The Ravina Project

Lovins on the Soft Path

A Critique

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An Introduction to The Ravina Project

The Ravina Project, conceived in late spring 2006 and up and running in November of that year is a household-focused engineering science project. We are collecting high fidelity data and writing formal papers on such topics as: household cooling and heating efficiencies, solar PV efficiencies versus ambient heat and sun angles, solar PV Capacity Factor, the invention and use of a new solar PV efficiency standard, household resiliency, household thermodynamics, and how 'livable' a lower carbon emission lifestyle can be, among other things.

Our high fidelity databases are large and growing, totaling over 100,000 pieces of data. They allow us to validate or falsify various speculative hypotheses. They also allow us to anchor our published papers in data rich analysis. Some papers rely upon the analysis of several thousands of observations.

Our programmable dynamic solar array structure is unique. It is specifically designed to enable the collecting surface to tilt and compensate for the sun's altitude in the sky on an hourly basis. This ability is critical here at 43.7 degrees latitude where for about 90 days a year, the sun does not get above 30 degrees in altitude above the horizon at noon, sun time. As a bonus the dynamic array produces observations which allow us to calculate a solar array's aperture. For those areas outside the Tropics, the calculations we have made help us define the best algorithms for low cost, simple, hand operated 2-axis sun tracking systems which lose little in potential harvested energy due to poor sun angles upon the collecting surface.

In addition to the science and data gathering, The Ravina Project is conceived and built as a prototype upgrade to an existing and very common housing type in the Greater Toronto Area. We are testing the integration of various sub-systems over an extended number of years to determine their compatibility both with each other and with the people, plants and pets making up the household. Our modified 1920s era house allows us to empirically test out our resiliency, especially Grid resiliency, as real world disruptive events occur. We understand that technology is changing and the particular technologies we are using to provide resilience will be obsolete in future years. However, we see the resilience functionality we have created being incorporated into future technologies which will be more powerful, compact and probably cheaper in real dollars to adopt. It is our view that future events will create market demand to the extent that Grid resilience is either designed into new houses or provided as an upgrade package to current householders at much lower cost than a new bathroom. Refurbished and reconfigured used electric automobile batteries may provide a key piece among the technologies included in the future Grid resilience packages available to householders.

We envision a future in which the availability of electrical Grid power and carbon based fuels will be, of necessity, much lower than today. Due to growing climate disruption/global warming, residential Grid power supply may become intermittent on a regular basis as it is today in many parts of the Second and Third Worlds. When resiliency to Grid interruptions are built into housing infrastructure, such interruptions will not be as catastrophic as they would be in present day First World neighbourhoods. On a city wide level household Grid resilience allows utilities to build smaller scaled, lower carbon, centralized power supplies because they have the option of disconnecting whole neighbourhoods during peak power demand.

We understand that reducing a household's carbon footprint is vital to reducing overall atmospheric carbon release. We are looking closely at our attitudes and lifestyle for insights into such areas as: household carbon accounting, using software rather than hardware defined devices, carbon based functional analysis of both the technology we employ and the consumer products we purchase. These changes are our attempt to modify our attitudes and desires so that we may decouple ourselves from the current and prevalent consumption based modernity. However, we also know that high technology, applied correctly, will allow for this decoupling on a massive scale.

As the changed lifestyle part of the experiment unfolds today, it becomes apparent we are living a future lifestyle in an old house modified for tomorrow.

All our data and papers are published on our WEB site at: www.theravinaproject.org

Regards,

Susan and Gordon Fraser
Directors

The Ravina Project

A Critique of “Lovins on the Soft Path”

Introduction

We will use the ideas found in Amory and Hunter Lovins’ film, “*Lovins on the Soft Path: An energy Future with a Future*”, http://www.bullfrogfilms.com/guides/lospguide.pdf as a basis for discussion on what we have found during the last nine years of The Ravina Project. More exactly, we are using the guide to the film for students and teachers as a template by which we will isolate their ideas and comment upon them. Note that we cannot comment directly upon the energy policies discussed in the guide because we are not a policy research project. However, there is much in the guide that focuses on the household so we will use our efforts and data to discuss how their ideas hold up today.

All quotations from the guide to the film are copyrighted material. We assume that our use of any quotes from the guide falls under Fair Use.

