, the powered enabled IoT sensor measures, analyzes, and reports on the vibration of the motor or pump.

Technology Overview

WePower's electromechanical Energy Harvesting Generators (EHGs) convert small mechanical motions into usable electrical energy. Unlike competing solutions, WePower's technology delivers sufficient energy for advanced wireless protocols and higher transmitter signal power.

Battery lifetimes in IoT devices are generally shorter than the lifetime of the IoT devices themselves. In a world of rapid technology change and planned obsolescence that contemplates billions of new IoT devices a year, the impact of battery replacement becomes a sobering reality. Batteries also become depleted ahead of the designer's planned lifetime, requiring maintenance to check batteries periodically in mission-critical applications and to service them on random schedules in other situations.

In the USA alone, around 3 billion batteries are thrown away every year, creating an estimated 180,00 tons of hazardous waste, not including 160 million phone batteries. They contain various metals including lead, mercury, and lithium. Old batteries pose a fire risk if they're submerged in water or damaged – from April 2019 to March 2020 there were 260 fires caused by 'zombie' batteries in recycling or waste management facilities. [1]

Between the downtime caused by dead batteries, the cost to test and replace them, and the risks and environmental costs of their improper disposal, batteries are an unwanted hit to the bottom line of commercial and industrial users and simply an annoyance to consumers. If you're a utility estimating the cost to roll a truck, you're likely low-balling the amount. Many utilities take an ultra-conservative guess, claiming truck rolls each average $250 to $500. But the reality is, there are many factors that can cause the cost to escalate quickly. A high cost is associated in sending someone out to check and service remote batteries. [2]

The cost of not testing or replacing a battery can be even worse if it powers an IoT device that monitors or controls a critical process. It is easy to imagine a battery powered sensor involved in industrial process control. If the battery fails unexpectedly, the process could need to be shut down and the operation would see lost profits until the battery was replaced. If the shutdown was not properly performed, equipment damage could also occur, further extending downtime.

The historical approach was to wire critical monitoring devices and controls. However, installing new wiring in conduit in industrial facilities can cost $6-$8 per foot. [3] In power generation facilities, this figure can easily double.

There is clear justification for a reliable, battery-free energy solution for these remote, wireless monitors and controls. Enter WePower Technologies' energy harvesting generators and circuits that can provide from under 1 mJ to well over 4 mJ from the flip of a switch or push of a button. A single mJ is enough to operate a Bluetooth beacon, or Zigbee green power device control or sensor with minimal security, while

[1] https://www.businesswaste.co.uk/your-waste/battery-recycling/battery-waste-facts/
[2] https://www.sandc.com/en/gridtalk/2017/march/20/the-real-cost-of-a-truck-roll
[3] https://accutechcom.com/conduit-installation-cost/

the 4 mJ level allows Z-Wave Long Range messaging with full security and potentially allows Thread protocol.

The advent of such self-powered controls and sensors comes just in time as the EU deadline approaches for a mandate that all batteries be user-replaceable, a rule that will all but eliminate batteries in wall switch fixtures. [4]

Key Features & Benefits

Obtaining energy more than 1 mJ per-action is useful for reliable BLE and related low-power protocols as it allows higher TX power for better range and more reliability. At 4 mJ, more secure protocols, such as Z-Wave LR, and secure pairing in Bluetooth become possible. New device options in Thread should also be possible with close to 4 mJ total energy.

In all IoT devices, there is a minimum energy cost to start the processor, synchronize the clocks, load the operating system, and prepare the transmission protocol. Historically, this one-time startup cost was higher than the harvested energy of push buttons and other simple controls and kinetic sensors. This forced the engineering choices towards battery-based systems. For example, the stored energy of a CR2025 coin cell is close to 2 kJ.

As systems with 100 µJ to 500 µJ became available, and as lower startup energy processors became available, it became possible to perform a tightly optimized boot up and transmission process without a battery. For these limited cases, it was finally possible to eliminate batteries in some applications. Even though the inexpensive coin cell could (in theory, but not in practice) power millions of cycles, much of the battery's stored energy is lost to idle backup power while the system waits for an action.

