CONFLOW WILL POWER

The Next Wave of Life

Market Research on Energy Harvesting for IoT Device

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Executive Summary

In Europe, market size of Energy Harvesting for IoT devices is expected to be USD 59 million in 2019. The market is expected to grow USD 96 million by 2025.

In Asia, market size of Energy Harvesting for IoT devices is expected to be USD 25 million in 2019. The market is expected to grow USD 48 million by 2025.

In North America, market size of Energy Harvesting for IoT devices is expected to be USD 59 million in 2019. The market is expected to grow USD 96 million by 2025.

There are less number of players in Energy Harvesting for IoT device applications around the world. Large players such as Texas Instruments, Analog Devices are mainly into energy harvesting for ICs.

Market Overview

It is estimated there will be around 85 billion devices connected to the internet by 2025. Furthermore, it is estimated that 200 things per person could be connected, potentially leading to several hundred billion devices through IOT.

There are many industries where reliable power sources are unavailable. IoT is one of them. Oftentimes, connected devices have to rely solely on battery power for operation, which adds cost and limits effectiveness in their application. There are also instances in which reliable power is accessible but undesirable.

For instance, a door entry sensor could be plugged into the nearest outlet, or have power running through the wall, but this can drastically increase installation costs and introduce potential security vulnerabilities. This makes battery life one of the biggest hurdles to IoT systems today.

Batteries don't currently last the life of a sensor, leaving system designers with two options: either let the battery determine the life of the sensor or create a strategy for replacing sensor batteries. Energy Harvesting can counter this problem.

Energy harvesting refers to the practice of capturing energy from ambient sources to power devices. This is how weather sensors out on a farm can use solar power to supplement their battery power. In other instances, such as wearables, the kinetic energy of the wearer can be used. This has large implications in IoT. It can increase the lifetime of a system while reducing maintenance.

Many IoT edge devices are battery powered, particularly actuators and sensors which are generally placed in decentralized locations. The corresponding energy use and physical waste related to batteries are considerable. One rough estimate yields a figure of more than 23 billion battery powered IoT devices in 2025.

Atmosic Technologies, working on Energy Harvesting technology, has developed Forever Battery - where the battery will last without replacement until the device itself fails or is made obsolete by emerging technologies. One of their solutions - M3 chip is an implementation of Bluetooth 5 that uses 5 to 10 times less energy than existing Bluetooth 5 solutions. In addition to this, they have made the device smarter, by taking advantage of a sleep state as much as possible and only waking up when the device has something to report or needs to perform its function. With these improvements, power usage is minimized, making energy harvesting methods viable for the lifetime of that device.

Energy Harvesting Potential

Though the power densities of some technologies are not outstanding and the additional cost may be an obstacle for mass implementation, there are possibilities and good arguments for implementing EHT:

- As the number of IoT devices increases so can also the number of implemented EHT, which may decrease the costs.
- Manufacturer alliances like EnOcean can have lower costs as a purchasing co-op, a larger promotional public appearance and a larger pool of knowledge and resources for product development with EHT.
- The life time of EHT is over 5 years. There are EHT devices which are used already for 15 years without component replacements. Thus, remote devices do not have to be regularly serviced -> Life time design without interruptions.
- Extrapolated from past transistor-driven improvements and the inclusion of Cloud-Computing for data processing, it is assumed that the energy consumption of electronics will further decrease, which increases the viability of EHT.
- The biggest energy saving potential of EHT is expected in building automation - copper wiring can be reduced, as well as materials, installation, and maintenance costs.

Application Area	Sub-Application Area	Application	Devices	Power Source	Energy source for EH
Smart Building	Smart Home	Smart Lighting	Smart Light Switches	Battery, Energy Harvesting (EH)	Vibrations (pressure)
		Home automation	Battery/EH powered sensors	Battery, EH	Light, thermal
	Smart Office	Office automation (HVAC, lighting)	Sensors (temperature, presence, light, smoke, CO, CO2)	Mains, battery, EH	Light, thermal
		Intrusion detection	Door / window sensors	Mains, battery, EH	Light, vibrations
			Motion sensors	Mains, battery, EH	Light
		Fire detection	Smoke detector / gas sensor	Battery, EH	Light, thermal
	Smart Factory	Asset tracking	RFID tag	Passive, battery, EH	Light, thermal, RF
		Inventory management	RFID tag	Passive, battery, EH	Light, thermal, RF
		Maintenance conditions	Dedicated sensors	Mains, battery, EH	
		Smart pipelines	Sensors (thermal, pressure, humidity)	Battery, EH	
Smart Health	Smart Health	Physical activity monitoring	Activity tracker	Battery, EH	Vibrations, thermal, light
		Weight monitoring	Smart body scale	rech. battery, EH	Vibrations, thermal, light
		Sleep monitoring	Sleep sensor / activity tracker	rech. battery, EH	Vibrations, thermal, light
		Nutrition monitoring	Smart cup	rech. battery, EH	Thermal
			Smart clothes	rech. battery, EH	Vibrations, thermal, light, RF
		Human monitoring	GPS tracker / beacons	rech. battery, EH	Vibrations, thermal, light
		Long term monitoring / preventive care	Body-core-temp sensors	rech. battery, EH	Thermal
		cardiologic health	Pacemaker	Battery, EH	Vibrations
		Dental health	Electrical toothbrush	rech. battery, EH	Light, RF, electromagnetic
		Emergency notification	Emergency tag (watch, pushbutton)	rech. battery, EH	Vibrations, thermal, light
		Fall detection	Fall sensor	Battery, EH	Vibrations, thermal, light
		biocompatible sensor	Smart pills	Battery, EH	Thermal, redox react

Probable IoT applications with Energy Harvesting Technology (EHT)

Application Area	Sub-Application Area	Application	Devices	Power Source	Energy source for EH
Smart Infrastructure	Smart Mobility	Road pricing	Transceiver in car	On-board, rech. battery, EH	Vibrations, solar
		Smart roads	Sensor networks in roads	Battery, EH	Vibrations, thermal, RF
			Smart road lights	Mains, battery, EH	Vibrations, solar
			Energy gaining roads/sport fields	EH	Vibrations
		Car-to-infrastructure communication	Various devices in car	On-board, battery, EH	Vibrations, solar
		Smart tunnels/bridges	Dedicated sensors (pressure, humidity, temperature etc.)	Mains, battery, EH	Vibrations, thermal
	Smart Logistics	Product tracking	RFID tag	Passive, battery, EH	Vibrations, thermal, light, RF
		Quality of storage condition monitoring	Dedicated sensors	Battery, EH	Vibrations, thermal, light, RF
		Quality of shipment conditions monitoring	Dedicated sensors	Battery, EH	Vibrations, thermal, light, RF
		Fleet racking	Maintenance conditions	Battery, EH	Vibrations, thermal, light
		Waste management	Waste containers with filling sensors	Battery, EH	Light, vibrations
	Smart Retail	Product tracking	RFID tag	Passive, battery, EH	Vibrations, RF, thermal, light
		Automatic shop check out	RFID tag	Passive, battery, EH	Vibrations, RF, thermal, light

Probable IoT applications with Energy Harvesting Technology (EHT)