Our 1925 era house has been modified to be an Amory Lovins inspired house. His ideas are so pervasive today that we forget how far he was ahead in his thinking in the 1980s. We just upgraded our house according to the common understanding of energy efficiency, little knowing at the time that we were following his plan. So for the rest of this paper we are going to isolate his ideas as described in the above film, describe our efforts to satisfy his ideals and then use our copious data to evaluate how we are doing according to the standards he sets.

Amory Lovins’ Ideas

In what follows we want to isolate and list his ideas that directly impact house design. We also want to keep in mind Jane Jacobs’ idea of the distinction between house and household. We agree with her that the house is the structure and the household is the structure plus the people, plants and pets inhabiting it. Our data clearly show that the household has different thermodynamic properties than the house.

Heat – Superinsulation

“*The cheapest way to provide the energy we need to keep people comfortable in a building is to design the shell of the building so it keeps heat in during the winter and keeps it out during the summertime. One technique is superinsulation.” [pg 3]*

Our insulation upgrades include the following: sealed off basement headers, all new modern double glazed windows, modern double doors with good seals, attic filled with 9 inches of pink insulation, tuck pointing on the double brick first floor exterior, the second floor capped with R 2.6 foam insulation and heat shield under vinyl siding. Note the second floor on our house is frame construction and the first is double brick. As you may know it is not a good idea to cover over brick walls on the outside so the house must be gutted and the insulation placed upon the inner walls if brick walls are to be further insulated. This was not part of our plan and certainly beyond our budget.

We have discovered several things that are not in Lovins’ superinsulation plan. We have analyzed the house’s internal heat flow and determined that we can make modifications to it such that we can see the results when we look at the house's heating efficiency. We'll look at our data and the results of our efforts in the next section.

Heat - Passive Solar

"Passive solar design is the next cheapest technology. It means using windows to let the sun in, and storing the resulting heat in water or masonry ('thermal mass) until it's needed. For summer cooling, it means window overhands to keep out the high summer sun but let in the low winter sun; shade trees: and thermal mass to store nighttime coolness for the daytime." [pg 4]

Passive solar is another mode of heating that Lovins proposes. We have several windows that do get direct sunlight from the southeast. We have a large side yard. We leverage this heat as much as we can in the wintertime. There is a problem in the summertime because the heating influence is dramatic. As shown on the left we use sun/heat shades we have built to mimic Lovins' idea of window overhangs.

Water Heating – Solar Hot Water

"Water heating needs can be taken care of by flat-plate solar collector such as you already see on many homes. Well-designed collectors can supply most of the hot water needs of the building. Their performance on cloudy days can also be improved by giving them a 'selective surface' that absorbs heat well but doesn't lose it as easily …" [pg 4]

Lovins suggests that the use of passive solar water heating is of benefit. We would be using it but our roof space is filled with our solar PV array. Our domestic hot water (DHW) heating and house heating through hot water radiators is accomplished by a super high efficiency Trinity T-150 boiler the size of two old style breadboxes bolted to the basement wall. It is powered by natural gas at about 95% efficiency and its computer and circulation pump are energized with electricity. We do not have a hot water tank. Hot water is produced 'on the fly' when we turn ON the hot water tap. See the Appendix for a link to the specifications.

Electricity – Solar Photovoltaic Power Generation

"Electricity is the smallest of our end-use needs: roughly 8 percent. But those uses require the very high-quality, expensive energy of electricity. No other energy form will do for such tasks as stereos, home appliances, industrial motors, computers and lighting. When electricity was cheap, however, we also began using a lot of it for tasks that don't give us our money's worth: heating and cooling. These uneconomic uses are now six percent of our energy demands and growing. Thus the first step in using electricity sustainably is to use electricity only where cost effective. The previous section on Heat (p. 3), showed how to supply all our heating energy needs renewably. This means letting superinsulation, passive solar, and other good architecture keep our buildings comfortable, and just using electricity where its real need justifies its high cost. If we then use efficiently the electricity we still need, we will find it is not hard to meet all our electrical needs with renewables." [pg 7]

Lovins goes on to list some of the technical fixes used to drop our electrical energy use. We have upgraded our house with exactly the fixes he mentions. All our lights are CFL types except for a few incandescents used in a few rooms in the wintertime. We found that incandescent lights which give off lots of heat, are great ways to both light and heat small rooms in the wintertime. Our favourite is a 100 W bulb. Not mentioned by Lovins is the power bar. There are so many appliances that suck power. This phenomenon has several terms for it: power vampires, phantom loads or ghost loads. They all draw power even if the appliance is turned OFF. We have introduced power bars such that all these appliances are plugged into them. One switch cuts the power to a whole range of energy sucking devices. This ease of use, one switch controls many devices, allows for regular daily use which, over time, eliminates substantial energy consumption.