With WePower's systems routinely providing 1-4 mJ per mechanical action, the security, reliability, and range of battery-free systems meet those of battery powered systems with no power dissipated during sleep times and no discarded batteries. WePower's generators have been cycle-tested to beyond 1-million activations.

For those applications where the press of a button or a mechanical impact is the event to be reported, kinetic energy harvesting has clear advantages in terms of maintenance, waste reduction, and simplicity. WePower's EHGs produce more than sufficient energy to allow secure and reliable transmission of events using a real time

[4] https://www.consilium.europa.eu/en/press/press-releases/2023/07/10/council-adopts-new-regulation-on-batteries-and-waste-batteries/

operating system (RTOS), such as Zephyr or FreeRTOS, with encrypted data and even per-transmission key exchange.

Low Power versus Low Energy

One aspect to enabling this new class of devices is to understand the difference between low power design and low energy design and to understand the vital role of startup transients and delays. Traditional firmware developers and electronics designers often sacrifice startup performance and focus on optimizing steady state operation because, for battery powered electronics, there will be one startup event but years of steady state average operation.

There is traditionally little concern if initial startup takes hundreds of milliseconds and tens of mJ when the total battery life could be a few years and a few kJ. In such cases, a quartz crystal is used for the 32 kHz clock to minimize sleep current and power. This power reduction saves considerable energy over the life of a battery but significantly delays startup and adds undesirable energy burden to the generator. Even within the generator, the performance of DC-DC regulators is completely focused on steady state power efficiency and startup energies can be large and variable.

Low energy design and operation is a very different paradigm because it is expected that not only startup, but the entire life cycle, will complete in tens or at most hundreds of milliseconds. Such devices cannot perform over the air (OTA) firmware upgrades without auxiliary power, so extensive secure boot checks are not required. Their functions are well defined and do not require loading operating system modules that won't ever be used. Boot time is boot energy and it needs to be small compared to the overall operational time and energy.

While capacitors are an absolute necessity to smooth and stabilize voltage rails and to store energy, every capacitor must be as small as possible to minimize abandoned energy and speed up the initial attainment of startup voltage. For a 1.8V system with an effective total capacitance, $0.5*(1.8v)^2*C_{eff}$ is unusable. Boost regulators can extract bulk stored energy below this level, but their efficiency and output current limits fall off quickly at low input voltages. For a 500 µF effective capacitance, 810 µJ are abandoned without boost mode regulators. Various cost-performance tradeoffs can recover 200-600 µJ of this energy.

Clock startup times are key factors, but there is a tradeoff in that the lowest power and most stable clocks have the highest Q resonator and take the longest to start up. High frequency crystal oscillators are mandatory for most transmission protocols, but low frequency crystal oscillators are not. Whereas battery powered devices spend over 80% - often well over 90% - of their lives in sleep mode and often need to maintain a real time clock accurately, battery-free systems are short-lived and very active. These latter systems are idle for only a small fraction of their time, and they almost never enter deep sleep because waking from deep sleep incurs restarting clocks, which costs more than the savings from deep sleep over normal idle sleep.

Paradigm shift from Low Power to Low Energy Management

IC designers need to consider startup time and energy to further expand the capabilities of battery-free systems.

While there are exemplary MCUs that do excel at startup performance, it is often not well characterized or well thought out. Even when MCUs are capable of it, the IDE developers do not always allow granularity of low-level settings for rapid firmware development options that take advantage of it.

While bare metal coding can be used to carefully wring every µJ and millisecond, developers of code libraries and IDE developers need to build in low energy, fast boot options and make them available in the user-selectable options. Application-level developers need to be aware of the costs and benefits of sleep cycles and use this knowledge to optimize sleep modes versus recovery energy and time.

Great care is needed to minimize quiescent currents. Resistive pullups, voltage dividers, LDOs and references, and even capacitor leakage rates must all be considered, not just the silicon datasheet values of quiescent current.

