Energy Harvesting without Batteries

by Dr. Peter Harrop

Introduction

Energy harvesting is the conversion of ambient energy into electricity to power small electric and electronic devices, making them self-sufficient, often for decades. It is not the replacement of power stations with tidal, hydroelectric, solar or other renewable power. However, there is a grey area in-between, as we see with automotive examples such as the solar panel on the new Toyota Prius plug-in hybrid electric car, the use of regenerative braking in electric cars, the planned capture of heat from engine and exhaust of cars, and even turning the energy in shock absorbers into electricity. Sometimes these technologies give enough energy to boost the motive power of the car, but sometimes they simply permit some accessories to be run wirelessly from local power. Another intermediate product is the sprung paving in some train stations that produces enough power for signage simply by the action of people walking over it.

However, the heartland of energy harvesting is replacing single-use batteries. Consider the nightmare caused by the 30 billion button batteries made yearly and appearing in everything from our car keys, key finders, clocks, alarms, wristwatches, calculators, children's toys, games, smart packages, gift cards and more. The number grows as the variety grows, and then we have cylindrical batteries in flashlights, radios, PDAs and so much more. The misery caused when they fail and the tedium of buying and inserting them cannot continue to increase. Wireless sensors in industry can automate manual processes, but, as an oil refinery manager said with some vehemence recently, "I am not replacing meter reading with battery replacement."

Why Have Energy Harvesting?

Energy harvesting is mainly aimed at making small electrical and electronic devices self-sufficient for reasons of convenience, cost, safety and reliability. Think of the bicycle dynamo or the solar powered satellite, calculator or wrist watch. Today that typically means maintenance-free for twenty years, but hundreds of years are in prospect.

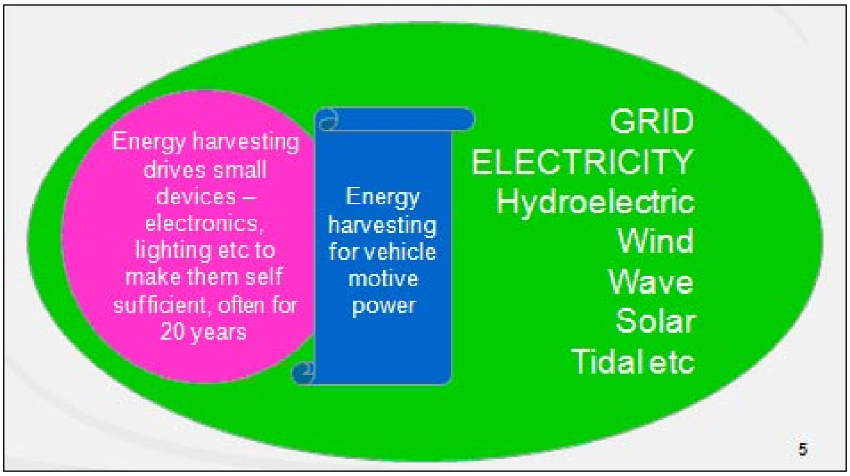


Figure 1—How energy harvesting fits into the renewable energy scene, with an example of something intermediate (courtesy of IDTechEx).

The Components of an Energy Harvesting System

An energy harvesting system consists of the device gathering ambient energy, an energy storage device, if needed, and an interface to the electrical or electronic device being driven. By far the favorite ways of creating the electricity are through photovoltaics and electrodynamic generators (e.g., dynamos or alternators). They are popular because they are proven, reliable, affordable and provide useful amounts of power. Photovoltaic systems have no moving parts, and they can be very thin, flexible and even transparent. Indeed, there are experimental versions that harvest ultraviolet and infrared light as well.

Electrodynamics can provide very large amounts of power, and so far that type of system has tended to be more reliable that piezoelectric moving parts—another candidate—which can wear out in wireless light switches, vibration harvesters and so on and produce less power. We see electrodynamics in wind-up lighting, radios and laptops for Africa, in flexing paving, wind turbines and bicycle dynamos. It is even being tested for use on the human heart to replace batteries driving embedded defibrillators, pacemakers and other devices. No further need to cut you up to change your battery. Electrodynamic harvesting also appears in automatic electronic watches.

