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CEDRO, with energy efficiency on our mind
Country Energy Efficiency and Renewable Energy
Demonstration Project for the Recovery of Lebanon

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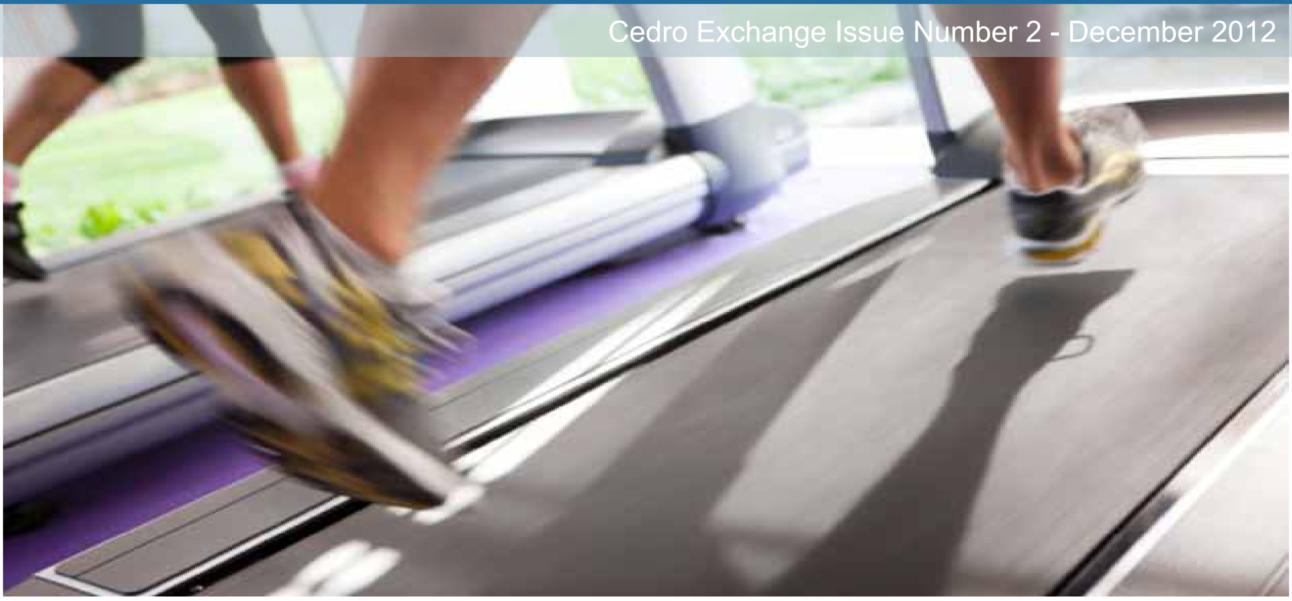


Power from the People; Energy Harvesting

1. Harvesting Energy from Human Power?

There is a need for the conception, development and deployment of cost-effective renewable energy alternatives. The human body is a bank of stored energy: as we move to perform actions we convert this stored chemical potential energy into useful kinetic energy. What if we could harvest this energy?

Many times the human body is likened to a motor: turning potential energy into mechanical energy that can be used to perform work, but the intriguing feature of well-designed motors is that when the motor is run in the opposite direction it becomes a generator: converting mechanical energy back to potential energy. Through human power, we are exploiting this aspect of the human body: we are reversing the concept of the human body as a motor, instead using our body's momentum as the mechanical energy that can be turned into potential energy. Theoretically, humans could be self-sufficient when it comes to energy generation, using nothing else than their own bodies. It is a striking realization that requires much reflection and thought.

Human power has the advantages of being readily available at all times, requiring no chemical fuel or special logistical measures, and having little heat signature. It is shown that harvesting human energy not only uses wasted energy but also can actually improve biochemical efficiency through negative work cycles. This is much like «regenerative braking» for humans (Khaligh, 2009).

There are two methods for harvesting energy from human power; active harvesting methods and passive harvesting methods, and these are shown in Figure 1.

Empowered lives, Resilient nations.
UNITED NATIONS DEVELOPMENT GROUP

Guest Author; Jad Abi Esber; An engineering student at the University of Cambridge, UK, and an intern at UNDP-CEDRO in the summer of 2012.