Technical Specifications

WePower Technologies has developed a range of EHGs to meet different application needs. Each model is optimized for specific types of motion and energy output. Each of the three base models should be considered as an example that can be scaled up by at least 10x in energy and down at least 4x to offer a flexible size-weight-cost vs. energy tradeoff. Each of these may be paired with a family of harvesting circuits and used to power a wide variety of loads. These include – but are not limited to – RF SOCs for wireless IoT applications.

Gemns G100: Industrial-Grade, Standard 22mm format Push Button

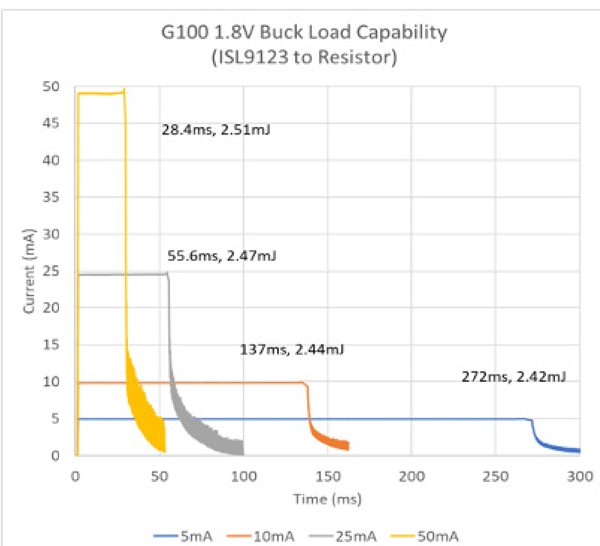
The G100 is a highly durable, wireless push button for industrial applications. Tested to over 1 million activations, this device was the first proof of concept for the Gemns technology, demonstrating how motion-based energy harvesting can replace traditional power sources.

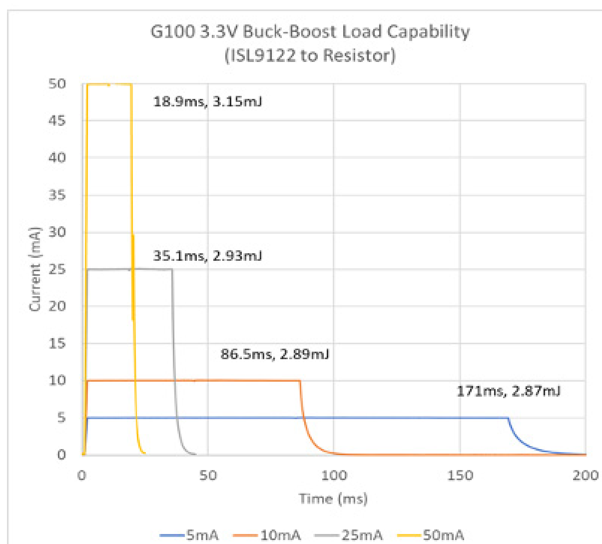
Key Features

- Generates power from button presses and other one-way, linear motion.
- Tested for over a million activations, ensuring durability.
- Future applications include automotive interfaces, military distress signals, and industrial machinery.
- Over 7 mJ of gross energy and over 3.5 mJ of net regulated energy over a range of voltages and load currents.

The amount of energy that can be used by the load is dependent on the output stage of the harvester. Buck-boost regulators are available that operate from about 1.5V to 5.5V with about 90% efficiency. Starting from a charged state of 4.5V and operating down to 1.5V leaves 1/9th of the energy behind while the remaining 8/9ths can be regulated at nominally 90% energy. This means that about 80% of the recovered energy is available to the system as regulated energy.