Our refrigerator is a modern design, well insulated and efficient. In the summertime however, it is the largest daily user of electricity at about 4 kWh per day. The rest of the house uses between 4 and 8 kWh per day on a low to moderate energy use day.

We have 2,800 Watts of solar PV panels on the house on a movable structure. We fulfill Lovins idea that when possible the house should be a generator of energy. But we are one step further along. He talks about energy sustainability and self-sufficiency at the household level. We are a hybrid between a neighbourhood clean energy generator and an off-Grid house. We generate our own electrical energy but we have a large battery in our basement kept charged by the solar panels and the Grid. When the Grid goes off line, all the important circuits in our house, which run totally on battery power at all times, are not affected. The battery is sized to contain enough energy for two days of emergency operation with no sun and no Grid. With a powerful sun, especially in the summertime, it is possible to live off-Grid for several weeks at a time at reduced energy use. We know this from our daily generation data. This is possible because we have included all the technical fixes Lovins suggested to keep our electrical needs low.

We have looked into wind energy here but we don’t have enough wind to make it worth while.

Lovins comments that electrical energy is not to be used for household cooling and heating. He believes that superinsulation will allow little or no energy use for this function. We have kept records of our use and used them to calculate our cooling and heating efficiency. We’ll explore those records below and see how close we get to Lovins ideal.

Changing Energy Paths Without changing Lifestyles [pg 13]

“For some people, the shift to a sustainable energy path raises images of a radical change in lifestyle, in which people may not drive as much as they want to or keep their houses as comfortable as they would like. Actually, a sustainable energy future will make all of those things easier to obtain than they would be under the so-called hard path.” [pg 13]

Lovins outlines three different ways to use less energy:

- curtailment,
- lifestyle changes,
- technical fixes.

Curtailment is basically using less energy. This is well known today as people turn down their thermostats in the wintertime so their houses are a bit cooler than they would be. This list is long.

We have set our computer controlled thermostat several years ago and have not changed it. We wear an extra layer of clothing in the wintertime. We use our fireplace on special occasions only because the draft takes much warm air out of the house. In the summertime we have developed different ways of cooling the house not involving the air conditioner. We have several papers on our WEB site detailing all we have done in this area. See the Appendix for more on this topic.

Lifestyle changes include taking public transport, walking instead of driving, cycling to work, moving to people friendly neighbourhoods. Living in neighbourhoods designed before the ‘car is king’ mentality took hold of urban planners, that is, living in walkable neighbourhoods designed assuming most people do not use or even own cars.

We know full well that energy is embodied in everything we purchase and use. We clean up our leftovers from meals and of course we plan our meals so the leftovers are really good to eat. We make all our meals in house and go ‘out’ to eat as a special treat several times a month. We never want to ‘throw out’ perfectly good food and on the other hand we purchase the amount of food we can actually use cutting down on spoilage. We buy in bulk to cut down on packaging. We look to finding something ‘second-hand’ if we need a piece of technology and we are loath to ‘throw out’ something that is only partially broken. For instance a device may have 80% of its functionality still working. We keep such a ‘broken’ device because in many instances the functionality in the broken 20% is never used. We wait until there is a problem with the functionality that we use before we throw it out.

We have stopped thinking about our lifestyle as a vehicle to impress people. Basically we have adopted the point of view that we have no one to impress. That liberated feeling allows us to sidestep fads and items of capricious frivolity that end up in the garbage once exhibiting them becomes a symbol of dated extravagance.

Technical fixes “saves energy in a way that users typically cannot tell that any change has occurred.” These fixes encompass lighting, heating, insulation and cooling. In all cases the household does not notice that they are using less energy.

Lovins’ argument is that to reduce energy use does NOT require us to live in energy poverty other than a small amount of curtailment. We have tried to follow his advice. In the sections below we present our data and evaluate ourselves.

General Comments upon "Lovins on the Soft Path"

We can't leave "Lovins on the Soft Path" without commenting of a few topics he presents given the world's changed circumstances today.