Application Area	Sub-Application Area	Application	Devices	Power Source	Energy source for EH
Smart Environment	Smart Agriculture	Animal tracking	RDID tags, GPS transceiver	Passive, battery, EH	Vibrations, solar
		Irrigation monitoring	Dedicated sensors	Battery, EH	
		Pest monitoring	Dedicated sensors	Battery, EH	
		Smart gardening	Dedicated sensors	Battery, EH	
	Smart Environment Monitoring	Water quality monitoring	Dedicated sensors	Battery, EH	
		Flood monitoring	Dedicated sensors	Battery, EH	
		Forest fire detection	Dedicated sensors	Battery, EH	
		Landslide / avalanche detection	Dedicated sensors	Battery, EH	
		Earthquake early detection	Dedicated sensors	Battery, EH	
		Glacier monitoring	Dedicated sensors	Solar, thermal	
Smart Law Enforcement/ Civil service	Smart Law Enforcement/ Civil service	Charging consumer electronics	Smart charger	Battery, EH	
		Location monitoring	Crowd GPS / beacons	Battery, EH	
		Safety monitoring	Health conditions of soldier	Battery, EH	

Probable IoT applications with Energy Harvesting Technology (EHT)

Product / Company	Energy Source	EH Technology	Country of origin
Thermostat / en:key	Thermal	TEG	Germany
Wireless Magnet Contact / EnOcean	Light/Solar Energy	Photovoltaic	Germany / USA
Wireless Light Switch / EnOcean	Kinetic energy (pressure)	Electrodynamic/Piezoelectric	Germany / USA
Key Card Switch / EnOcean	Kinetic energy (pressure)	Electrodynamic/Piezoelectric	Germany / USA
Occupancy Sensor / EnOcean	Indoor light	Photovoltaic	Germany / USA
Room Thermostat / Peha - Honeywell	Indoor light	Photovoltaic	Germany / USA
Remote Control / Arveni	Kinetic energy (pressure)	Piezoelectricity	France
Smart Charging at Home / Energous Corp.	RF energy	RF to DC	USA
Fleet Tracking / Perpetuum	Kinetic energy (Vibration)	Piezoelectricity	England
Roads / Sidewalks / Pavegen	Kinetic energy (Vibration)	Piezoelectricity/Induction	USA
Street Lights / EnGoPlanet	Kinetic energy (pressure)	Solar -> Day Piezo -> Night	USA
Outdoor Temperature Sensor / EnOcean	Light/Solar Energy	Photovoltaic	Germany
Pipeline/Industry Monitoring / Perpetua	Thermal energy	TEG	USA
Sewer Level Monitoring System / NTT Data	Thermal energy	TEG	Japan
Smart Watch / Matrix Ind	Thermal energy	TEG	USA
Smart Gardening / EDYN	Light/Solar Energy	Photovoltaic	USA

Competitors Development in Energy Harvesting Technology

Smart Building Applications

EnOcean Alliance is the biggest alliance in this area.

Thermostat

The en:key valve controller is screwed on to the radiator valve like a conventional thermostat valve head. As on other radiator thermostats, users can set the desired comfort temperature for the room. The thermostat insert on the valve controller controls the room temperature by opening or closing the heating valve. The valve controller is supplied with power by the integrated thermoelectric generator that uses the thermal energy of the heating water to generate electrical energy. A high-quality internal energy storage unit stores the energy and provides the valve controller with power as required.

Wireless Magnet Contact

The STM 250 is a solar powered maintenance free magnet contact radio module. An integrated energy store allows unrestricted functionality for several days in total darkness. Using the integrated Reed contact the module monitors the position of the laterally mounted magnet and informs about changes of the status. In addition, a life signal is sent with an interval of about 15 min.

Wireless Light Switch

Self-powered wireless switch for lightning and shading. Self-powered wireless controls are simple to install. The Single and Double Rocker Pads use EnOcean energy harvesting technology to communicate wirelessly with other wireless devices and provide convenient control of lighting, temperature and miscellaneous electric loads.

Key Card Switch

The Key Card Switch is one of the simplest, most economical ways to save energy through occupancy based control of lighting, HVAC and miscellaneous electric loads. To operate the switch, guests simply insert their key card in the slot when they enter the room and then remove it when they leave. The key card switch is wireless and can be installed in minutes without having to drill into the wall or run additional wiring. Embedded mechanical energy harvesting element harvests power from the motion of inserting or removing a hotel key card.

Occupancy Sensor

The ceiling-mounted occupancy sensor saves energy and adds convenience by accurately detecting when an area is occupied or vacant. This device is wireless, powered by indoor light using photovoltaic cells, and uses a passive infrared (PIR) sensor to detect motion. The occupancy sensor transmits RF signals to control lighting, HVAC and outlets more efficiently.

Room Thermostat

Universal room temperature sensor with solar energy storage for combination frame with internal dimensions 55 x 55 mm, with change-over switch for two temperature ranges (day / night) for temperature detection and local set point adjustment for individual room controls with integrated temperature sensor. The room temperature sensor transmits the measured values without battery to the receiver.

Remote Control

Arveni develops piezo electric energy harvesting devices for a wide range of applications, from vibration to pulse harvesting. The device (pictured) uses a piezoelectric energy harvester that converts mechanical energy to electricity by pressing the central green button on the remote-control unit, which provides enough power for several button switches on the remote.

Smart Charging at Home

Energous Corporation is the developer of WattUp®—an award-winning, wire-free charging technology that will transform the way consumers and industries charge and power electronic devices at home, in the office, in the car and beyond. WattUp is a revolutionary radio frequency (RF) based charging solution that delivers intelligent, scalable power via radio bands, similar to a Wi-Fi router. WattUp differs from older wireless charging systems in that it delivers power at a distance, to multiple devices – thus resulting in a wire-free experience that saves users from having to remember to plug in their devices.

Smart Infrastructure Applications

Fleet Tracking

The patented electromagnetic energy harvesters convert mechanical energy produced by vibration to electrical energy, which in turn powers the Wireless Sensor Nodes. These nodes transmit real time data back to the desktop or mobile device of the asset owner. The energy harvester is designed to last over 100 years without maintenance, and the sensor nodes 20 years, easily outlasting other battery-only powered systems. This proven, fail-safe technology is also quick and easy to install. The vibration energy harvesters and wireless sensor nodes can be used to monitor valuable equipment and assets across a wide variety of industries, but most commonly used in rail.

Roads / Sidewalks

Pavegen uses what it calls a hybrid black box technology to convert the energy of a footstep into electricity, which is either stored in a battery or fed directly to devices. A typical tile is made of recycled polymer, with the top surface made from recycled truck tires. A foot stomp that depresses a single tile by five millimetres produces between one and seven watts. These tiles generate electricity with a hybrid solution of mechanisms that include the piezoelectric effect (an electric charge produced when pressure is exerted on crystals such as quartz) and induction, which uses copper coils and magnets.

Street Lights

EnGoPLANET Smart Solar/Kinetic Street Lights are ideal to be installed at pedestrian zones where people can be directly involved in producing clean and free energy. Every footstep creates from 4 to 8 watts.

Smart Environment Monitoring Applications

Outdoor Temperature Sensor

Battery and wireless outdoor sensor for temperature. Transmission to receiver by means of radio telegrams according to EnOcean standard. With integrated temperature sensor and solar energy storage for maintenance free operation.

Pipeline/Industry Monitoring

Challenge: Measuring temperature, pressure, and flow data are critical to optimize yield quality and production output in steam injection wells for this top tier oil producer. Their preference is to use wireless versus wired sensors, but because of battery life constraints, they have historically been forced to lengthen sensor update rates when using wireless and forego gathering data at the desired update rates. Solution: Using Perpetua Power Pucks for these wireless sensors, the update rates can be configured as fast as 1 second without having to trade-off battery life. This enables the use of wireless versus wired sensors with the ability to configure sensors at rates to meet business requirements.

Sewer Level Monitoring System

These modules were attached to the bottoms of the manhole covers, to monitor the sewer water level 24/7. It is combined with a battery pack and due to the implemented TEG's the battery life time is extended up to 5 years.

