Trends in Locally Generated Power (Bernard Murphy)

https://www.linkedin.com/pulse/trends-locally-generated-power-bernard-murphy?trk=mp-reader-card

I already wrote about limits to wearable power, with some discussion of energy harvesting, and thought it would be interesting to expand somewhat on the broader topic of energy-generation. I struggled initially to come up with a title for a range of possible techniques and finally decided they could all be encompassed under “local energy generation” as a catch-all for methods that draw power from somewhere other than the grid. This includes batteries and harvesting, both personal (body movement) home-based and industrial-based. I don’t consider windmills, wave and geothermal harvesting because these are not typically thought of as local-scale solutions.

Units of power vary depending on whether the method is volume-based or area-based, or where I was only able to find absolute power numbers (in the case of some bio-mechanical sources which are necessarily mechanically constrained). In some cases I was only able to find percentage contribution to overall power demand.

Type	Class	Method	Power density	Continuous Source?	Charge lifetime
Batteries	Chemical	Lithium-ion	0.2-0.6Wh/ cm^3	Yes	Several days
		Lithium-sulfur Zinc-air Lithium-air	Perhaps 500 Wh/kg	Yes	Several days
	Nuclear	Radio-thermal	0.04-0.1W/ cm^3	Yes	Pu^{238} – 87 year half-life
		Alpha- or Beta-voltaic	~2-500nW/ cm^2	Yes	Gd^{148} – 4 yr half-life
		Radiolytic conversion	80uW/ cm^2	Yes	Sr^{90} – 29 yr half-life
		Electro-mechanical	4nW/ cm^2	Yes	Ni^{63} – 100 year half-life
Home generation	Solar	Photovoltaic	0.2W/ cm^2	Variable	N/A
	Backup generator	Gasoline, propane,…	120kWh	Yes	1-few days
Bio harvesting	Biomechanical	Implanted kinetic	300uW/ cm^3	No	Indefinite
		Heel strike, elbow, shoulder	2W	No	Mech limit
		Ankle	20W	No	Mech limit
		Knees	34W	No	Mech limit
		Attached to the heart	0.2uW/ cm^2	Yes	Several years?
		Backpack loads	7W	No	Mech limit
	Biochemical	Blood sugar oxidation	uW-1mW/ cm^2	Yes	Couple of years
		Fermentation	~200W/ m^3	Yes	Substrate-limited
Traffic /industrial harvesting	Vehicle brakes	Regenerative braking	10-20% of EV driving energy	During braking	Mechanical limit
	Vehicle suspensions	Regenerative shock absorbers	~300W	Variable	Mechanical limit
	Building/ bridge vibrations	Vibration dampers	>10kW	Variable	Mechanical limit
	Railway tracks	Rail deflections	200W	Variable	Mechanical limit
	High-traffic walkways	Piezo-electric pads	~5W	~steady during busy periods	Limited due to stress aging
	Machine vibrations	Piezo-electric	uW-mW/ cm^2	Steady during operation	Mechanical limit

Batteries

It is common knowledge that battery technology is not evolving as fast as silicon technology, but that doesn't mean it's not evolving. One of the best known types is of course the lithium-ion battery, used exclusively in cell-phones and in many other devices. Progress in energy density stalled for a couple of years until 2012 when new electrode chemistries started to appear and we now seem back on a track of ~120mAh/year improvement in a typical 18650 battery. But there are limits to how far these chemistries can be pushed. More exotic options including lithium-sulfur, zinc-air and lithium-air are being explored but look like they may be many years from production.

Another interesting possibility is nuclear batteries. Popular opinion is not exactly pro-nuclear these days given safety and terrorism concerns, but nuclear covers a broad spectrum of possibilities and at least in an informed debate, shouldn't simply be ruled out without reasoned technical analysis. In fact, it seems technology and engineering may rule them out at least in the near-term. Many of the interesting materials are radio-isotopes (such as strontium-90) which have modest half-lives and might be considered at small battery scale. Implanting isotopes on nano-scale silicon structures has been demonstrated, from which beta radiation (electrons) can be used to generate current or to flex piezoelectric cantilevers through electrical attraction. The cantilever collects electrons and discharges then springs back on touching the attracting surface, producing oscillating energy generation. Even for beta-radiation, sources must be chosen to limit decay energy in order to minimize damage to supporting structures. Alpha and neutron emitters cause higher damage and are more difficult to shield, making these sources quite impractical for nano-structures.

Unfortunately low power densities and challenges in damage to the generators make nuclear approaches seem more interesting than practical at a micro-scale. A further consideration is the supply of suitable materials. From the world-wide annual supply of one of the most abundant isotopes released in fission, Sr-90, it is estimated that total realistic power production would be no more than about 1 MW. Other isotopes look even worse, leaving us with more conventional radio-thermal generation (RTG) at more moderate sizes and using materials (typically plutonium) that for safety and security reasons need to be limited to closely-guarded or inaccessible (space) applications.

Home

Photovoltaics are the best-known and best-developed harvesting application. These are very practical at a home or industrial scale, less so at a personal scale, except mostly in toy applications. Germany, for example, is estimated to generate 6% of its national energy needs through photovoltaics. Enough has been written about this domain that there little I can usefully add, other than to note that the idea of making money by selling back to the power utilities is probably unrealistic. We have to pay for mainstream power generation and distribution somewhere.