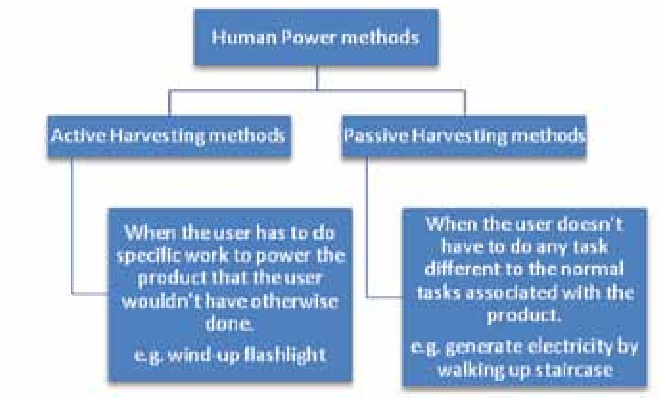


Figure 1. Active and Passive Harvesting

How does it work?

There are two stages for energy harvesting applications;

1. Capturing human power and using it to generate electricity for use: using the inherent properties of certain materials that generate an electric current when there is a specific physical change or due to certain physical phenomena.

2. The storage of the captured energy in biochemical, electromagnetic or mechanical forms.

Why energy harvesting?

Energy harvesting is becoming increasingly popular with the total market for energy harvesting devices expected to rise to over $5 billion by 2022 (Harrop & Das, 2010). From an environmental point of view, energy harvesting is a very attractive concept: its applications effectively emit zero carbon dioxide emissions or other such pollutants during operation.

The human generator

The human body is a tremendous storehouse of energy. An average person of 68 kg with 15% body fat stores enough energy to provide a 4-bedroom house with the electricity it needs for 2.67 days (Starner & Paradiso, 2005), giving us an indication of how well our bodies act as storage of potential energy.

The amount of power used by humans during various activities is highlighted in Table 2. Table 2 shows that even sleeping contracts a sizeable amount of power, comparable to the wattage needed to power an old-school 17” cathode ray tube (CRT) monitor (≈ 80W), whilst sprinting requires the most power at 1630 W. However, any application that parasitically scavenges energy from human activity must be totally unobtrusive to be commonly adopted. So only a fraction of this power can be scavenged effectively without putting an onerous load on the user. From Figure 2, it can be seen that footfalls harvest the highest amount of power.

Activity	Kilocal/hr	Watts
Sleeping	70	81
lying quitely	80	93
Sitting	100	116
standing at ease	110	128
conversation	110	128
eating meal	110	128
strolling	140	163
driving car	140	163
playing violin or piano	140	163
housekeeping	150	175
carpentry	230	268
Hiking, 4 mph	350	407
Swimming	500	582
Mountain climbing	600	698
Long distance run	900	1,048
Sprinting	1400	1,630

Table 2: Human energy expenditures for selected activities (Starner & Paradiso, 2005; derived from Morton, 1952)

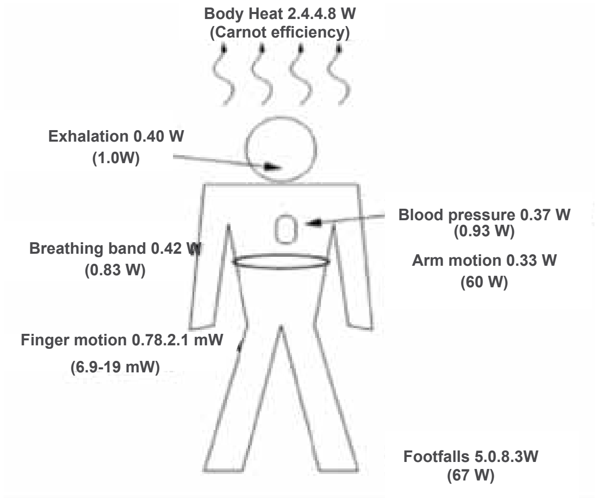


Figure 2: Possible power recovery from body-centered sources. Total power for each action is included in parentheses

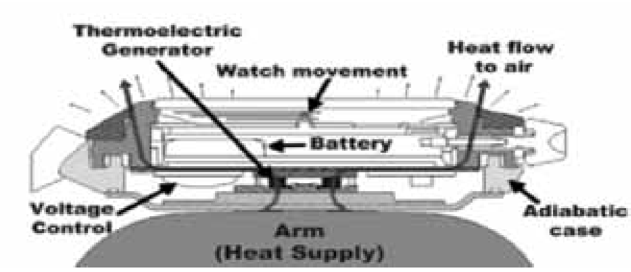
(Starner & Paradiso, 2005)

2. Energy Harvesting Projects; Existing Examples

From charging watches using body heat to pedal powered laptops

Feeling hot? Use your body heat to generate electricity!