Why Eliminate Batteries?

Using a rechargeable battery and harvesting instead of a single-use battery is scarcely elegant. The rechargeable battery may last longer, but not in the case of lithium thionyl chloride single-use batteries, which last more than twenty years. The rechargeable battery is usually much smaller, but it can cost as much. Indeed, the life of an energy harvesting module tends to be longer if there are no batteries involved. Often, dispensing with any form of battery can also give lower cost, smaller size, lighter weight, greater reliability, convenience, labor savings and reduced environmental problems (e.g., from battery disposal). Little wonder that NASA has made many advances in this direction. Life of hundreds of years can even be contemplated, and more than twenty years is immediately achievable. That is what your bicycle dynamo provides. That is what the clockwork radios for Africa do—the energy is stored in a spring and presented at constant torque to a generator when required. Indeed, it is possible that the microbial fuel cells burning dirt that are planned by Harvard University as an alternative approach to lighting in Africa will operate without batteries.

How Do You Eeliminate Batteries in Energy Harvesting Units?

The long-life harvesting units have no energy storage to compensate for the intermittent nature of most forms of energy harvesting. This is achieved in either of three ways, together or separately:

1. Use a capacitor, supercapacitor or so-called supercabattery, which combines the functions of both in one electrochemical cell. For example, a bicycle dynamo sometimes has a capacitor to provide light for awhile when you stop at the traffic lights. However, capacitors and supercapacitors storing useful amounts of energy can lose much of it within one day.
2. Use two or more forms of energy harvesting so there less chance of the harvested supply failing. For example, devices signalling if rocks have fallen into steel containment nets on mountain sides typically have both photovoltaics and the movement of the hawser to provide power to signal an alert. Road furniture often has both photovoltaics with small wind turbines.
3. Use electronics that can cope with fitful supplies. For example, it may only send signals when it gets the electricity, as with a satellite signalling when it is sunlit or it may be the new electronics that works at microvolts on a whisper of electricity so it can use what little power is harvested in poor periods.

To look at it more closely, we show examples of needs, solutions

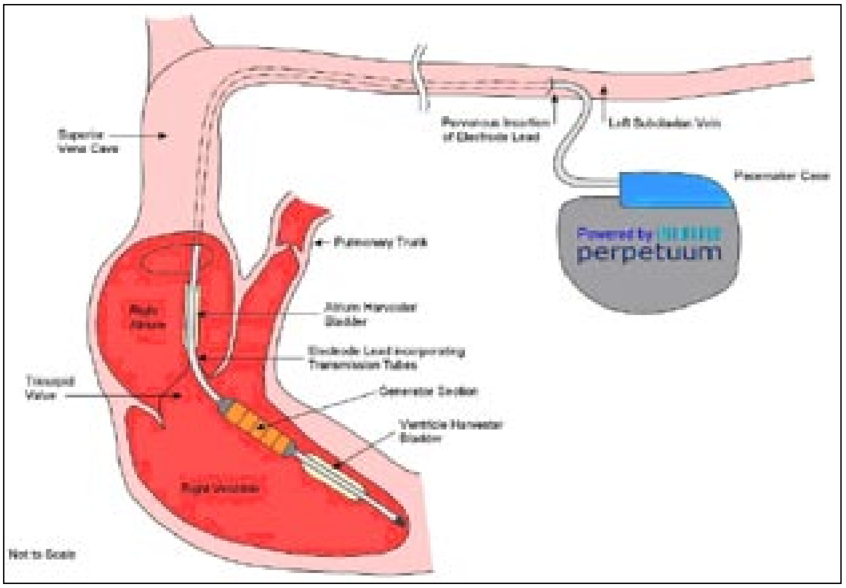


Figure 2— Experimental harvester implanted onto the human heart (courtesy of Perpetuum and Southampton University Hospital).