I live in an area where power outages can be measured in days, so backup generators are important. These can be standard gas-powered devices generating ~3-6kW or whole-house back-up generators delivering at least 10kW, more commonly driven by propane as one example. Both of these are useful options for short-term generation but are ineffective as long-term sources. A gas powered generator needs to be re-filled daily. A propane generator connected to a large tank might run for a few weeks, but then you'll need a refill from your local propane supplier. And neither of these options is cheap or green – your local power supplier does a much better job on both counts.

Bio harvesting

Personal energy harvesting seems like such an attractive idea, until you look more closely at the numbers. We tend to think in this domain about motion-generated harvesting (as you walk for example), but that generates tiny amounts of energy (nanowatts to microwatts) for short periods of time. To generate more energy you have to dig into the body's budget. An average person burns energy at a rate of about 115W averaged over a day. Some of that goes into heat, but there are problems in using that resource. First, heat engines are notoriously inefficient and second you actually need that heat. Start draining it away and you are effectively refrigerating your body which will fight to raise its temperature (by shivering for example), burning yet more energy which will be taken from other vital functions.

How about tapping more effectively into motion? The most obvious problem with this energy source is that it is neither dependable nor steady (with limited exceptions). You might generate interesting power while you are running or walking, but you probably don't plan to do either of these for the whole day. There is another less frequently mentioned problem. To tap more energy from motion, you have to create resistance against motion in some (possibly mechanical) manner. Doing work against that resistance is how you generate energy. But it is you who are going to have to do that work and that means motion is going to be more tiring, and you’re not going to be able to keep it up for as long. Generators of this nature are potentially interesting in prosthetics in a usage mode similar to regenerative braking – if work is being done anyway by a powered prosthetic, maybe you can recapture some of that energy to partially recharge batteries.

A possible exception is piezoelectric generation for heart pacers. Heart motion is a dependable source of energy (when it isn’t, energy harvesting is not your biggest problem). And pacing doesn’t need a lot of energy and therefore presumably won’t create significant additional load on heart muscle. Generators attached to animal hearts have demonstrated effectiveness for this function. Possibly this approach might become a practical replacement for battery-powered pacers.

Some biochemical approaches are intriguing, effectively forming a battery using blood glucose as the electrolyte. Electrodes must be coated with an enzyme to catalyze the reaction and that enzyme has a lifetime on the order of a couple of years, much shorter than the charge lifetime of implantable batteries, leaving these approaches firmly in the lab until some other compelling advantage makes them more appealing.

A very interesting application is in treatment of wastewater using anaerobic bacterial breakdown. This can generate an interesting percentage (~40%) of the energy otherwise required to drive breakdown through oxygenation. This could be particularly appealing in poverty stricken areas.

Vehicle / industrial

Regenerative braking, like photovoltaics, is an energy-harvesting success story, but primarily to extend time between charges, rather than as a cost-saving measure. As much as 10-20% of total battery drain can be recaptured during braking. Another opportunity, though much smaller, is to harvest vibration through shock absorbers. This might also help smooth the ride. Deflection in rail tracks as a train passes over can generate enough energy to power trackside electronics, though this will need battery smoothing to supply a continuous source.

Another source is capturing vibration energy from large buildings and bridges. Think of a skyscraper as a very tall wind turbine, flexing and vibrating in response to wind pressures. Dampers near the top of these structures can reduce vibration, structurally desirable in its own right, but could also in principle generate a significant amount of power. If you consider the moment of inertia of a large building, kilowatts of power could potentially be recovered, enough possibly to power emergency lighting.

A university and a Tokyo subway station have experimented with generation powered by foot traffic over piezoelectric pads. But they don’t generate enough power to light a small bulb and efficiency falls off quickly as the pads degrade rather quickly due to stress. Harvesting energy from machine vibrations seems like it should be a practical possibility but the power density is not very high, so the tradeoffs for self-powering rather than direct powering a monitor attached to a machine do not seem particularly compelling. One problem, common to all mechanical approaches, is that you can't easily tap all modes of vibration. An effective transducer has to focus on a resonant or dominant mode, leaving a large part of the vibration spectrum effectively wasted unless you can add yet more transducers. Perhaps there could still be an interesting application if vibration damping induced by generation could extend the useful life of a machine.

Conclusions

It is difficult to get excited about sources of local energy beyond the few practical methods we already know. While many harvesting techniques are technically intriguing, I see few that show promise of widespread commercial viability. There will of course be a green angle – corporations can show a commitment to renewable sources, but this will be driven more by corporate image management than by real cost-saving. One distinctive exception (waste-water treatment) could possibly be a literal life-saver in the third world.

Without exception, the problem seems to be that tapping new sources starts with a relatively small amount of practically and theoretically accessible energy which is then substantially reduced by unavoidable limits and inefficiencies in conversion. One way to offset this problem is through massive scale-up, but then you are limited to platforms like buildings and bridges. And even in those cases, the amount of energy that can be generated is dwarfed by the daily needs of the structure (a skyscraper for instance). I might wish the reality were different, but I suspect outside of the commercial successes we already know, this aspect of the green movement will have a rather short life.

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