The 80% estimate should suggest that the G100 would provide as much as 5.23 mJ regulated; however preliminary tests with a simple harvester attained 2.25~2.75 mJ. Improvements to that circuit and to the actuation have improved this to 3.2~3.6 mJ and an improved circuit has attained as much as 4.2 mJ. This is much more than required for BLE and Zigbee GPD. Z-Wave Long Range sensors can cold boot and transmit alarms in as little as 2 mJ. Full security capabilities are expected to require 3-4 mJ with well over 400 feet of reliable operating range.





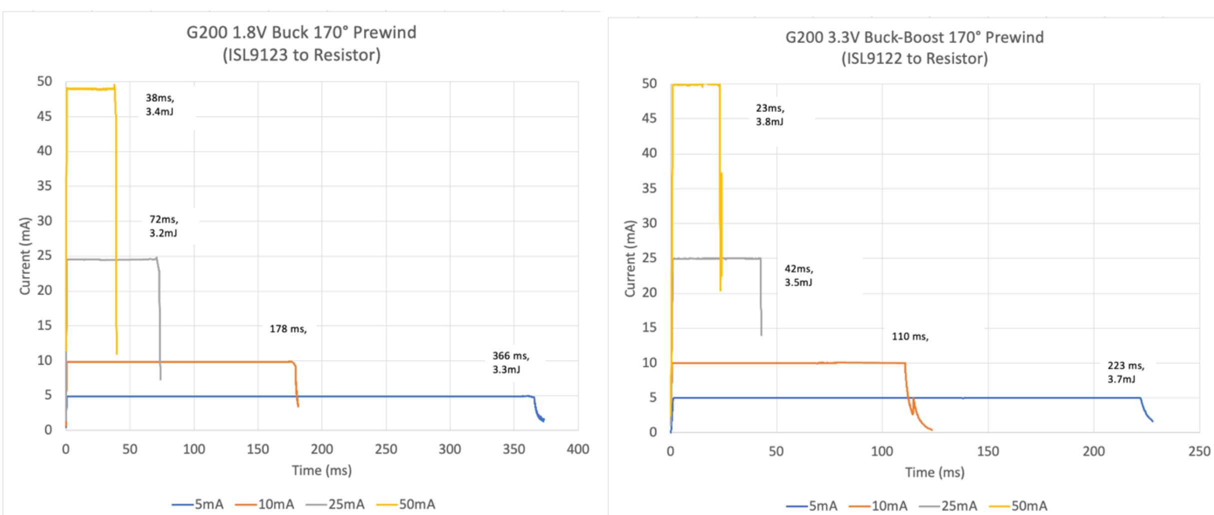
Performance of G100 with a lower cost harvesting circuit. Subsequent improvements attain 3.5 mJ.

Gemns G200: High-Power Energy Harvesting for IoT

The G200 is the most powerful EHG in the Gemns lineup, capable of generating a larger energy output for applications that require more power. Initially designed for safety and limit switches in industrial environments, the G200 is ideal for applications where reliability and robustness are essential.

Key Features

- Produces a higher energy output than the G100, yielding over 8 mJ of gross energy and over 4.5 mJ of net regulated energy.
- Rotational generator can sense the direction of initial motion (ON/OFF switches)
  - can be driven by bidirectional or unidirectional linear motion.
  - can be driven by rotational sources.
  - Energy can be pre-charged, retained, and released on event.
- Designed for demanding applications in industrial automation and IoT.
- Enables wireless operation of safety sensors, access controls, and high-energy IoT systems.
- The small form factor allows integration into limitless applications.



