**An Affordable Zero Energy Off-Grid House + EV Combination**

In an increasingly crowded, complex, resource scarce, and globally interdependent world, long supply lines for energy, water, and food become perilous and subject to natural and man-made disruptions. A return to a more local and self-reliant method of resource use may be a better approach than large centralized scenarios.

In an earlier report, see:

<http://www.staff.washington.edu/larryg/Energy/housePV.doc>

I compared a centralized energy scenario with a partly local scenario: Family I versus Family II, where both live in the same location, have the same size house and quality of appliances, and drive one or more automobiles the same distances per year. The differences were that Family I possesses a conventional house + car combination, whereas the house for Family II was built according to the European Passive House standard, the cars were electric, and, while still connected to the electrical grid, the house and cars got their power from a large (approx. 8 KW) PV array making it a net-zero-energy house + car combination for the next 30+ years.

Despite the large increase in the initial cost of the house for Family II, there were no additional upfront costs for Family II, and the annual overall savings were typically several thousand dollars/year. So the economics appears to work for a house still connected to the grid.

I would like to extend this concept to a small community, say 20 families, that can operate almost totally off the grid in terms of energy and water (perhaps later this could extend to food). But initially I will do so by extending it to a single household where the house is not connected to the grid: no pipes, wires, or cables connect it to the outside world (other than TV/Internet). If the economics works for that case, then the extension to a small community should be even more economical due to the ability to share resources and dampen large swings in energy and materials usage.

In order to do so I will:

* Summarize the findings and costs in the net-zero-energy report in the above URL (without references or discussions which are available in the above URL)
* Determine the shortfall in solar PV energy due to nights and seasons (mostly winter)
* Determine the type and cost of energy and water resources needed to overcome that shortfall
* Add the cost of the additional energy and water resources to the initial net-zero-energy scenario to determine if it makes economic sense.

**Summary of Costs and Findings in the above URL:**

* Cost of house for Family I: $220,000 (the median price of a new house in the U.S. 2010)
* Mortgage cost at 6% for Family I ($0 down payment): $1,319/month = $15,828/year
* Home energy cost for Family I = $2350/year (grows at 3%/year)
* Gasoline cost for Family I at 21,000 miles/year travel = $2100 (grows at 3%/year)
* Total annual energy cost for Family I = $4450/year (which grows at 3%/year)
* Base cost of house for family II: $220,000
* Cost of building the house to the European Passive House standard (at 7%) = $15,000
* 8 KW Solar PV array for Family II at $5/watt = $40,000
* Total cost of new house for Family II = $220,000 + $15,000 + $40,000 = $275,000
* Mortgage cost for Family II at 6% ($0 down payment): $1,649/month = $19,788/year
* Annual difference in mortgage costs: Family II - Family I = $3960
* Energy cost of house + car combination for Family II: $0.00
* First year difference in total energy + mortgage costs (II-I) = -$490 (but grows at 3%/year)
* 30-th year difference in total energy + mortgage costs (II-I) = $19,788 - ($10947 + $15,828) = -$6987
* Average annual reduction in cost for Family II is ($6987-$490)/2 = $3248/year

**Shortfall in Solar PV Energy Due to Nights and Seasons**

In order to determine the cost of an off-grid house + car combination, we need to determine the shortfall in

daily/seasonal energy supply from the solar PV array and the additional energy and water resources

required to make up that shortfall.

According to the first URL, an 8 KW PV array in an average part of the U.S. will produce an average

of 8,800 KWH/yr for over 30 years, enough to supply all the power for the house + cars. However, that

power is not available at night and is reduced in the winter and so the house uses the electrical grid

as a giant battery to store and retrieve energy.

We will address the night time energy needs with a storage battery that can store 48 hours worth

of average electrical use. To address the seasonal problem, we need to know how much solar PV

energy is reduced in the winter.

Now if we take a representative sample of 13 cities showing summer versus winter sun-hours for selected cities

in the U.S.: Little Rock, Boulder, Boise, Chicago, Boston, St. Louis, Great Falls, New York, Columbus,

Pittsburgh, Nashville, Forth Worth, and Seattle:

<http://www.green-trust.org/2003/pvsizing/default.htm>

we find that the average disparity in sun-hours between summer and winter is less than 2 (1.9),

although in some cases, such as Seattle, it is more than a factor of 3. If 8,800 KWH/year provides

Family II with all the power they need, then the average power needed per month is 8800/12 = 733

KWH/mo. Given the data that we have, if we assume all three months in each season are similar, then the

solar PV intensity is 100% for summer, 75% for spring and autumn, and 50% for winter, yielding an

average of 75%. So the winter solar PV (at 50% of the summer PV) is 66% that of the average needed or

483 KWH/month, averaged over the continental U.S. So the average shortfall in the winter is 733-483 =

250 KWH. So we need to provide an average of at least 250 KWH/month during the winter from other

sources (we actually need a somewhat larger amount due to the fact that not all winter months

are the same, for example in December in Seattle, the disparity is much larger than 3).