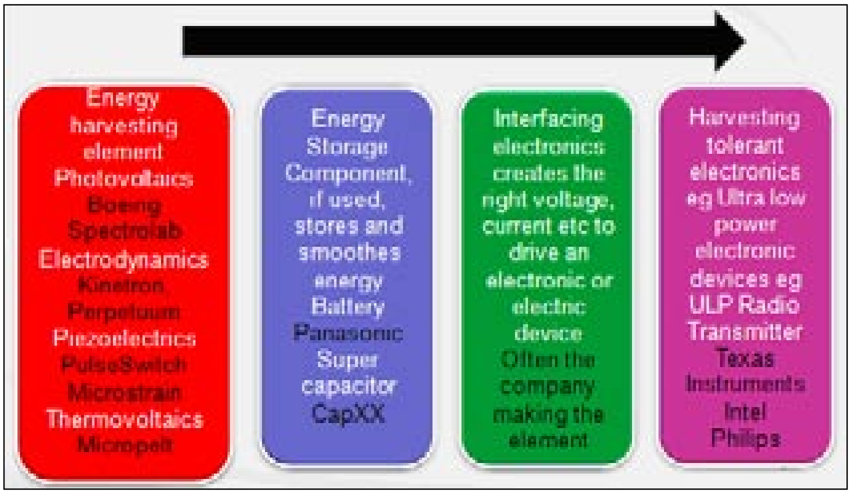


Figure 3—Elements of an electronic device powered by energy harvesting (courtesy of IDTechEx).

and suppliers below, though actual systems often employ only some of these elements. For example, photovoltaics may provide DC power at the right voltage, whereas vibration harvesting may provide AC power when DC is needed at a different voltage.

Consider an example—the Perpetuum electrodynamic energy harvester shown in Figure 4 with its supercapacitor. The whole package is much smaller than a can of beans, yet it provides useful milliwatts when mounted on the almost silent and vibration-free electric motors found by the millions in the chemical, oil and gas industries.

Figure 4—Perpetuum vibration harvester (courtesy of Perpetuum).

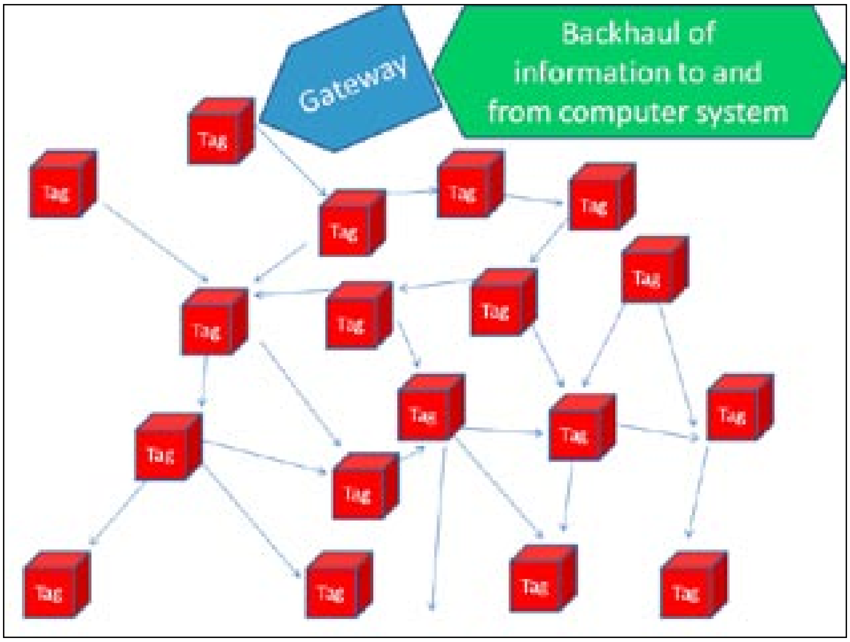


Figure 5—Basic wireless sensor network (courtesy of IDTechEx, from the report "Wireless Sensor Networks 2009-2019").

Achieving the Impossible

Sometimes eliminating batteries to get longer life means that something previously impossible can be achieved. For example, 90% of the potential applications of wireless sensor networks (WSN) are impossible without energy harvesting. WSNs consist of small tags known as nodes that pass information among each other so many short ranges add up to a long range and they are "meshed," meaning they work rather like the internet, being self healing and self organizing. They are required to send modest amounts of data when they can —e.g., when another node comes near or when the energy harvesting part is working. Potential applications include being dropped on billions of trees to monitor forest fires and in engines and the concrete of buildings and bridges. You cannot change batteries in such applications.