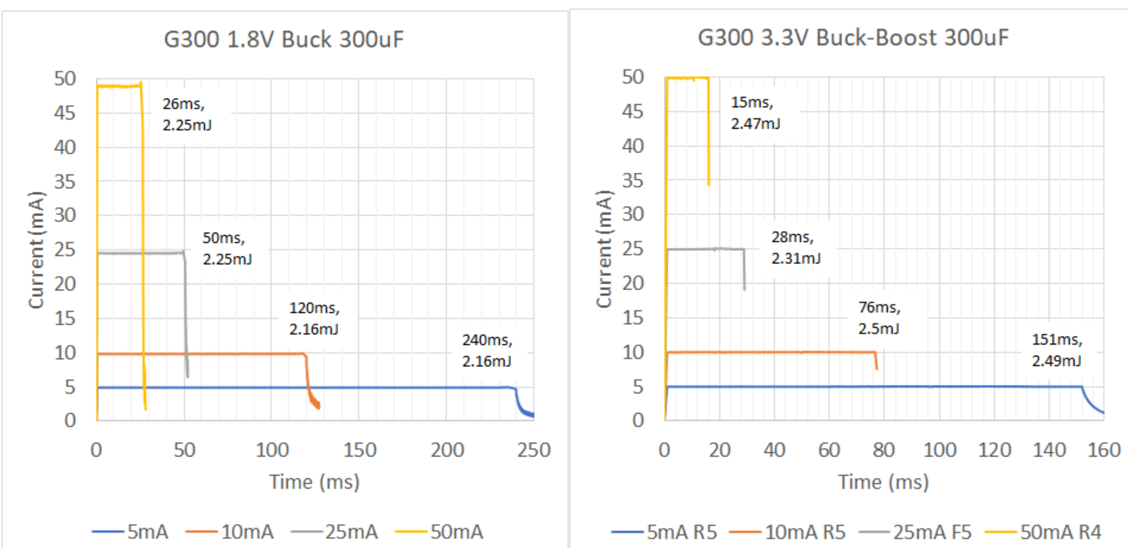
Performance of G200 with a lower cost harvesting circuit. Subsequent improvements attain as much as 4.5 mJ.

Gemns G300: Wireless Slide Switch for Smart Homes

The G300 is a high-output, low-force activation EHG optimized for consumer electronics. Its slide-switch mechanism allows for smoother operation while generating enough energy to transmit a wireless signal. This makes it well-suited for lighting control, smart home devices, and new forms of IoT interactions.

Key Features

- Generates power with a sliding motion, requiring less force than traditional switches.
- Can support magnetically coupled actuation (i.e. in non-contact window monitoring).
- Designed for consumer applications, including lighting controls and smart home automation.
- Future potential in innovative activation methods for IoT products.



Performance of G300 with a lower cost harvesting circuit.

Application and Use Cases

Gemns energy harvesting technology is suitable for application in any industry, replacing batteries and wired connections where motion is performed as the event to be reported. Some of our reference products demonstrate the capabilities of the technology.

Wireless Battery-free Leak Detector

The leak detector is a unique product energized by the G200 that is preloaded with energy via a magnetic tray. Energy is stored in an indelible permanent magnet field until a release latch is activated. A liquid-soluble strip retains the release latch until exposure to liquid with subsequent release of stored energy. The energy is recovered and regulated in tens of milliseconds, providing enough energy for the demanding requirements of Z-Wave Long Range and other protocols of smart home networks. This novel solution of and indelible energy source allows for battery-free operation that will never degrade and is assured to work at the moment of a leak event, whether a day, a year, or a decade from activation.

Wireless Light Controller

A lighting controller can also be energized by the G200, allowing users to control lights wirelessly without batteries or wiring. In this case, the user physically flips a switch or rocker on a panel with the energy harvested off the switch action by the user. In fact, the G200 generates excessive energy for simple light switches using low security protocols like BLE beacon for Zigbee GPD, Z-Wave Long Range, Thread, and others where economies of downsizing can be realized. The G300 is also suitable for this application. Wireless and battery-free operation enables quick installation and greater flexibility, particularly in smart homes and office environments. The world is now presented with a more sustainable solution to batteries, making WePower's solutions a game-changer.

Door Sensor

A security sensor using the G200 or G300 to monitor door movements has been demonstrated. The sensor generates energy every time the door opens or closes and sends alerts wirelessly without requiring an external power source. Their unique bi-directional detection capability not only notifies of door usage, but also reports the door opening or closing status.