Smart Wearable

Smart Watch

The MATRIX PowerWatch is the world's first smartwatch that you never have to charge. Powered by your body heat, it measures calories burned, activity level, and sleep using our advanced thermoelectric technology. It is the only smartwatch to feature a power meter which displays how much electrical power you are generating.

Smart Gardening

EDYN Smart Garden System uses solar power to monitor the garden soil with its sensors. The Edyn Garden Sensor tracks light, humidity, temperature, soil nutrition, and moisture — and then cross-references this information with plant databases, soil science, and the weather to give you customized gardening guidance. The Edyn Water Valve tailors watering to fit the plants' needs. It automatically controls existing irrigation system based on data from the Garden Sensor and local weather forecasts to save water, lower utility bills, and never worry about thirsty plants again.

Innovative techniques and technologies

Some very interesting energy harvesting technologies that are still in the laboratory could change the face of the energy harvesting industry over the next few years.

Medical and Fitness Devices

Researchers at the University of Michigan have developed a device that harvests energy from the reverberation of heartbeats through the chest and converts it to electricity to run a pacemaker or an implanted defibrillator, hopefully obviating the need for periodic battery replacement. Research is also under way looking for ways to scavenge body heat, movement, and vibration to power other implantable devices.

Researchers at MIT and Harvard have developed a chip that can be implanted into the inner ear, with power provided by harvesting the energy in sound waves. The chip is designed to monitor biological activity in the ears of people with hearing or balance impairments. Fitness buffs will be happy to learn that they can recapture some of the energy they expend at the gym. Three British universities have teamed up to develop a piezoelectric energy harvesting device that attaches to the knee, generating power as they walk or run on the treadmill.

Riga Technical University offers a mechanical energy harvester that requires magnets to be sewn into the sleeves and coils into the pockets of a jacket; swinging the arms past the pockets while walking generates a current that can be stored in a battery. Anything to keep that iPhone charged!

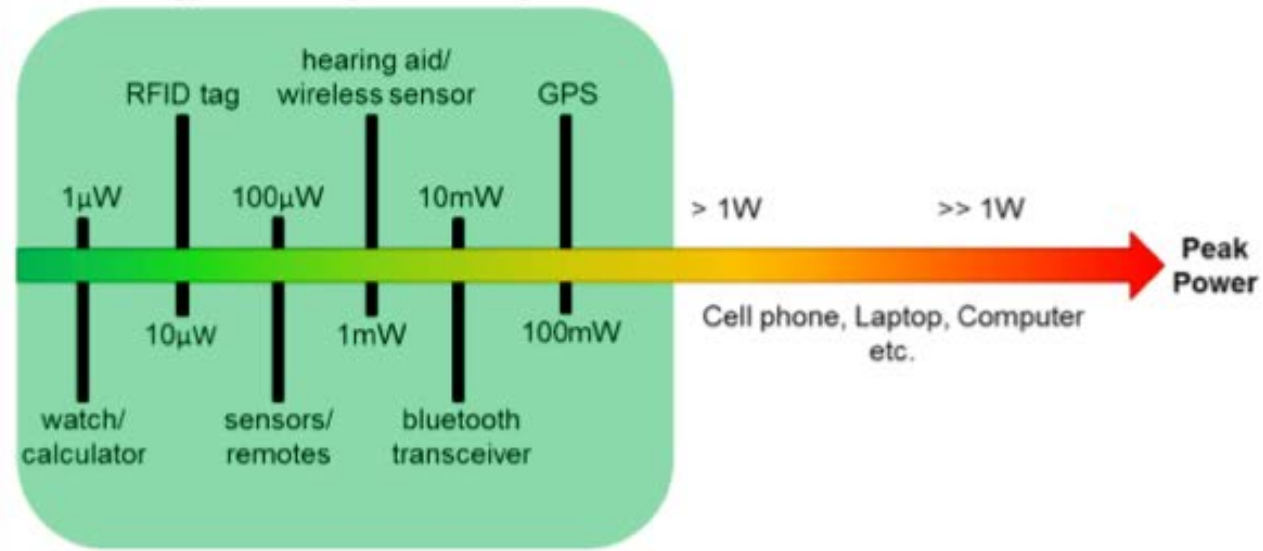
MEMS pyroelectric generator

Oak Ridge National Laboratories has developed a unique pyroelectric generator that can cool electronic devices, photocells, computers, and even large waste-heat producing systems while generating electricity. The device is based on a MEMS pyroelectric capacitor at the end of a bimetal cantilever that oscillates between hot and cold surfaces. The tip of the hot cantilever comes into contact with a cold surface, the heat sink, where it rapidly loses its heat and causes the cantilever to move back and make contact with the hot surface. The oscillation continues as long as long as there is a sufficient temperature differential – anywhere from a few degrees to several hundred degrees – between the two surfaces.

Nantennas

Photovoltaic cells are the most widely used energy harvesting source, but they are not very efficient. The best monocrystalline PV cells – with a theoretical maximum efficiency of 30% – do well to top 20% efficiency. Now scientists at the University of Missouri and the Idaho National Laboratory have developed a flexible solar film that can theoretically achieve 90% efficiency.

In contrast to conventional photovoltaic cells, the film is essentially an array of nanoantennas (or “nantennas”), each tuned to a specific frequency of light. Rather than generating single electron-hole pairs, as in the case of PVs, the incoming electromagnetic field from the sun induces a current in the antenna that is then collected at the feed point, rectified, and stored. Nanoelectronic electromagnetic collectors (NECs) can be configured as frequency selective surfaces to efficiently absorb the entire solar spectrum. NECs can be integrated into polymer materials so they might also be incorporated into the skin of consumer electronic devices to continuously charge batteries.



Power consumption overview of devices incl. energy harvesting power range

The relevant range for IoT devices and sensors are between 0.1 µW and 1 W. As illustrated in Figure above, the feasible power generation range of an energy harvesting device (photovoltaic cell) with a manageable size is up to 500 mW. This is because the power consumption of IoT edge devices is around 100µW/cm2. Since energy supply and demand may come at different times, in practice a temporary energy buffer (e.g. supercapacitor) and power management electronics are necessary to effectively deliver the energy from the harvester to the IoT edge device.

Costs Impact

Integrating an EHT into the device design will increase the costs. Batteries are a mass produced cheap commodity and EHT are not. The costs include beside the component costs the redevelopment costs of the device since just adding an EHT on top of the device is often not feasible .

Figure below presents one approach to the design process for a self-powered device. However, not all manufacturers have the resources to follow this approach. As IoT becomes more and more ubiquitous, there will be edge devices from different manufacturers which perform the same simple tasks and use similar or even the same systems-on-a-chips (SoC). This would increase the possibility to standardize the appropriate EHT for this kind of IoT devices.

Secondly, the manufacturers are already passing the running costs, e.g. battery replacements at least every half a year, to the user. Removing these costs and increasing the user friendliness of the device by eliminating maintenance tasks could offset higher sales prices.

Process for developing self-powered sensor nodes

Market Challenges

Low power capacities

Application of energy harvesting remains limited due to its small conversion efficiency (around 5%) and its low power storage capacities. Therefore, the utilization of energy harvesting remains limited to low-power-consuming devices. This is particularly relevant for thermoelectric materials due to the lack of cost effective materials that can work at high temperatures. Huge progress are expected following the recent ability to create nanostructured thermoelectric materials.

High entry costs

The high production and implementation costs of energy harvesting devices are the most important barriers that have hampered the growth of the market over the past few years. This explains why, despite their attractive promises, energy harvesters have not been a lot deployed yet.

Need for interoperability

The output of electricity through energy harvesting can be unstable and depends on the energy received. There is thus a need for additional devices to provide regular supply in order to meet standards enabling the commercialization of energy harvesting devices. Standards to enable interoperability between energy harvesters and application components are therefore essentials and are today lacking.