A basic Wireless Sensor Network (WSN) is shown in Figure 5.

Coping with High Temperatures

Indeed, in high temperature situations, the batteries would be destroyed, but energy harvesting by thermovoltaics works fine. Thermovoltaics is use of the so-called Seebeck effect, by which dissimilar metals (a "pn junction") generate electricity from temperature difference. A thermovoltaic energy harvesting system has no moving parts and is small, but so far it is relatively expensive and inefficient. Nonetheless they are being tested for use in the human body as well as in engines and aircraft.

EnOcean Alliance

Similarly successful are the piezoelectric or electrodynamic light switches from the EnOcean Alliance of over 70 members offering interchangeable battery-free, wireless products under the strapline “No wires. No batteries. No limits.” Indeed, the Lighting Switch™ in the USA is a similar device, in this case based on piezoelectric advances at NASA. Over 500,000 wireless, battery-free electronic building controls and similar products have been sold to date by the EnOcean Alliance. Those include sensors and actuators for blinds and vents, mainly reliant on electrodynamics, photovoltaics and other forms of harvesting. The EnOcean Dolphin™ range even has two-way signalling, which might pave the way for complete Wireless Sensor Networks.

Unfortunately, today’s WSNs use a lot of energy—sometimes more than 100mW (approaching the load of a PDA or mobile phone). Consequently, the primary batteries currently used in WSN sometimes last only a few weeks, and it is a challenge for today’s forms of energy harvesting. However, new forms are coming along all the time. For instance, this year, researchers at Intel in Seattle demonstrated harvesting RF power from a TV transmission tower more than four kilometers away, to power a commercially available thermometer/hygrometer with LCD display.

Typical power requirements and how energy harvesting is usually working up from the bottom are shown in Figure 6.

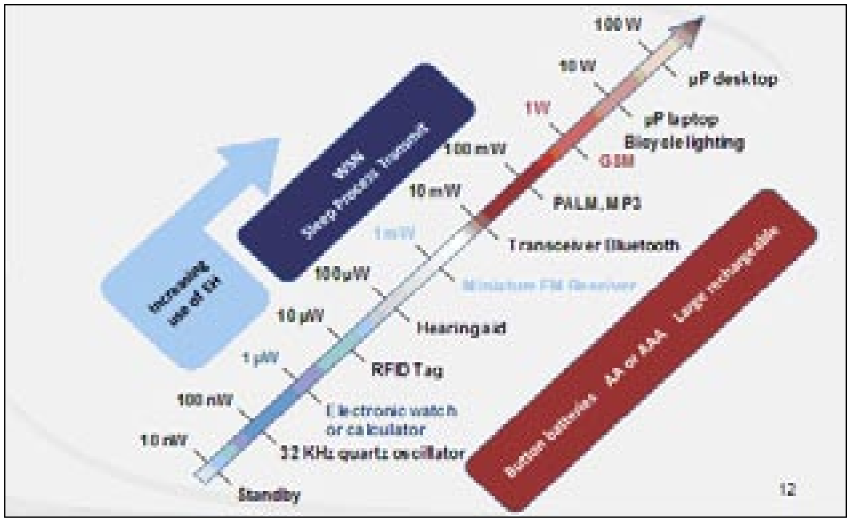


Figure 6—Typical power requirements of devices that need harvesting (courtesy of IDTechEx).

Environmental Benefits

At present, energy harvesting does not directly save enough power to have much impact on the environment or electricity supplies. However, it makes the application of electronics and electrics practicable where they can provide huge energy savings. To take one example, the EnOcean Alliance recently put wireless and battery-less light switches, occupancy sensors and daylight sensors in a building in Italy where they are powered by embedded energy harvesters. This saves 40% of lighting energy costs by automatically controlling the lighting in the building. It saved 20 miles in copper cables. Consider the energy used in obtaining that copper. It will save 42,000 batteries over the 25-year life of the harvesters and most of the cost of retrofitting.