**Additional Energy Sources to Make Up the Seasonal Solar PV Shortfall**

There are two obvious energy sources that may make up the shortfall: wind energy and

the combustion of waste material. There is now on the market a very unique wind turbine, called

the Honeywell Wind Turbine that appears to be the only wind turbine that is suitable for

typical urban environments, in that it is compact, quiet, and can generate energy in

winds as low as 2 MPH(!) and as high as 38 MPH. We need to look at the wind resources

in urban environments to determine if it is useful.

The Honeywell Wind Turbine is said to generate 2750 KWH/yr in Class 4 winds. See:

<http://www.earthtronics.com/pdf2/Energy-Output-Curve-11-22-2010.pdf>

Most places in the U.S. do not have class 4 winds, but most cities in the U.S. do have class 2 winds during the winter. According to this reference:

<http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html>

class 2 winds at 33 feet range from 9.8 to 11.5 mph (average = 10.62 mph); class 4 winds range from 12.5 to 13.4 (average =12.95). I sampled a slice of 28 cities from Grand Island NE to Rochester NY in the middle of larger set of cities in the U.S. from this data set:

<http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/avgwind.html>

and found that more than half of them had class 2 wind speeds during the months of December, January, and February, when solar PV is usually at its minimum. Since wind power goes as the cube of the wind speed, class 4 winds should produce (ave-class-4-winds/ave-class-2-winds)\*\*3 or (12.95/10.62)\*\*3 = 1.81 times more power than class 2 winds, so class 2 winds should produce 1519 KWH/yr. Since we are only concerned with the 3 winter months, most places in the U.S. should be able to generate 1519/4 = 380 KWH during the winter three months from wind. That is 127 KWH/month, which is about 1/2 of the 250 KWH/month we need to make up.

.**Combustion of Waste Material:**

The other major energy source is combustion of waste material and here the best engine to use is a Stirling engine which is not only highly efficient, but it can turn **any** source of heat into electrical energy: solid, liquid, gas, or even sunlight. There is a small Stirling engine on the market that can generate 800 watts of electrical energy. This particular one uses liquid fuel, so the burner part needs to be modified to burn waste material such as paper, wood chips, cooking oil, etc. So we need to determine the amount of waste material available to a typical residence in the U.S.

**Paper/Cardboard/Etc Waste:**

There are two main sources of burnable waste: paper, cardboard, plastic bags; and dry renewable biomass. We have data for the amount of residential consumption of paper/cardboard in the U.K. and data for the total amount of paper/cardboard production in both the U.S. and U.K., so we can estimate the amount of residential U.S. paper/cardboard consumption based on these production and population figures.

The US consumption of paper/yr = 84,300\*10\*\*6 tons/yr, and The UK consumption of paper/yr = 5,800\* 10\*\*6 tons/yr. See:

<http://statinfo.biz/Data.aspx?act=6128&lang=2>

The paper waste per household in the UK is more than 4 kg (about 9 lbs)/week: 468 lbs/yr. See:

<http://www.wasteonline.org.uk/resources/informationsheets/paper.htm>

So we can calculate the total consumption of waste paper in the US using this formula:

Waste paper/week in US = ( ( USppr/UKppr) / (USpop/UKpop) ) \* UKwst where:

|  |  |
| --- | --- |
| USppr = US total paper/cardboard production/yr | = 84.4 M tons |
| UKppr = UK total paper/cardboard production/yr | = 5.8 M tons |
| USpop = total US population | = 300 M people |
| UKpop = total UK population | = 60 M people |
| UKwst = lbs waste paper/cardboard/wk | = 9 lbs |
| So, lbs/household/yr in US waste | = ( (84.8/5.8) / (300/60) )\*9 = 26 lbs/week = 1352 lbs/yr |

Now you get 6,500 BTUs/lb to burn waste paper. See:

<http://www.generatorjoe.net/html/energy.html>

This yields 8,788,000 BTUs/family/yr. Given that there are 3413 BTUs/KWH this yields 2575 KWH/yr. Assuming that the Stirling engine is 30% efficient, this yields 772 KWH/yr. If we assume that we can only access 2/3's of that waste, we still get 509 KWH/yr from paper/cardboard waste which yields 170 KWH/month (at 30% Stirling engine efficiency) for the 3 winter months.