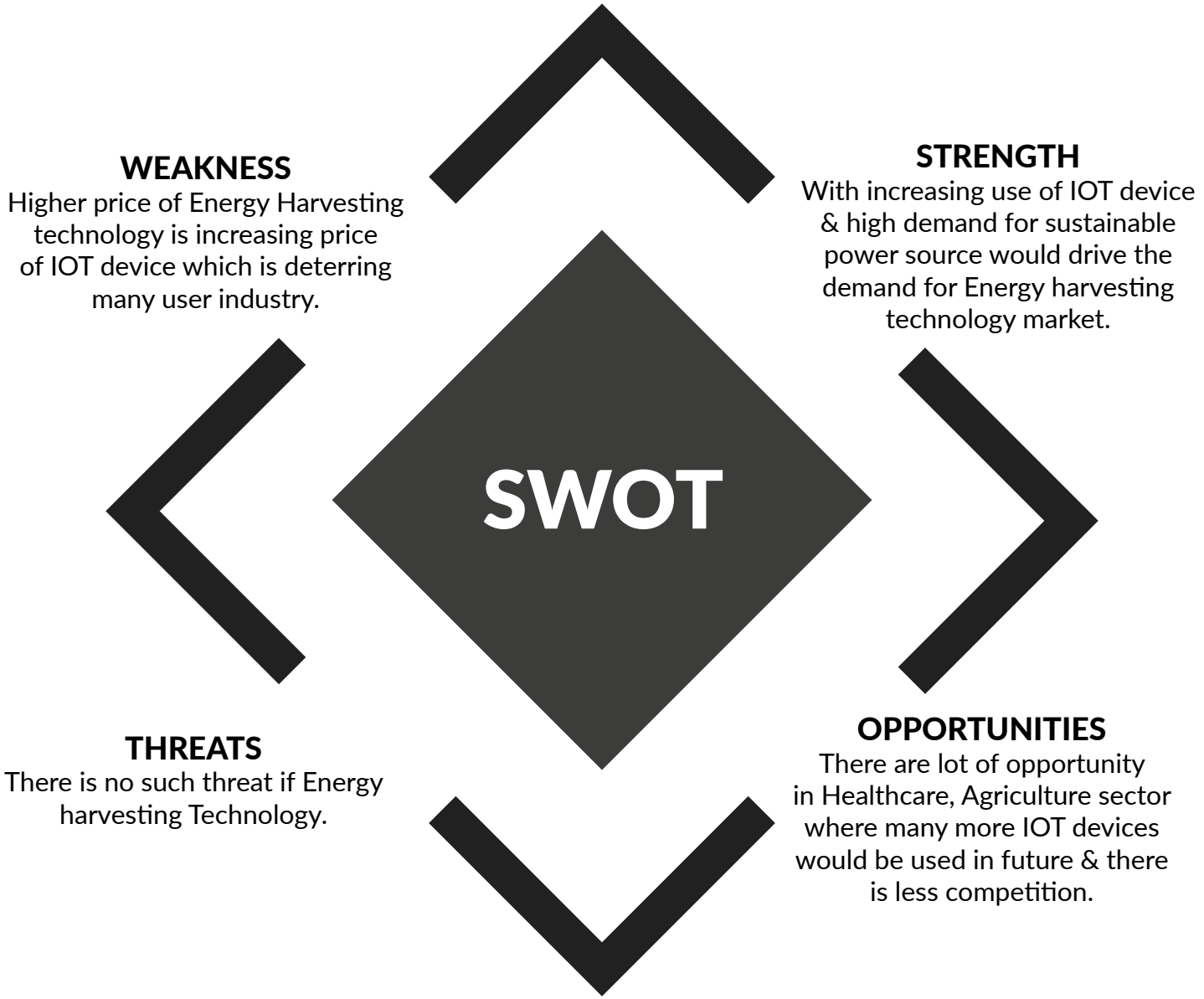
Lack of standardisation

Measurement stands as one of the main barriers to commercial development of energy harvesting technologies. The lack of accurate measurement hinders development, innovation and market acceptance of energy harvesting devices. This is why there is a great need for internationally-recognised standards to measure, define and compare energy harvesting systems efficiency.

Initiatives are being taken to tackle the issue, such as the Metrology for Energy Harvesting Project, funded by the European Metrology Research Programme. It aims to help Europe commercialize energy harvesting technologies by developing measurement methods that enable industries and consumers to compare different energy harvesting technologies. The objective is to lower costs, increase energy efficiency and improve market sustainability.

Lack of awareness among end-users

There are still many people and industrials that do not know the principle of energy harvesting and its benefits. Vendors are currently targeting only a few specific and small segments such as consumer electronics and lack of sufficient marketing budget to expand the applications of energy harvesting devices and drive public awareness.

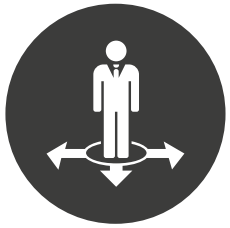


SWOT Analysis

Porter's 5 Forces

Threat of new entrants

The market is capital intensive and requires heavy investments and advanced technologies which can be relate to less entry of new player in the market. Threat of entry of new player is less.



Threat of substitutes

There is no direct substitute for energy harvesting devices.

Bargaining power of customers

In Energy Harvesting Technology market due to less number of suppliers, demand exceeds supply which normally forces customers to pay as asked by suppliers.

Bargaining power of suppliers

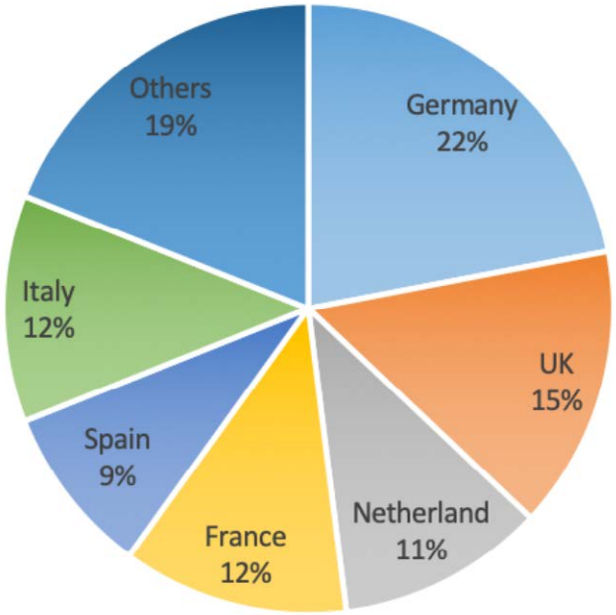
Due to presence of relatively small number of companies operating in the market bargaining power suppliers/ companies is medium to high.

Competitive rivalry

Since number of players in the energy harvesting device market is less, the competition is comparatively less in energy harvesting device market.