Nuclear Power

The incredible speed at which the earth is warming, unprecedented even in the paleoclimate record, means we must decarbonize our civilizations with great haste over the next 35 years, that is, between now and 2050.

Lovins makes the case that we should shutter all our nuclear power plants and burn wood [pg 12]. There are many today who advocate using biomass to produce electricity for the Grid. Their argument is that since the carbon in the biomass has been recently extracted from the atmosphere by plants, returning it to the atmosphere today is a net zero activity. We return only the carbon that was originally in the atmosphere. The logic is valid and so is the chemistry. However, a simple timeline analysis will uncover the flaws.

A Simple Biomass Combustion Model

Consider the chart below constructed from our simple wood-based biomass combustion model.

Firstly, the set up for our idealized model is as follows.

In year one the combusted trees come from a plot that is cleared totally. We see on the chart that the total release of CO2 into the atmosphere is 100 units. We also see that the accumulated CO2 from this release is 100 units.

At the start of year two's growing season the plot consumed in year one is replanted instantaneously. So, at the end of year two the saplings have one full growing season behind them.

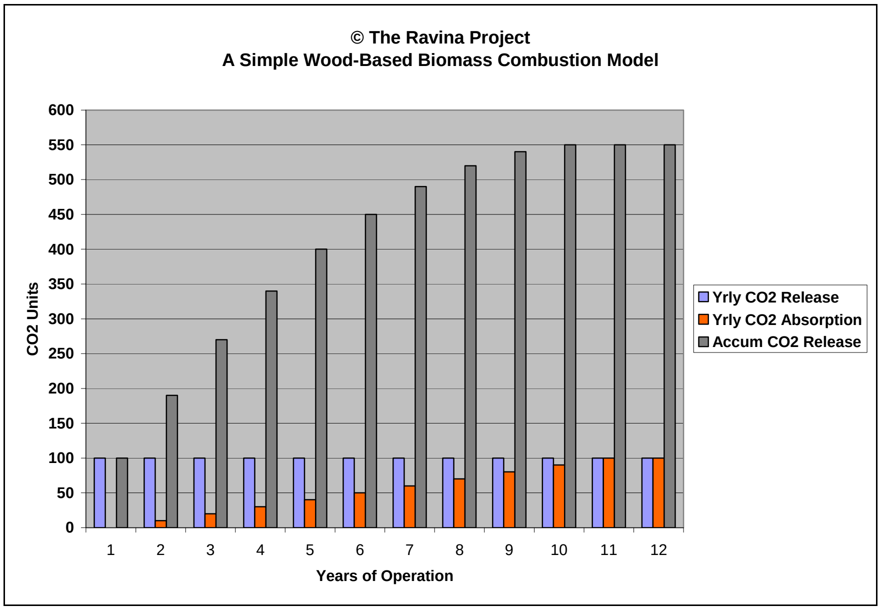
How much CO2 do the saplings take out of the atmosphere every growing year? We assign them 1/10th of the total amount of CO2 in a mature tree. How long will it be before a sapling matures? We will assign 10 years.

So after the tenth year of growth and 11th year of harvesting, a tree planted at the start of year two is ready for harvest.

Looking at the chart below at year TWO notice that 100 units are released into the atmosphere. The orange bar 'Yrly CO2 Absorption' makes its first appearance. It represents a full growing season for the saplings which absorb 1/10th of the 100 units of CO2 released when combusted. Note the increase in 'Accum CO2 Increase' bar is not 100 Units but 90 units. It takes into consideration the absorption of the saplings for the year.

That's the chart and how it works. Each year as more plots of saplings are planted, the accumulated number of plots also absorb a larger and larger amount of CO2 from that atmosphere such that by year 11 the amount absorbed and the amount released by combustion are in balance.

Looking at the bar labeled ‘Accum CO2 Release’ We see it rising incrementally with a smaller marginal rise every year until it stops rising in year 11. After that there will be net no new release annually because there are 10 plots of saplings each absorbing 10 CO2 units for a total of 100 CO2 units covering off the 100 units of release into the atmosphere from combustion.



So Lovins has a point, we can construct a wood based regimen where we can get to CO2 release balance after a startup period. But in today’s world with a larger population, with a better understanding of the many important, valuable ecological functions of trees in forest ecology, with more land required for farming/solarPV/people and finally with the push towards dramatic decarbonization in 35 years, this model has some faults, limited as it is.