Seiko Thermic and Citizen Quartz are two examples of thermoelectrically powered wristwatches that are currently available on the market. They are powered by body heat, utilizing the concept of thermoelectricity. This device is self-powered and generates energy continuously whilst the user is simply wearing the watch. A disadvantage of thermoelectric generators, which as of 2011, has prevented their adoption on a wider scale, lies in their cost: a single thermoelectric module capable of producing 14W of electrical power costs approximately $100 (Chepko, 2002).



Pedaling and winding = powering

As the legs naturally project the force of the body's weight, up to 60W can be obtained in this manner. Today, there are wide ranges of applications for 'pedal power', from fitness exercise bicycles that are powered by their own pedalling, to pedal powered laptop and mobile chargers. In fact, some Indian schools combine physical education with computer class; one half of the students cycle to provide the power for the other half's computers! (Starner & Paradiso, 2005)

I cycle, you type!

An example of a successful project where pedal power has made a significant positive difference was Felsenstein and his team's project to bring Internet to the impoverished village Phon Kam in Laos, which has no electricity, running water or phones. They managed to do this through a hand-built, bicycle-powered PC that would send signals, via an IEEE 802.11b connection, to a solar-powered mountaintop relay station. The signal would then bounce to a server in the nearest town with phone service and electricity, 11 km away—and from there to the Internet and the world (Applewhite, 2003).

Freeplay develops an array of human-powered devices, including the Fetal Heart monitor with the intent to safeguard childbirth for mothers and infants in remote areas of the developing world where expert care and electrical power are in short supply. It measures the infant's heart rate during birth and only consists of a switch and a hand crank that is turned to generate its own electricity (Design to Improve Life, 2009).

Figure 4: Exploded diagram of wind-up Freeplay Fetal Heart Monitor

Put some pep in your step: power walking, literally.

Using our legs is one of the most energy consuming activities the human body performs. In fact, a 68 kg man walking at 3.5 mph uses 280 kcal/hr or 324W of power (Morton, 1952).

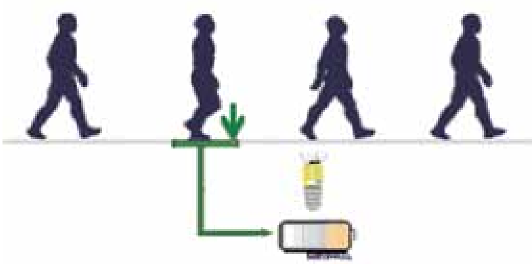


Figure 5. Pavegen Systems

The London Olympics 2012 saw the inclusion of a pioneering walkway that will be lit round-the-clock by the footsteps of a million spectators during the London 2012 Games. The walkway will have 12 Pavegen energy harvesting floor tiles, which when stepped on, convert kinetic energy to between 5 and 7 Watts over the duration of the footstep, depending on the force of the impact. It is expected to receive more than 12 million impressions, generating enough energy to charge 10,000 mobile phones for an hour (London 2012 press release). In an interview with the inventor, Laurence Kemball-Cook, (published in; www.theengineer.co.uk), he said: "Piezo relies on high spikes… We know the gap between those spikes makes it very hard to give a constant flow of energy. What our technology does is reduce those gaps and give you more of a constant flow of power." He doesn't give out the secret, but when pushed he said: "It's a hybrid solution; something that can effectively capture [and store energy] after it's been converted and be delivered in to a regulated 12V feed."

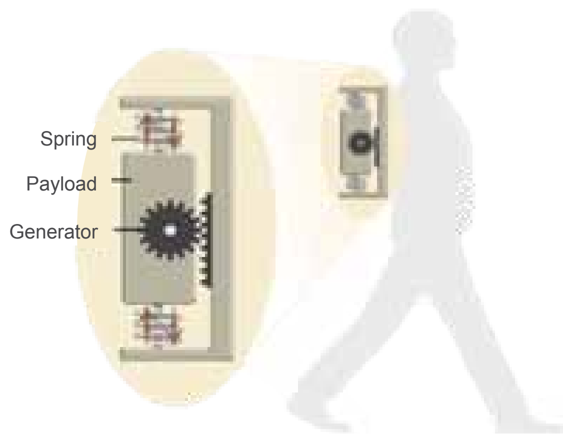


Figure 6: Electromechanical mechanism (Rome et al., 2005)

In the same vein, the energy harvesting backpack invented by Dr. Larry Rome transfers the kinetic energy from the up-and-down oscillations of a backpack on someone walking to electrical energy via an electromechanical mechanism. It is attached to the human torso much like any other backpack, however the backpack load is suspended from the frame by strings (Figure 6). When following a normal walking motion, the hips (and so the backpack) follow a sinusoidal motion, rising and falling throughout the gait cycle. The oscillatory motion causes the toothed rack to roll the pinion gear (Figure 7a), which in turn spins a magnet inside an electric field (or vice versa), thus causing the initial mechanical energy to be converted (at some fractional efficiency) to electrical energy via electromagnetic induction, voila! The maximum output of the device is said to be 7W and it has the capacity to carry a mass of 38 kg (Cain, 2010).