Vibration Sensor

A variation of the G100 has been used to harvest energy from vibration – e.g. motors, engines, pumps, and transmissions – and uses that vibrational energy to measure and report the vibration signature. Continuous asset monitoring of vibration can offer early prediction of bearing failure and other issues. Scheduled predictive maintenance can dramatically reduce industrial downtime and maintenance costs and prevent potentially dangerous catastrophic failures.

Scalable and Tailorable to Suit Application Needs

Some applications can reliably operate with less energy and smaller harvesters with lower cost electronics - for these cases, WePower's EHGs can be scaled down from existing designs. Perhaps of more interest is the ability to scale up the designs and address other communications options such as cellular and Wi-Fi. These solutions scale up with the only meaningful limitation being how much mechanical energy can be applied.

Examples have shown linear and rotational harvesting. A wide variety of mechanical motions may be adapted to either of these harvesters through mechanical translation if kinematics through various traditional mechanisms. Whether it's a twist, push, slide, open/close event, or vibration or shock, WePower can harvest the motion.

WePower Harvester Solution Focus

- Focus on Kinetic Energy harvesting – virtually any application that inherently involves motion can leverage our harvesting technology.
- WePower's core competency in simple kinematic adaptation of the application's motion to our harvester providing for elegant and novel solutions.
- Electromagnetic Harvesters have a relatively high energy/volume density.

Mechanical Design

- Mechanical harvester design must focus on all parasitic sources of losses for optimal design efficiency.
- Reducing stiction, friction, and windage become a key focus on mJ and sub-mJ levels of generators.
- High volumetric efficiency allows compact designs.

Electrical Design

- High-efficiency extraction of energy.
- Rapid Energy Extraction.

- Long-duration hold-up time.

Competitive Advantages

EnOcean was one of the first companies to launch a product with a RF transmitter based on push button energy. With 120 µJ total energy, careful optimization of MCU code and limited transmitter power allows them to send BLE beacons or Zigbee GPD packets, as well as proprietary ISM band packets. EnOcean's solution also uses a custom (non-standard) BLE software stack due to energy limitations.

Various Chinese copies and improvements have attained 400~500 µJ and begin to provide the energy levels needed for better transmitter range. These still do not support higher-security RF protocols and the bidirectional handshakes needed to reauthenticate a control switch.

With 3-5 mJ attainable in multiple formats and scalability to meet varying application needs, WePower Technologies products support secure protocols like Z-Wave Long Range, Thread, and allow BLE confirmation and retry cycles that significantly enhance the reliability of the system.

Integration and Licensing

WePower offers its technology through licensing agreements, enabling partners to integrate energy harvesting into their products without the need for battery-based solutions.

The typical implementation process starts with WePower working collectively with clients to understand the application's harvesting means/take-off point, development of output energy requirements, and understanding integrated packaging constraints. WePower will then perform an assessment identifying candidate harvester model(s), work collectively with the client's engineering team to design the packaging, mechanical linkages, and integration of the application solution. With a formal design and BOM available, the client can work with their existing contract manufacturer (CM) to get costing information. WePower can also be involved in Product Validation activities with the client.

In the end, the client owns the supplier/CM process, the design elements specific to their application, and the rights to manufacture the WePower EHG and supporting electronics. A per unit royalty is paid to WePower Technologies.

Conclusion

Traditional power sources such as batteries and wired connections limit the scalability and sustainability of IoT and wireless devices. Gemns technology addresses these challenges by providing a self-sustaining power solution that offers multiple benefits:

- No Battery Replacements – Reduces service/maintenance costs and improves device longevity.
- Eliminates Wiring – Enables flexible installations in locations where running power is difficult or impractical.
- Eco-Friendly – Reduces electronic waste by eliminating disposable batteries.
- Scalable for IoT – Allows for seamless integration into industrial, automotive, and smart home applications.

WePower's technology presents a paradigm shift in power generation, eliminating the need for disposable primary cell or rechargeable batteries and providing a long-term sustainable solution for the IoT and smart device industries.

To learn more about how Gemns energy harvesting technology can power your devices, visit www.gemns.com.