The most problematic is the CO2 up front cost to get the system in operation. The ‘Accum CO2 Release’ details the CO2 that can never be recovered. If the saplings took 15 or 20 years to reach maturity the CO2 debt would only be larger. If a plot is ravaged by bugs or fire then more CO2 debt is incurred never to be recovered. In fact this model is the tightest model for CO2 release. In the real world, we can’t really envision any scenario where the CO2 costs of this program would be lower and conversely, we envision many where the CO2 load would be much larger.

So bottom line, Lovins has a point but events of the world have overtaken his ideas in this area. In the most basic terms, the new century of rapid and necessary decarbonization kills biomass electrical generation even as a theoretical construct.

Brittle Power: A Fragile System

Lovins’ critique of the power Grid is based upon several Grid failures experienced in the 1960s and 1970s. Electrification is seen by many as the turning point for any country trying to embrace modernity. Electricity, far from being an expensive energy to be used only when other energy sources can't be used as in Lovins' view, is now essential for the survival of our complex civilization. Just imagine a modern city without Grid power for more than a few days, that is, a modern city suddenly thrown back into the 19th century, and you can envision the disaster it could become.

Getting rid of nuclear and carbon fuelled baseload high capacity factor power supplies and replacing them with overbuilt wind, water, geothermal and solar generation requires a new kind of system control software to create a virtual baseload power supply out of the various types of generation within each Grid. This new control software does not exist today. There is limited testing of a simulation. However, new wind, geothermal and solar are being added to the Grid all the time now. Grid stability is an issue now and becoming more so as we progress with renewable roll out. Lovins' fears may become reality as we go forward with rapid decarbonization.

One of our projects here is Grid resilience. We have batteries on line, a solar power plant and re-wired house that allows us to live off-Grid for a substantial amount of time. Why would we turn our house into a Grid resilient prototype house? Why is this part of The Ravina Project an important part in our view? We envision the sense of urgency reaching much higher into the daily lives of people over the next 10 years or so. We do not discount the idea that we may have to live without electrical power for part of each day for no other reason than our generation infrastructure has been cut so dramatically because of decarbonization. As well, there are now political parties in many jurisdictions that are dedicated to shuttering nuclear power generation. The weight of power generation would fall upon solar PV, wind and hydro dams. Only hydro dams have the capacity factor able to become a base load power supply. Wind and solar are intermittent, non-dispatchable and have lower capacity factors. It is for this reason we see, for a time at least in the near future, the first world will require electrical energy rationing to deal with rapid and necessary decarbonization. Households will be modified to endure the outages for a period of time, they will need to be Grid resilient. Our prototype house is one possible solution to reducing the effects of energy rationing.

Do we measure up to Lovins' ideals?

Heating and Cooling

Heating and cooling are two of our major energy uses. In fact they dwarf everything else. For the purposes of this paper we are going to divide up the energy and allocate it to either heating or cooling. We can do that safely because the energy used for heating is natural gas and that used for cooling is electricity. We also will direct the reader to our papers on the topics of wintertime and summertime Household Thermodynamics to augment this paper. See the links in the Appendix.

Heating

Ideally Lovins wants to implement household heating via a wood stove and lots of insulation. He wants the domestic hot water to be solar driven and the limited electricity used by the household harvested from the sun using solar PV panels and a battery.

In order to gut and rebuild our house to implement these ideas is an expensive task, a task much more than the tens of thousands of dollars we have used to fund this project. Such modifications are beyond our capabilities. We are retired and on fixed income pensions. However, instead of this being a negative it is a positive because hardly anyone, in our hot real estate market where the average detached home costs over one million dollars, will have another several hundred thousand to completely redo their new house to Lovins specifications. Most people want to purchase a house and with a few upgrades, have a comfy place to stay with heating and cooling energy utility bills not too high. So our modifications are similar to those attempted by others which is great because they will achieve similar results. We have demonstrated that with a limited budget an efficiency improvement of 33% is possible.