Interestingly, the metabolic cost (amount of energy consumed as a result of performing given work; usually expressed in calories and is an indicator of how strenuous an activity is) would be lower when walking with a doubly supported oscillating payload, thus we not only utilize the oscillatory motion, but it also makes it less strenuous to carry a load (Rome et al., 2005).

PowerWalk™ is a wearable technology that resembles an athletic knee brace, weighing

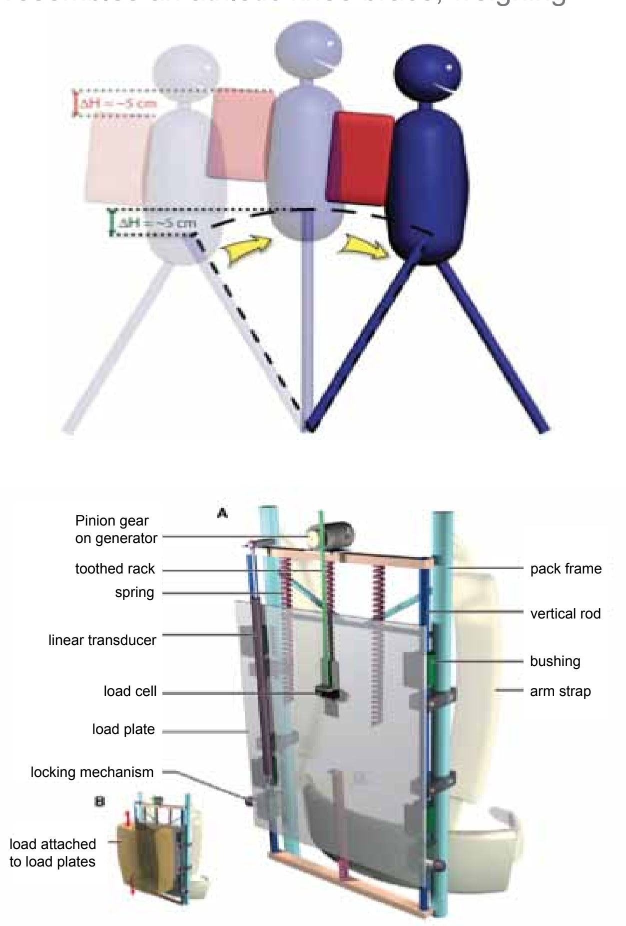


Figure 7: The energy harvesting backpack (top left), a closer look at the internal mechanism (7a & 7b).

about 750 gram per leg, and unobtrusively generates electricity from the natural motion of walking and then uses it to charge a wide range of portable battery-powered devices. The developer, Bionic Power, boasts that with a device on each leg, a user walking at a comfortable speed generates enough electricity to charge four mobile phones for a little over an hour of walking. Most intriguingly, PowerWalk™ intelligently adjusts the amount of energy that it harvests as a function of walking speed and terrain, harvesting more energy when available, targeting peak generation during regions of the stride where the muscles are normally performing a breaking action and dialing back energy harvesting when it might be obtrusive. This results in considerably reduced user effort and even assistance to the user on down slopes. The effort level can be adjusted on the fly to meet the user's needs through a simple user interface (Bionic Power Inc., 2008).

3. Where does Lebanon Stand?

Energy harvesting in Lebanon: The scenario and 2 case studies

The Lebanese electricity sector (see MEW, 2010) is at the epicenter of a major crisis. If the predicted inability to secure electricity for the Lebanese population continues and costly diesel self-generation remains a major source of the electricity supply, the importance of energy harvesting technologies may become more obvious.

Case study 1: Green Wheel

Mr. Nadim Inaty is using an innovative concept for a device for the city of Beirut, which harvests energy from human power with the intention of empowering pedestrians whilst generating power. He believes the first step to tackling the energy problem is creating awareness. “I wanted people to actually sweat and generate their own energy just as the earth sweats when we use up its resources…, I want people to sweat it out so they understand what it takes to make electricity…”. With those words echoing in the back of his head, Nadim went on to implement the innovative concept in the ‘Green Wheel’ design project.