Market Size Estimation

Europe

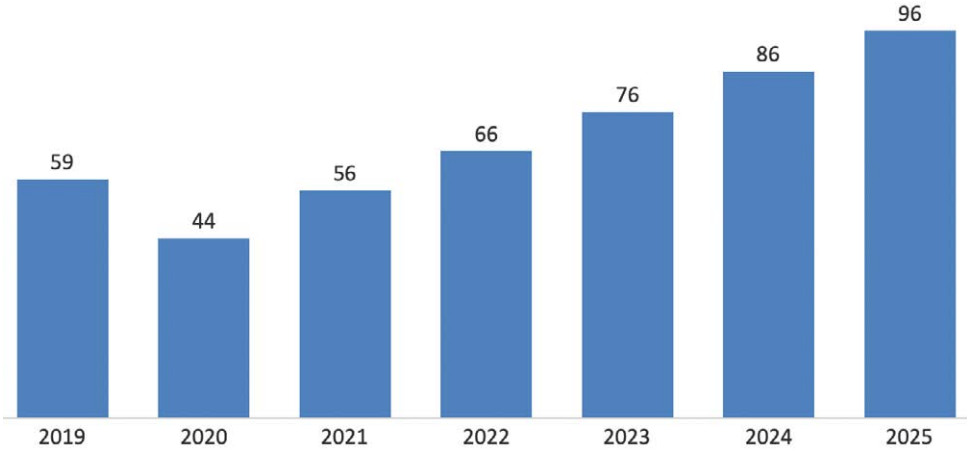


Market Share by Country %

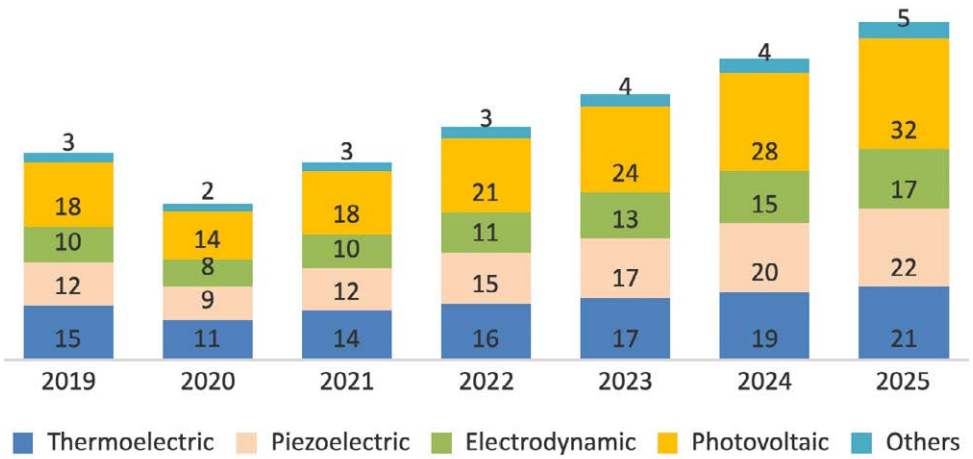
In Europe market size of Energy Harvesting market for IOT is estimated USD 59 million in 2019. The market is expected to grow at a CAGR of 16.6% during forecasting period of 2020-25 to reach market size USD 96 million by 2025.

The market is expected to suffer revenue loss in 2020 but expected to recover by 2021.

Germany, UK, Netherland, France & Italy are the largest market covering 72% of total Europe market.



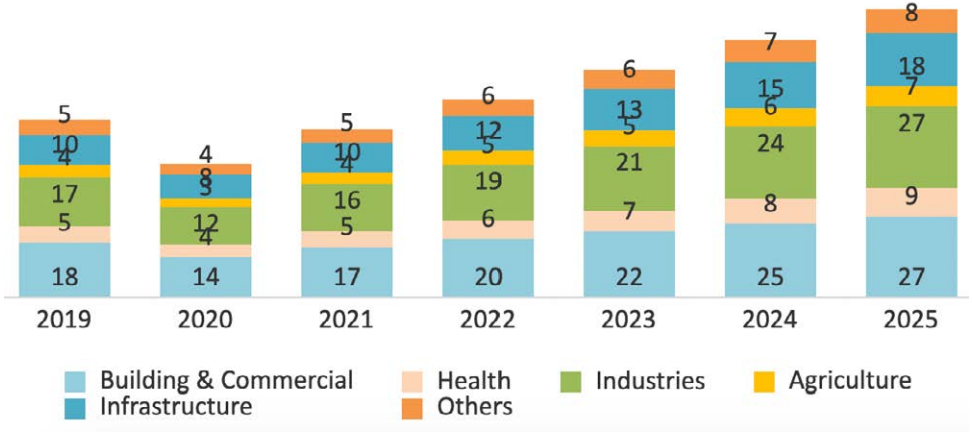
Energy Harvesting Market size for IoT (USD million)



MARKET BY TECHNOLOGY (USD MILLION)

By Technology, Photovoltaic is the largest segment in terms of use followed by Thermoelectric & Piezoelectric. Both 3 segments covers 78% of total market.

In terms of future growth Piezoelectric, Photovoltaic, Electrodynamic segments are expected to grow more in future.



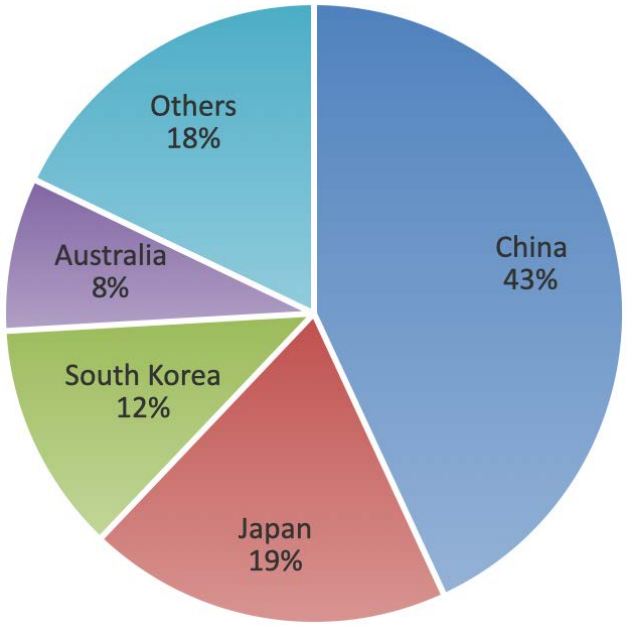
MARKET BY INDUSTRY APPLICATION (USD MILLION)

By Industry application Building & Commercial and Industries application segments are two major application segments covers 59% of total market.

Though all application segments are expected to grow in future but Infrastructure & Health segments are expected to grow in future compared to other applications.