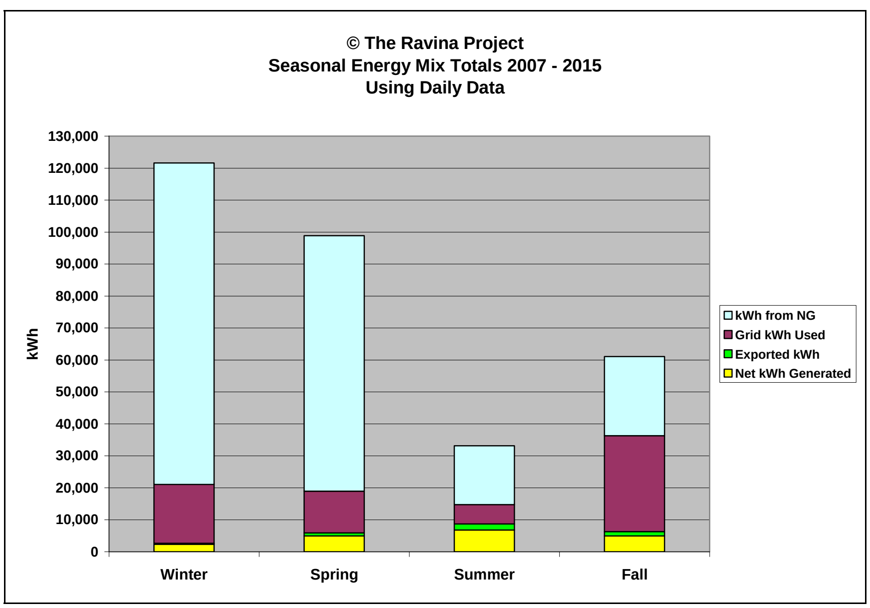
So the bottom line is as follows, Lovins goals are laudable but unachievable in anything other than a freshly built house where his ideas are designed into the structure by the architect. With our house, built in 1925, the best we can do is to approach his ideals which when boiled down means making the house much more efficient both for heating and cooling, harvesting our own energy plus changing our lifestyle.

Energy Use Breakout

Our energy flow is about a 65% – 35% split. Sixty-five percent of our energy comes from natural gas and the remainder comes from a combination of the Grid and our solar PV panels.

All the natural gas is used to make heat. We have a gas clothes dryer, gas boiler that provides hot water on demand (no hot water storage tank) and provides hot water to heat the radiators in the wintertime and a gas kitchen stove. Why natural gas? We use it because it’s cheaper energy.

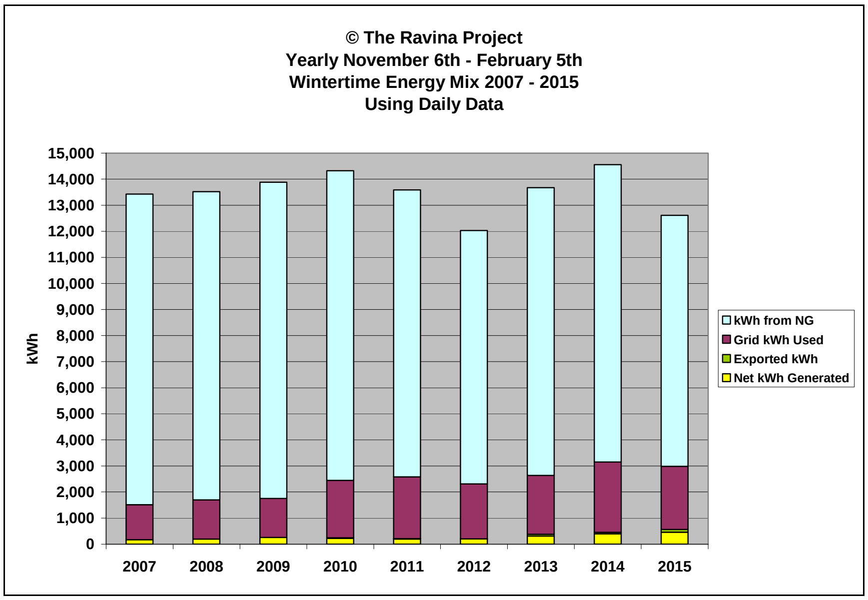
Consider the following chart:



The yellow, ‘Net kWh Generated’ is the amount of energy generated by our solar panels that we used to energize our household. The green ‘Exported kWh’ represents the energy we pushed back to the Grid. The violet ‘Grid kWh Used’ represents the amount of Grid energy we used. And lastly, the blue represents the amount of energy we used from natural gas converted to kWh with the conversion factor of one cubic meter of natural gas is equal to 10.35 kWh at STP (Standard Temperature and Pressure).

