Personal Energy Systems Calculations: Part II

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In Part I, http://www.analogZONE.com/col_060407.htm we did some basic calculations on the feasibility of using raised and rotating (flywheel) weights to store energy, and how feasible it is to reduce power usage so that some alternative generation and storage methods might become feasible on a small scale, that of a household. In this Part II the calculations continue for power from flowing streams of water and from small- or medium-scale ethanol production. By putting numeric values to the requisite equations, the feasibilities of various schemes is made more apparent. This includes the reasons why the world is not bursting with all kinds of alternative-energy generation and storage techniques. However, as the older solutions become increasingly less attractive, these calculations can guide the effort to select alternatives.

Energy Generation From Streams

The energy problem is not solved directly by addressing storage or use reduction. New sources must be considered beyond geofuels. Solar PV and wind are leading contenders and highly dependent upon location. Another possibility is solar thermal with thermoelectric modules. This has been covered in detail in other TechNotes. Large-scale hydroelectric potential has been largely exploited, though smaller creeks and rivers have not. Rural and even suburban dwellers not uncommonly have creeks, with ponds, on or near their property. The feasibility of *microhydro* generation, as it is called, depends on the power in a stream. This leads to some basic fluidic power calculations.

The basic equation for *flow work* is: $W = P \cdot V$, where P is pressure (not power) and V is the volume of fluid displaced at that pressure. The power equation is therefore:

$$\dot{W} = P \cdot \dot{V}$$

where, the dots indicate time derivatives.

Pressure drop from an open stream is due to a change in height in the gravitational field. This is a dynamic variation on raised-weight storage. The pressure difference (or *head*, as civil engineers call it) is:

$$P = \rho \cdot g \cdot h$$

and stream power is then:

$$\dot{W} = \rho \cdot g \cdot h \cdot \dot{V}$$

Water has a convenient metric density of:

$$\rho(\mathrm{H_2O}) = 1\,\mathrm{kg/l}$$

where, a liter, l, is 1000 $\mathrm{cm}^3 = 10^{-3}\ \mathrm{m}^3$. (A US gallon is 3.785 *l*.) Then with earth surface gravity:

$$\dot{W} = (1\,\mathrm{kg/l}) \cdot (9.81\,\mathrm{N/kg}) \cdot h \cdot \dot{V} = 9.81 \frac{\mathrm{W}}{(\mathrm{l/s}) \cdot \mathrm{m}} \cdot h \cdot \dot{V}$$

For a 1 m drop of a water stream flowing at 102 *l*/s, the stream power is 1 kW. To relate this in Imperial units of gallons/minute (gpm):

$$1 \frac{\mathrm{gal}}{\mathrm{min}} \cdot \frac{1\,\mathrm{min}}{60\,\mathrm{s}} \cdot \frac{3.785\,\mathrm{l}}{\mathrm{gal}} = 0.06308\,\mathrm{l/s}$$

or:

1 *l*/s = 15.85 gpm

Consequently, it would take 1617 gpm to produce 1 kW, a considerable flow. Analogically, this is a low-impedance example. A high-pressure, low-flow example of 1 kW, typical for those in hilly terrain, is 162 gpm falling 10 m, or about 33 ft.

To gain further quantitative intuition for the flow rates required, 100 *l*/s is 0.1 m^3/s. This is a stream 0.5 m deep by 2 m wide flowing at 0.1 m/s -- a common size for a creek. A 1 m fall of the creek provides 1 kW of input power to a microhydro generator. Optimized *impedance matching* for flow volume and speed is required of the impeller to maximize efficiency. Beyond impeller matching, the electric generator will have a typical electric-machine efficiency in the mid-90% range.

One additional consideration for stream power is storage. How much energy can be stored in a pond? A rectangular pond of 100 m by 50 m by 2 m depth contains 10^4 m^3 or 10 M*l*. At 100 *l*/s, the time it would take to drain it is:

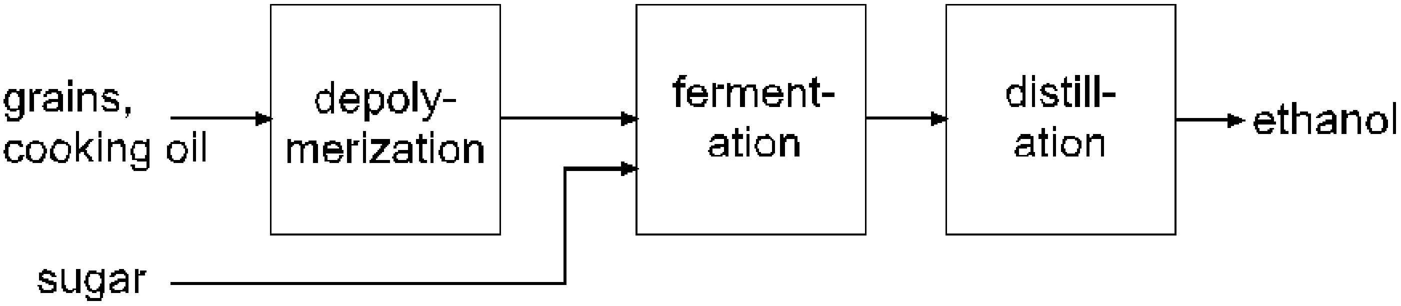
$$\Delta t = \frac{10^7\,\mathrm{l}}{100\,\mathrm{l/s}} = 10^5\ \mathrm{s} = 27.8\ \mathrm{h}$$