Market Size Estimation

Asia

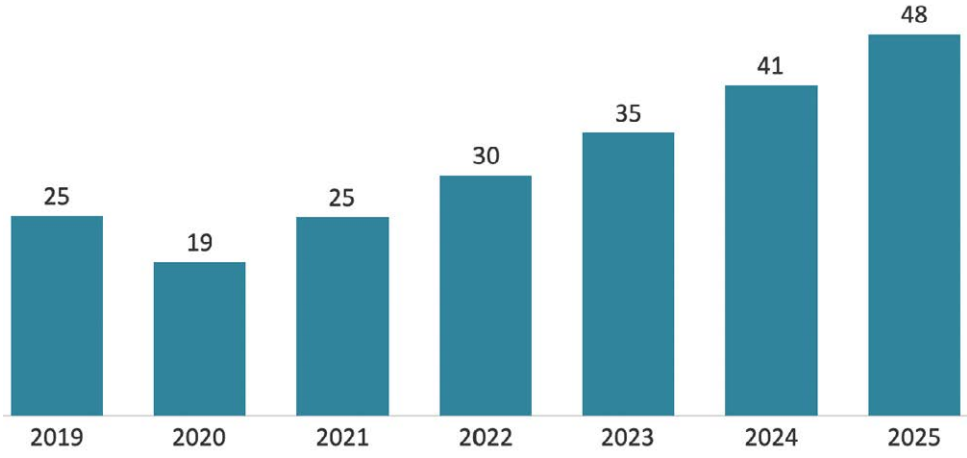


MARKET SHARE BY TOP COUNTRY

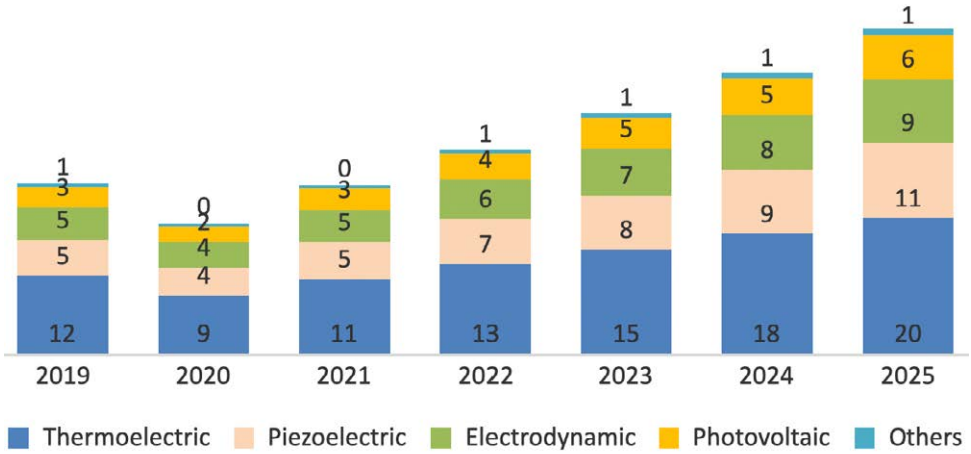
In Asia market size of Energy Harvesting market for IOT is estimated USD 25 million in 2019. The market is expected to grow at a CAGR of 19.9% during forecasting period of 2020-25 to reach market size USD 48 million by 2025.

Due to COVID 19 , Asia market is expected to suffer revenue loss in 2020 but expected to recover by 2021.

China, Japan, South Korea, Australia are the largest market covering 82% of total Asia market.



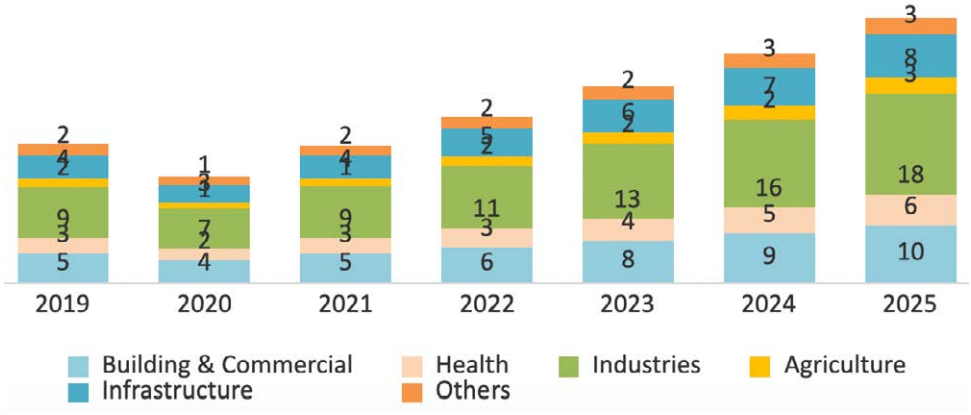
Energy Harvesting Market size for IoT (USD million)



MARKET BY TECHNOLOGY (USD MILLION)

By Technology, Thermoelectric is the largest segment in terms of use followed by Piezoelectric & Electrodynamic. Both 3 segments covers 86% of total market.

In terms of future growth Photovoltaic, Piezoelectric segments are expected to grow more in future.



MARKET BY INDUSTRY APPLICATION (USD MILLION)

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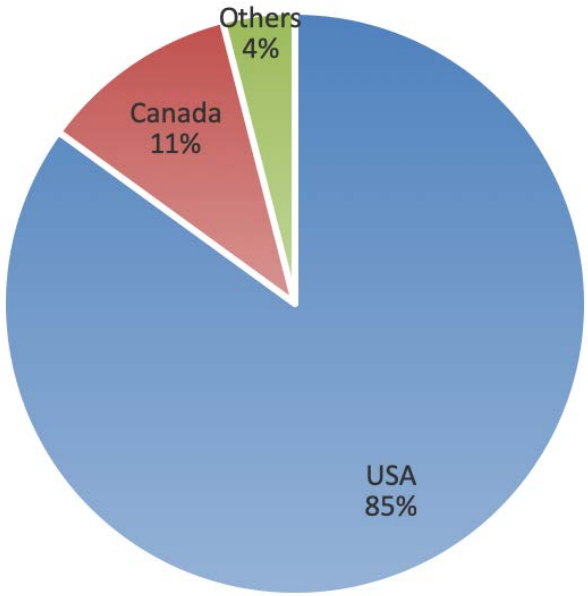
Market Size Estimation

North America

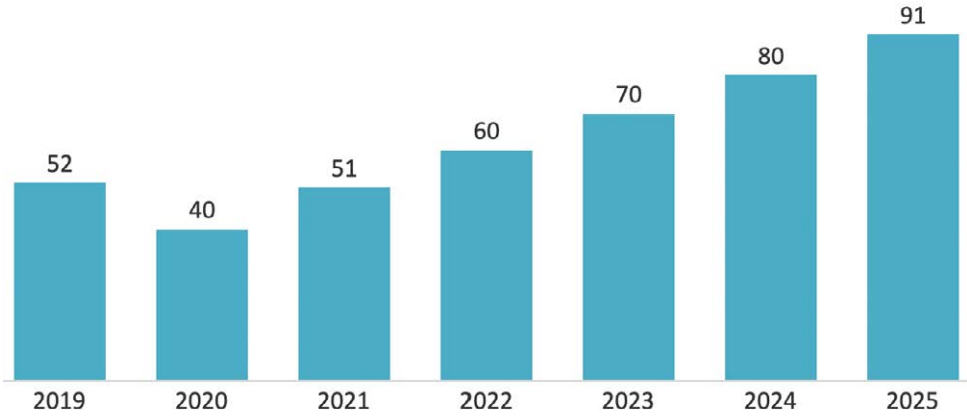


Market Share by Country %

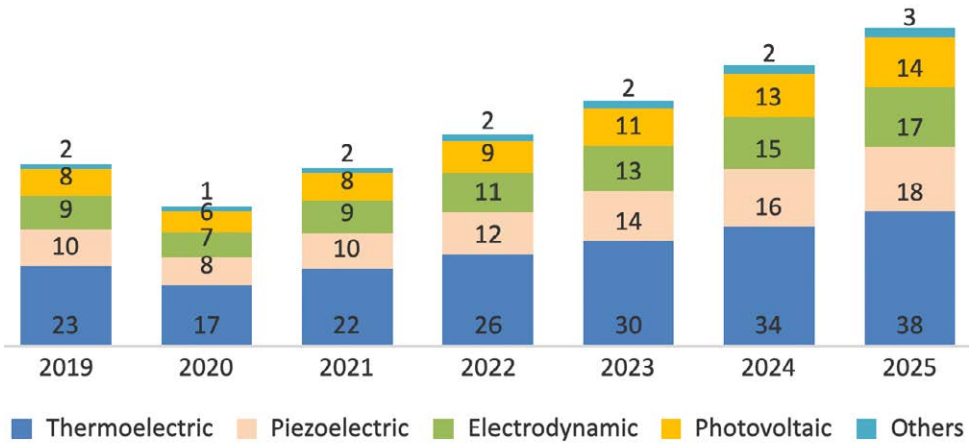
In North America market size of Energy Harvesting market for IOT is estimated USD 52 million in 2019. The market is expected to grow at a CAGR of 18% during forecasting period of 2020-25 to reach market size USD 91 million by 2025.

Due to COVID 19 , North America market is expected to suffer revenue loss in 2020 but expected to recover by 2021.

USA is the single largest market covering 85% of total North America market.