The Green Wheel was conceived with ‘Corniche Al Manara’ in mind, a crowded seaside promenade as the location. It is well known for jogging, rollerblading, cycling and other physical outdoor activities. The design project includes the running wheel and a side bench to make the unit more approachable and complete as a gathering point.

Thirty minutes of running on the ‘Green Wheel’ generates enough power to run a laptop for 2 hours (120 W) according to Mr. Inaty’s estimation.

Case study 2: The energy harvesting speed bump

Although energy from speed bumps is not totally human power, harvesting from speed bumps is capturing energy produced as a result of human activity, thus is intrinsically linked to the concept of harvesting energy from human power. A team of Lebanese engineering professors from Hariri Canadian University and the Lebanese University (Dr. Mohammad Akkawi, Dr. Suhail Matar and Dr. Nizar Al-Awar) who started working together in 2011, with the support of two engineering firms (NEEDS and Sakkal), have gained a patent from the Lebanese Ministry of Economy and built prototypes of speed bumps to generate power and are making ambitious plans for mass implementation to make “Beirut streets generate their own electricity”.

The operation of the technology is quite simple. There are four main steps:

1. When a vehicle crosses over a conventional speed bump, potential energy is generated.

2. In speed bump power generation, potential energy is not wasted it’s converted into kinetic energy using a special mechanism.

3. The output of a rotating shaft is coupled with a dynamo to convert kinetic energy into electricity.

4. The electrical energy generated is stored in a power unit (battery).

The technology was named a ‘linear generator’, for its ability to convert linear motion to rotational motion. There were three mechanisms that were studied. In the end, an amalgam of the three mechanisms was developed and used. The speed bump was designed with the intention to power traffic lights, advertising panels and other electronic devices along Beirut's streets. Dr. Akkawi stated that in one day, the speed bump generates enough power to light fifteen **250W lamps for 10 hours!**

Future ambitions include implementing the technology in downtown Beirut, in the Solidere area with the hopes to light up all the streets in the region and even to power the lights of the municipality building. Further research and development is being conducted at the moment.

4. A Strategy for Lebanon Limitations and potential: energizing the Lebanese electricity frontier

To truly penetrate the Lebanese market across all socioeconomic groups and extend the greatest societal gain, the power generation alternative must be simple to incorporate into our daily lives (without much effort to put in place and maintain), inexpensive and reliable, as well as having a long life-cycle. First, we must analyze how we can facilitate their conception and deployment.

A social tangent: Human behavior and governmental bureaucracy when it comes to power generation

Many times, energy harvesting devices minimally impede human activity. These changes in human experience or the introduction of unfamiliar devices that require a certain human input need a psychological analysis to best understand the necessary policies to be implemented to ease their penetration in the Lebanese energy market. Humans base their activity on rational decisions or they act habitually (Lopes, 2012). According to Dr. Mahmoud Kreidie, a distinguished Neurologist and Psychologist in Lebanon, 'post-traumatic stress disorder is endemic, leading to hyper-vigilance and agitation amongst other things, hence the penetration of technologies that require human interaction in Lebanon require close attention'. For the effective permeation of energy harvesting, it is integral to put in place information-related strategies to adjust social norms and strengthen arguments for their implementation when rational decisions are made, as well as to change habitual behavior away from the conventional methods of self-generation, but bring about a new set of 'positive habits' that aid in the implementation of such technologies. The positive externalities of energy harvesting methods need to be highlighted to businesses and government, in order to increase investment in the field and encourage the funding of research and development programs in this area.

Five proposed strategies to support the permeation of energy harvesting technologies in Lebanon are introduced under five main headers. These include short-term and more long-term steps covering technical, economical, social and political fronts related to conception and implementation of 'harvesting energy from human power';

1. Research and development: increased funding for research in the field, including the introduction of 'energy harvesting' university courses and reward programs for companies that carry out or support R&D efforts in this field.

2. Governmental support: Dr. Lina Haddad suggests that alternative energy solutions should be presented to parliamentary committees focusing on Public Private Partnership (PPP), where they are most likely to be feasible if they were privately funded but involve government. An 'energy harvesting' lobby/advocacy group, with the support of the press, could help push for favorable changes in government policies.

3. Demonstration projects and awareness campaigns: to raise awareness amongst the general public (influencing rational behavior to ease integration of such technologies), act as an experience to build from and raise interest in energy harvesting.

4. Innovation and entrepreneurial spirit: increased investment from business angels and venture capitalists in budding entrepreneurs and inventors, as well as putting in place youth innovation programs to inspire entrepreneurialism.

5. Independent regulatory and technical authority: a commission of experts is better equipped to regulate the industry, but requires funding and government support.

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