A pond the length of an American Football field, half the width, and the depth of a tall person is not very small, yet for a 1 m waterfall out of it, it would provide 1 kW for little more than a day. With these numbers, we can see that there is no point outfitting a drainage ditch to provide power. Yet a year-round stream of common size is worth considering.

Energy Generation From Home-Made Ethanol

For those in warmer climates, or in grain-producing areas of the world, we now proceed somewhat outside the usual range of possibilities to consider family-sized ethanol production. The family of veterinarian and leader of the tractorcade political protest that tied up government Washington streets with farm equipment, Dr Eugene Schroder of Colorado, produces commercial amounts of ethanol in the processing plant that they built themselves in their barn. Electronics engineers are not inclined to become chemical engineers for this option, though most creative electronics (or even software) engineers are not artificially limiting in their skill sets.

While building such a plant is a nontrivial exercise, the Schroders are not chemical engineers either. One of the Schroders, Micki Nellis, has written a very detailed book/CD on just how to do it, titled *How to Make Alcohol Fuel*. http://buffalo-creek-press.com/alcohol.htm You need not necessarily grow your own crops from which to derive ethanol, for unless you are an EE-farmer, crops are better left for economy-of-scale specialization. If you are urban, you can still get there by acquiring and recycling cooking oil used in fast-food restaurants. The organic input material goes through three processing steps, as shown below.



An enzyme is used to break down grains and oils for the fermentation process, which results in ethanol in water. The water is removed through distillation. If you are blessed to live in an area that produces sugar cane, the first process can be skipped. Sugar is immediately fermentable. This process is a subset of that used by breweries, and with microbreweries sprouting up in many places, another approach is to collaborate with a local brewer to make ethanol on weekends or between batches of beer.

In the Corozal district of Belize, sugar cane is grown in abundance. A formerly Canadian engineer from southern Quebec province, Peter Singfield, lives there. We went through the numbers on ethanol production. His calculations follow. A ton of sugar can be produced from 10 tons of cane. (The residue, called *bagasse*, can be burned to run the processing plant.) Cane growing wild will produce 30 tons per acre. With fertilization, 50 tons per acre are achievable. To be conservative, assume 30 tons per acre. Then one acre yields 3 tons of sugar. The sugar-to-ethanol yield is 50 %. (This agrees with Nellis' ethanol/sugar mass ratio of 0.511.) Then one acre yields 1.5 tons of ethanol. The density of ethanol is 6.6 lb/gal = 11.36 kg/*l*. Then one acre of cane will produce 1720 *l*. The heating value of ethanol is 23.53 MJ/*l* (89.0 MJ/gal), resulting in an ethanol energy production per acre of cane of 40.48 GJ = 11.25 MW·h.

This is enough energy to supply 1 kW average power for 1.283 years -- about right for a family household with some additional energy use and accounting for conversion inefficiencies. Conclusion: one acre of sugar cane can supply one American family for a year with energy. A direct alcohol fuel cell, or a diesel-, Otto-, or Stirling-cycle engine must be used to convert it to mechanical power, then a generator to electricity -- readily available technology (at least the heat engines are) and increasingly so for the fuel cell.

What is the cost of ethanol production from sugar cane? At Belizean labor rates, a cane cutter would cut an acre for $75 US. Brazil has refined the technology, from sugar factories to gasohol plants, and has offered the technology to Belize, a country not far from the US Caribbean coast. An abandoned sugar production facility in Libertad, Corozal, awaits capitalization. Perhaps a few engineers should get together and solve the energy problem for their network of friends and associates by capitalizing the plant and providing themselves a personal lifetime supply of ethanol. The sugar cane industry could certainly use the diversification and we all need the energy. The right timing for this is in 1.5 years, when the current political party will probably be voted out and the next ruling party will be almost certainly more amenable to such a venture.

Acknowledgement: thanks to Peter Singfield for the "napkin e-mail" calculations of July 4, 2001, on ethanol production from sugar cane fields in Corozal.

Closure

Not all alternative energy solutions have been calculated here. Wind turbines are notably absent and might be covered in a future TechNote. (Those calculations are not quite so simple as the ones we considered here.) So is ocean-wave generation. Australia has uranium ore; Aussie readers might consider a small thermonuclear pile for heating thermoelectric modules and a truck drive to the outback to mine some. The tropics and SW North America have sun, also good for heating and growing sugar cane. The alternative possibilities, while early in development, are attractive, and our basic calculations have provided some idea of what it takes to make some of them happen.

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