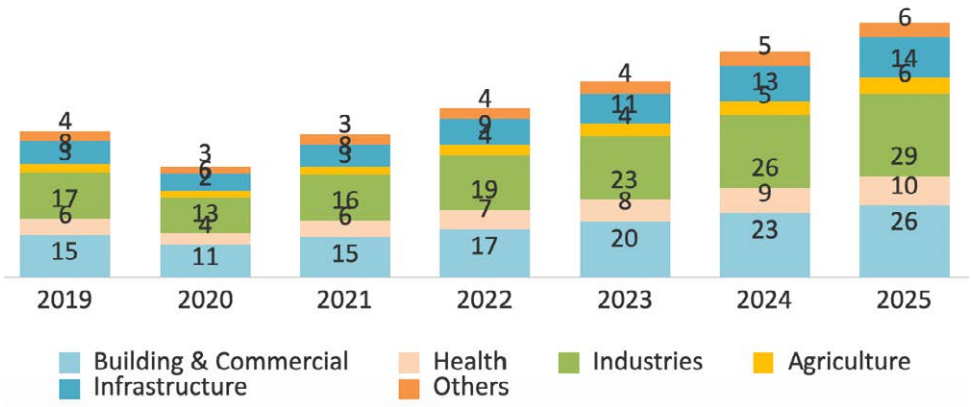
Energy Harvesting Market size for IoT (USD million)



MARKET BY TECHNOLOGY (USD MILLION)

By Technology, Thermoelectric is the largest segment in terms of use followed by Piezoelectric & Electrodynamic. Both 3 segments covers 82% of total market.

In terms of future growth Photovoltaic, Electrodynamic segments are expected to grow more in future.



MARKET BY INDUSTRY APPLICATION (USD MILLION)

By Industry application Industries, Building & Commercial application segments are two major application segments covers 61% of total market.

Infrastructure & Health segments are expected to grow in future compared to other applications.

Competitors Analysis

EnOcean
Self-powered IoT

Company Name	EnOcean GmbH
Company Type	Private Type
Founded	2001
Headquarters	Oberhaching, Germany
Key People	Andreas Schneider, Co-Founder & CEO
No. of Employee	183
Revenue (2019)	USD 36 million
Products	Energy Harvesting, ISO/IEC 14543-3-10, Building and Industrial Automation, Internet of Things, and Wireless Standard
Website	www.enocean.com

Strength

- Good & Extensive exposure in Energy Harvesting technology.
- Strong in Europe & North American market.
- Have wide applications such as building and home automation, lighting, industrial, automated meter reading, and environmental applications.

Weakness

- Do not have product offerings in Healthcare, Agriculture, Infrastructure sector.

Products & their applications

Switch Applications :

EnOcean supplies battery less switch and sensor applications with kinetic energy. Some applications are:

- Battery-free wireless switches in worldwide switch design
- The lights switch from Vimar's Friends of Hue program
- The industrial switch SEMD
- The window contact from Eltako
- The water sensor from Afriso
- Bus stop buttons from Happich

Self-powered sensors:

Self-powered wireless sensors for a sustainable system. Some applications are:

- Room control panels for biulding automation
- Sensors for air quality monitoring
- Motion detectors
- Magnetic contacts
- Self-powered radiator valves

Wireless LED Controls:

For North America, EnOcean's introduced wireless white label LED control devices for lighting systems. This Easyfit product line includes battery-free sensors and switches, actuators, LED lighting controls and a commissioning tool that enable easy configuration, intelligent local control and seamless integration into building automation. In North America, their target markets are schools, department stores, office buildings and other existing buildings can easily retrofit modern LED lighting control to meet California's strictest environmental laws.

Building Automation:

Self-powered sensors are used for building automation systems. With them, lighting, heating, security and other services can be controlled intelligently and in an energy-saving way.

Company Name	e-peas
Company Type	Private Type
Founded	2014
Headquarters	Mont-Saint-Guibert, Belgium
Key People	Geoffroy Gosset, Co-Founder & CEO
No. of Employee	27+
Revenue (2019)	USD 4.5 million
Products	Ultra-Low-Power Semiconductors, Energy Harvesters, Microcontrollers, and Image Sensors
Website	www.e-peas.com

Strength

- Have very extension application in various IOT areas.
- Have coverage in Asia, Europe & North America Market through various distributors.
- Have leverage of using Fujitsu Electronics extensive distributorship around the world.
- Started lot of promotional activities across Europe & North America.

Weakness

- Not so strong Financially.
- No self network or offices even in Europe. Have to depends on distributors for sales.

Products & their applications

Home Automation:

Light switches, sensors, smart valves, thermostats, smart locks, motion sensors, smart cameras, smart kitchen, aroma diffuser sensor, fire detectors.

Industry:

Smoke detector sensors, air pollution sensor, real time localization trackers, pressure, temperature, activity sensors on motors and machines, green houses monitoring.

Smart metering:

Water meters, gas meters, onroad car counting, tank level monitoring, monitoring solar energy plants.

Retail:

Electronic price tags, smart fridge thermometers, humidity sensors, goods tracking, asset location.

E-health:

Patients tracking monitors, automatic disinfecting sprays, medication dispensing devices, body temperature thermometers, activity trackers, asset localization in the hospital.

Mobility:

Speed sensors, coolant temperature sensor, TPMS, parking sensors, airplane sensors, rail sensors, cargo temperature.

Security:

Motion sensors, smart security cameras, smart alarms, perimeter location, people detection, gas leakage monitoring.

Society and wear:

People tracking, pet tracking, smart watches, smart clothes, smart glasses, smart toys.

Smart Agriculture:

Livestock tracking, Soil moisture monitoring, livestock feeding, smart logistics and warehousing

Type of Energy Harvesting

- Photovoltaic
- Thermal
- Vibration
- RF

Company Name	Kinergizer
Company Type	Private Type
Founded	2012
Headquarters	South Holland, Netherlands
Key People	N/A
No. of Employee	21
Revenue (2019)	USD 4 million
Products	Energy harvesting, kinetic energy, IoT, and motion to electricity
Website	www.kinergizer.com

Strength

- Provides customized Energy harvesting devices based on Client's requirements.
- Energy harvesting device specific for railway application.

Weakness

- Not very strong product portfolio in Energy harvesting devices.
- Product applications are very limited.
- Not very strong presence in North America, Asia.

Developments related to Energy harvesting

Dutch startup Kinergizer manufactures energy harvesting systems for wireless industrial internet of things (IIoT) sensors. Their technology is focused on industrial equipment that has continuous motion such as motors, gearboxes, and rail tracks, and harnesses mechanical energy to provide a continuous and sustainable source of power for IIoT/IoT devices. Mechanical energy can be harvested from a variety of sources such as vibrations, pressure, and strain.

The energy produced by the mechanical motions of the equipment being monitored provides the energy used to power the sensor. The methods of energy conversion are electromagnetism, electrostatics, and electroactive polymers.

Key Customers:

BOSCH

CSIRO

Strukton Rail

ALPS

SWECO

TU Delft

Company Name	NOWI B.V.
Company Type	Private Type
Founded	2015
Headquarters	South Holland, Netherlands
Key People	Simon van der Jagt, CEO
No. of Employee	25
Revenue (2019)	USD 3 million
Products	Energy Harvesting Power management integrated circuit (PMIC)
Website	www.nowi-energy.com

Strength

- Product strength - Reduced form factor, lowered BOM cost and on-chip intelligence.
- NOWI Energy harvesting device is ideal for small size for smart device.
- Have presence in Europe, North America & Asia.

Weakness

- Market Applications are limited.