Energy Harvesting-Tolerant Electronics

All this opens up the market for energy harvesting-tolerant electronics—now a topic of research in many parts of the world. This covers electronics that require much lower power so as to put less demand on the harvesting and which are tolerant of highly variable, intermittent voltages and currents that are unpredictable. For example, the University of Bologna and Swiss Federal Institute of Technology are working on the mathematics of so called “Lazy Scheduling for Energy Harvesting Sensor Nodes.”

Battery-Free Energy Harvesting Radio Transmitter

On the hardware side, Kansas State University engineers are supporting Peregrine Semiconductor with its idea of an energy-harvesting radio. It will transmit important data without ever needing a change of batteries. Bill Kuhn, professor of electrical and computer engineering, and Xiaohu Zhang, master’s student in electrical engineering, are developing this device.

“This type of radio technology may exist in your house, for instance if you have a temperature sensor outside that radios data to a display inside,” Kuhn says. “But those devices need to have their batteries changed. This radio doesn’t.”

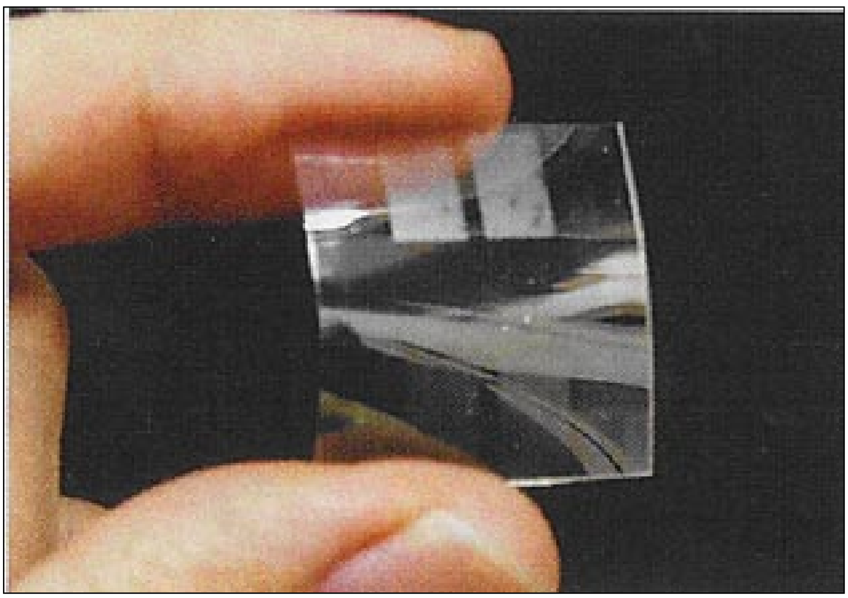
Peregrine Semiconductor is looking at possible applications for the technology. This could include monitoring stress, temperature and pressure on bridges and other structures. Ron Reedy, Peregrine’s chief technical officer, said that fulfilling this vision of autonomous sensors requires highly integrated, low-power radio chips. These are the kind that Kansas State and Peregrine have demonstrated to NASA’s Jet Propulsion Laboratory on Peregrine’s trademarked UltraCMOS silicon-on-sapphire technology.

Kansas State engineers are

Figure 7—ExoMars Lander (courtesy of NASA).

addressing the design challenges and creating a demonstration to test how far the signals can travel from the sensors. Firstly, Zhang constructed a demonstration board using solar cells from inexpensive calculators to power the radio. The board had capacitors that capture and store the light energy to power the radio without a battery. Electrochemical, mechanical or thermal energy are also in the frame. The demonstration board included a microprocessor to store data before transmission via radio. The radio used is the "Mars chip" that Professor Kuhn helped develop in a successful project that Kansas State, Cal Tech's Jet Propulsion Laboratory and Peregrine Semiconductor did for NASA. They designed a micro transceiver to use on Mars rovers and scouts.

When the stored data are ready to be transmitted in the model, the radio sends out a data-burst every five seconds. Frequencies, timing and wake-up commands are now being optimized for the anticipated environment.



Figures 8—Transparent rechargeable battery from NEC and Waseda University (courtesy of Waseda University).