From our databases we extracted the daily data from all energy inputs and outputs over nine years (3,287 days) and then divided the days up into the four seasons.

Consider the following chart:



Let’s point out some things of interest in this chart. All the colour values are the same as the previous chart.

Note the rise in the Grid kWh used. The reason for this change is the fact that here in Ontario we have one of the lowest Grid carbon releases in the world at about 23 – 45 grams of CO2 release for every kWh of electrical energy generated because of our investment in nuclear power generation.

Currently at this time of writing the Ontario Grid energy mix is:

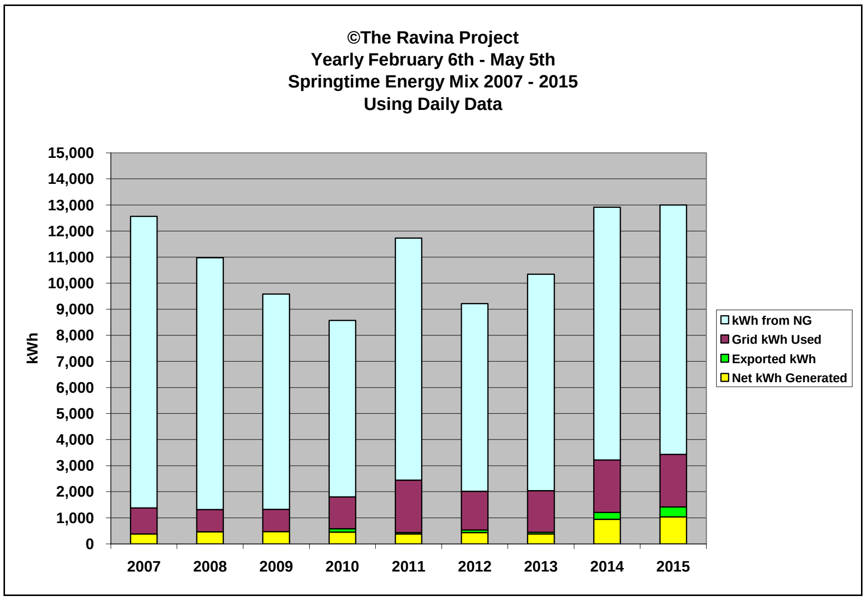
61.9% 10,031 MW Nuclear
25.4 % 4,113 MW Hydro dams
7.6% 1,236 MW Wind
4.0% 656 MW Natural Gas
1.1% 172 MW Solar
0.0% Biofuel

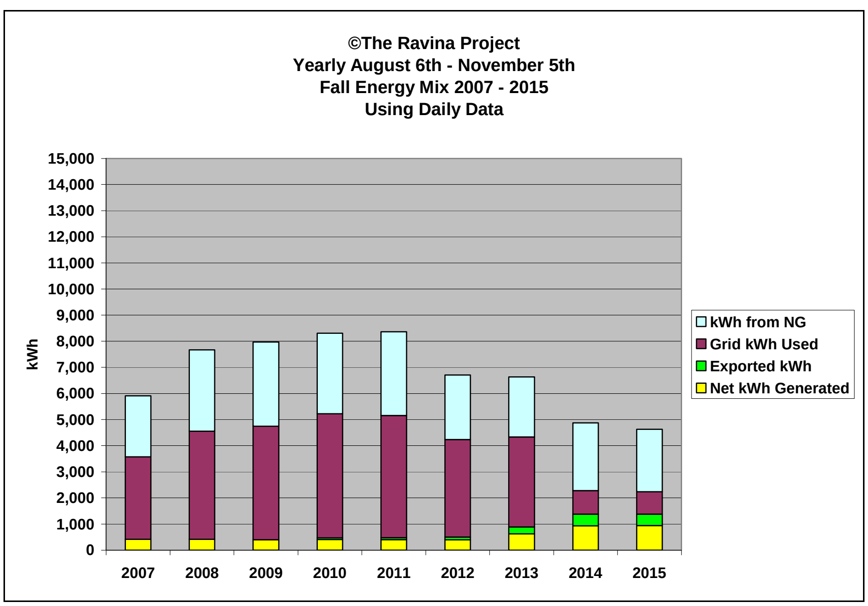
So to use electrical energy in the coldest season and reduce the use of natural gas (100% carbon release per kWh) is just adopting a low carbon footprint. You can see that winters with similar total energy used have a smaller natural gas usage starting in 2010.