Developments related to Energy harvesting

NOWI's energy harvesting power management integrated circuit (PMIC) enables companies to use the energy that is already readily available around the devices. This can be light, heat, movement or even radio waves.

Applications are Smart Infrastructure monitoring, IOT Beacons, Hybrid Smart Watch.

Huawei Has Combined It's Market Leading NB-IoT Device Soc With NOWI's Energy Harvesting PMIC to Enable New Internet of Things Applications Requiring Ultra-low Power Autonomous Operation

Nowi Energy Harvesting Technology Enables Groundbreaking Hybrid Smart Watch Module for MMT

Raised USD 14 million in 2019 through Series A investment round from DTV

Key Customers:

CASA
第三代半导体产业技术创新战略联盟
China advanced semiconductor industry innovation alliance

INNOVATION WORLD CUP SERIES

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PERPETUA
Power Source Technologies

Company Name	Perpetua Power Source Technologies, Inc.
Company Type	Private Type
Founded	2005
Headquarters	Oregon, United States
Key People	Nick Fowler, Executive Chairman
No. of Employee	42
Revenue (2019)	USD 8 million
Products	Energy harvesting technology, thermoelectric generators, and wireless sensors
Website	www.perpetuapower.com

Strength

- Strong product line for industrial IOT application.
- Partnership with Honeywell give Perpetua Power the access of wide network of Honeywell.

Weakness

- Not active in other sector except industrial application.
- Depends on Honeywell for major sales of its products.

Developments related to Energy harvesting

Power Pucks, in particular, are Class I Div 1 Intrinsically Safe certified products that perform thermoelectric energy harvesting, which converts temperature differences from any heat source such as pumps, motors, and warm pipes into energy.

Power Pucks harvest energy from the difference in temperature between a heat source and ambient air using solid-state materials in a process called the Seebeck Effect.

Perpetua announces an Energy Harvester for use with Honeywell XYR6000 OneWireless transmitters.

Perpetua's products align with the requirements of the devices they power:

- Industrial wireless sensors for temperature, pressure, and vibration, and more.
- Wired sensors including pressure and flow devices, as well as multiple wireless transmitters and some gateways.

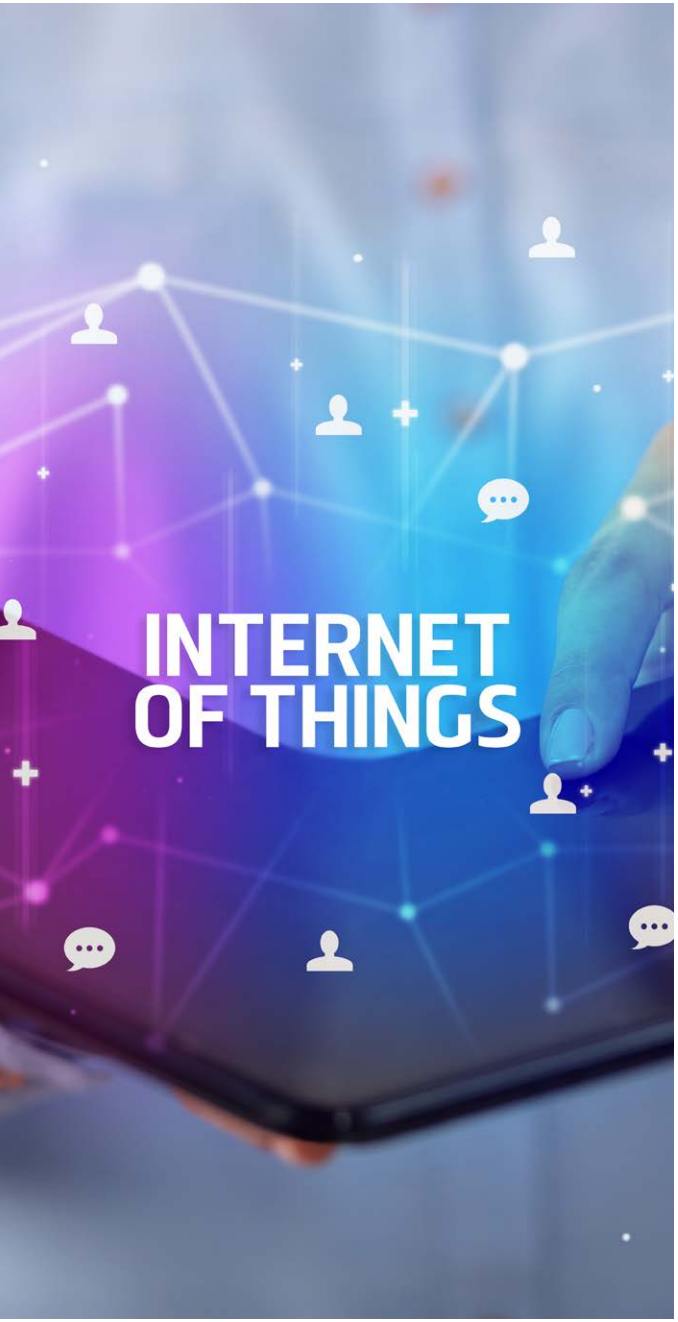
Company Name	Texas Instruments
Company Type	Public Type
Founded	1930
Headquarters	Dallas, Texas, U.S.
Key People	Rich Templeton, Chairman President, CEO
No. of Employee	29,888
Revenue (2019)	USD 14.38 Billion
Products	Mainly analog chips and embedded processors, which account for more than 80% of its revenue. TI also produces TI digital light processing technology and education technology[8] products
Website	www.ti.com

Strength

- Texas Instrument has developed energy harvesting ICs in collaboration with Cymbet which is in high demand in industrial application in North America.

Weakness

- Besides industrial application it does not have much presence in other application area like Building, healthcare, retail, agriculture.
- Not so strong presence in IOT device applications.



Texas Instrument – Key Development

Texas Instrument's nano-power energy harvesting technologies allow the most efficient low power designs today. With several devices that feature low quiescent currents and >90% conversion efficiency, TI enables self-powered and battery-based devices across many different applications using solar, thermal-electric, piezoelectric and other energy sources.

G24 Innovations (G24i of Cardiff, UK), the global pioneer of Dye Sensitized Solar Cell technology (DSSC), has signed a strategic development agreement with Texas Instruments to create a joint technology platform by combining G24i's solar cell technology with TI's nano-powered converter. Under this strategic development agreement, the companies create a new opportunity for global OEMs to give birth to a whole new family of autonomous self-powering devices.

Company Name	Analog Devices, Inc.
Company Type	Public Type
Founded	2001
Headquarters	Massachusetts, U.S.
Key People	Vincent Roche, CEO & President
No. of Employee	15,300
Revenue (2019)	USD 6.2 Billion
Products	American multinational semiconductor company specializing in data conversion, signal processing and power management technology
Website	www.analog.com

Strength

- Analog Device ICs with energy harvesting technology are widely used in mainly Industrial, building, automotive industry which are in high demand in bulk.
- Strong presence of Analog Device in all regions & all major countries & good relationship with all major industrial players gives the company strong customer base.

Weakness

- Do not have strong presence in consumer durables, healthcare IOT products with harvesting technology

Products & their applications

Analog Devices offers a wide range of ultra low power ICs for energy harvesting applications. Power management products that convert energy from vibration (piezoelectric), photovoltaic (solar), and thermal (TEC, TEG, thermopiles, thermocouples) sources provide high efficiency conversion to regulated voltages or to charge batteries and super capacitor storage elements.

Analog Devices ICs are mainly used in industrial automation and control, wireless sensor, transportation, automotive, and building management applications. Ultra low quiescent current linear regulators, op amps, comparators, voltage supervisors, ADCs, DACs, and micro power voltage references provide additional building blocks for autonomous systems.