Figure 9—Transparent photovoltaics from AIST Japan (courtesy of AIST Tsubaka).

Rechargeable Batteries Still Needed

Although these elegant, battery-free energy harvesting solutions will rapidly gain market share, there will still be huge markets for energy harvesting involving rechargeable batteries. For at least ten more years, they will be needed where considerable power storage and/or high security of supply is required. Here the new laminar lithium batteries are an exciting innovation. Some are only 0.1 millimeters thick; others come with the interfacing electronics and/or capacitors for smoothing all in one unit. There is no danger of fire or explosion with the tiny amounts of lithium employed, and the format means that recharging time is unusually short. True, some only guarantee 1,000 recharges, but others can achieve one million recharges as long as they are not deep ones. Transparent, flexible printed batteries are being developed by NEC working with Waseda University in Japan. They charge in only one minute, which opens up interesting possibilities, given the advent of transparent photovoltaics and even transparent printed logic from Hewlett Packard and others (Figs. 8–9).

Futuristic New Products

Energy harvesting is making possible some futuristic new products. Researchers at the

University of British Columbia in Vancouver, Canada have created a fuel cell that can be powered by human blood. The microbial fuel cell is a flexible and biocompatible structure suitable for body implantation as a potential power source for implanted medical devices, and is able to convert chemical energy stored in glucose in the blood stream into electrical energy using yeast.

Robot Fly

Robert Wood, an assistant professor of engineering and applied sciences at Harvard University, has developed a revolutionary fabrication technique that allows engineers to make a range of very tiny parts for any kind of robot resulting in a life-size robotic fly. This tiny robot has a wingspan of three centimeters, weighs 60 milligrams and can generate nearly twice its weight in thrust, which is almost on par with a real fly. The robot fly is intended to perform rescue and reconnaissance operations in areas that humans cannot reach. For example, during rescue missions after earthquakes, thousands of paper clip-size flying robots could be dispersed throughout the collapsed buildings. The tiny robots would detect signs of life, perhaps by sniffing the carbon dioxide of survivors' breath or detecting the warmth of their bodies. And although some flies might smash into windows or get stuck in corners, others would make their way to the survivors, where they would perch and expend their remaining energy transmitting their findings to rescue workers. They may have onboard radio-frequency transmitters to communicate short, low-bandwidth chirps, to be picked up by receivers around the site. Even if 99 percent of the robots are lost, the search mission would still be a success.

Then there is the question of getting a power source onto the fly. A battery small enough to fit aboard a robotic fly will have a much higher surface-area-to-volume ratio than its macroscale counterpart, so a greater percentage of its mass will be the packaging. Wood expects that scaled-down versions of today's best lithium-polymer batteries will weigh about 50 mg, accounting for half the fly's weight, and will provide 5 to 10 minutes of flight. For more flight time the battery will need an increased energy density, the propulsion must be more efficient, or energy-harvesting techniques must be developed, perhaps by mounting tiny solar panels on the insect's back or converting the fly's vibrations into electric current. All that will be ready in five years, he believes.

Figure 10—University of Michigan/U.S. Army COM-BAT (courtesy of University of Michigan).

Robot Jellyfish and Bat

The U.S. Navy is deploying robot jellyfish for ocean surveillance that last for years, thanks to energy harvesting. In water, light can be harvested when a device is on the surface; a piezo flag can flap under water to gather energy; and there are also temperature differences to exploit. The U.S. Army has placed a $24 million contract to develop a tiny robot surveillance bat that, it is hoped, will hover and perch to gather intelligence day and night, its electronics and motors gathering energy from light, vibration and so on.

Major Conference

The energy harvesting industry is now ready to sell products in volume, leading to a multi-billion dollar business in ten years, as detailed in the new IDTechEx report "Energy Harvesting 2009-2019." IDTechEx recently staged an energy harvesting conference with emphasis on potential customers saying what they want, the market potential and the technological roadmap. The conference, "Energy Harvesting and Storage," took place at Cambridge University June 3–4.

For more information about the Energy Harvesting and Storage Conference, visit [www.idtechex.com/eh].

Read the Energy Harvesting Journal *at* [www.idtechex.com/ehj].