**Biomass Waste:**

The amount of residential biomass in the U.S. is 0.33 quads = 3300 \* 10\*\*11 BTU. See:

[**http://tinyurl.com/4txe9pf**](http://tinyurl.com/4txe9pf)

Assuming 100 million (10\*\*8) households in the U.S. that yields 3300\*10\*\*3 BTUs/household/year.

Since 1 KWH = 3413 BTUs, we have a potential of just under 1000 KWH (of heat)/household/year. Assuming that we can use 1/2 of that biomass for heat (500 KWH heat) we get 150 KWH electricity/household/year at 30% efficiency. So we get a total of 150 + 380 +509 = 1039 KWH/yr electricity from non-direct solar sources.

So let us look at the total energy picture:

* We need 8,800 KWH/year
* We get 8,800 KWH/year AVERAGED over the year from Solar PV
* This translates to 733 KWH/month
* At night we get 0 KWH from solar PV
* The battery gives us 48 hours of storage
* During winter we get an average of 484 KWH/month from solar PV leaving a deficit of 250 KWH/month
* From the Honeywell wind turbine we get an average of 127 KWH/month in winter
* From burning paper etc waste we get an average of 170 KWH/month in winter
* From burning waste biomass we get an average of 50 KWH/month during winter
* This yield a total of 347 KWH/month during the winter, leaving us an excess of 97 KWH/month to cover non-solar PV energy needs

So even given the variations in energy within the 3 month winter period we should have enough excess energy to handle most residences.

**Additional energy and water resources and cost:**

* Product: A 48 KWH zinc-bromide flow battery
* Cost : $20,000 ($400/KWH)
* Reference: <http://en.wikipedia.org/wiki/Zinc-bromine_flow_battery>
* Notes: this battery should last 30+ years

* Product: A Honeywell wind turbine
* Cost: $7000
* Reference: <http://www.earthtronics.com/honeywell.aspx>
* Notes: this is a radically different wind turbine that appears to be only wind turbine suitable for typical urban environments in that it can generate power in winds as little as 2 MPH or as much as 38 MPH

* Product: A modified 800 watt "WisperGen" Stirling engine generator
* (estimated cost): $5000
* Reference: <http://www.whispergen.com/main/dchomesspecs_info/>
* Notes: this product is on the market but it is difficult to determine the cost, so I estimated it at about 6 times the cost of a gasoline generator of the same size (e.g., the $799 Yamaha EF1000iS - 900 Watt Inverter/Generator). In addition, the fuel part would have to be modified: a Stirling engine can burn anything: rags, wood chips, cooking oil, dried leaves, but the combustion part would have to be modified to do so

* Product: 4000 gallon cistern + water purification
* Cost: $5000 (a 2500 gallon cistern cost about $2900)
* Reference: <http://www.plastic-mart.com/class.php?item=1536>
* Notes: while this would not work in all areas, the size is far more than adequate for Western Washington which only gets an average amount of rain per year. 4000 gallons is 8% of the total collectible rainfall from a 2000 sq foot roof per year, and equal to 60 toilet flushes/day, or 3 laundry loads/day

* Product: septic tank
* Cost: $7,000
* Reference: <http://www.eco-nomic.com/indexsdd.htm#Septic%20System%20Costs>
* Notes: this is a high estimate

So, let us total up the cost of the house for Family II:

|  |  |
| --- | --- |
| House | $220,000 |
| Passive House design | $15,000 |
| 8 KW Solar PV array | $40,000 |
| Honeywell wind turbine | $7,000 |
| 48 KWH zinc/bromide battery | $20,000 |
| Modified "WisperGen" Stirling generator | $5,000 |
| 4000 gallon cistern | $5,000 |
| Septic tank | $7,000 |
| **TOTAL** | $319,000 |

So, the monthly payment is now: $1,913/month or $22,956/year

Even if we ignore the savings in water costs, Family II pays more the first few years:

$22,956 - $20,278 = + $2678

After 30 years, the difference is:

$22,956 - $26,775 = - $3819 (given a 3% inflation rate for energy and gasoline)

So even in this case Family II saves an average of $570/year, or a modest $17,115 over 30 years

and the cash flow is positive after 5 years.

Since this appears to be reasonably affordable for a single household, it means that a small community built along those lines should definitely be affordable.