Compare the years 2007/2008 with the years 2011/2013. We see this as a Lovins lifestyle change but of course the goal is not overall energy reduction, the goal is to reduce our CO2 release totals. This is a theme, decarbonization, which must be applied to all Lovins' ideas because of its changed importance since the 1980s.

Note the increase in the yellow part of the chart for the years 2014 and 15. This is the result of our new set of solar PV panels. We increased our harvesting power from 1,500 Watts to 2,800 Watts.

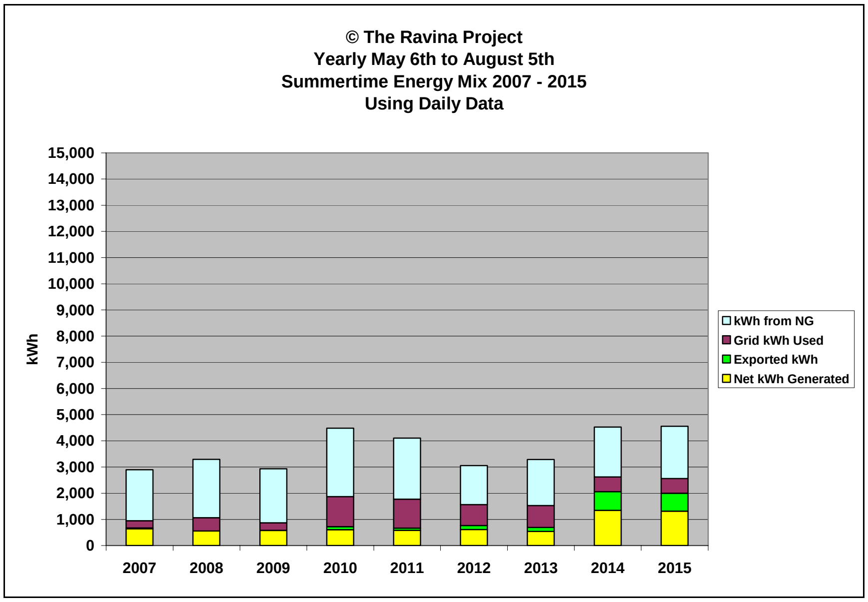
Consider the following charts:





If nothing else these charts tell us that the last two springs were cold, colder that some of the winters and the last two falls were warm. The boost we get from the increased harvesting power is getting more pronounced.

Consider the following chart:



Summertime is the best season for harvesting the sun's energy. The yellow plus green parts of the bar chart shows substantial growth in the first two years of using the new panels.

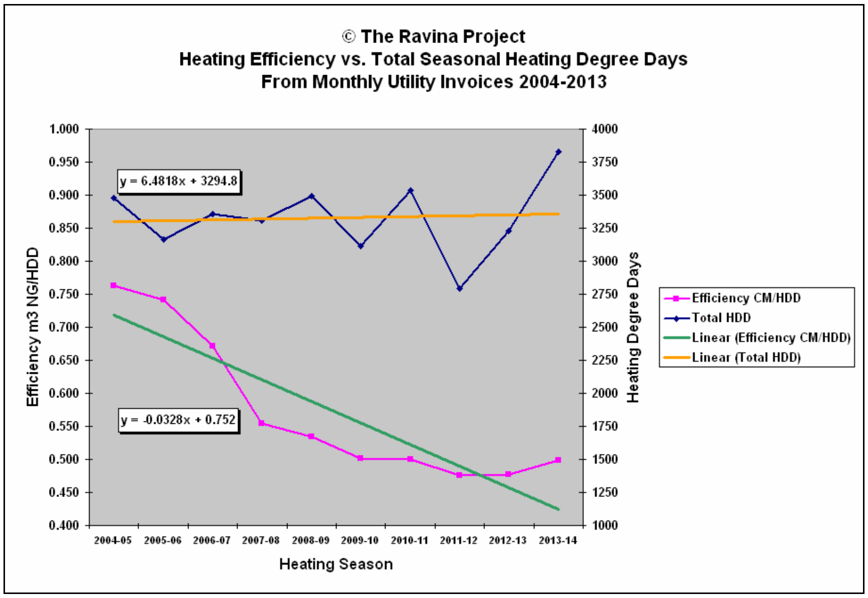
Superinsulation

Our two story 1,200 square foot house was built in 1925 consisting of a double brick first floor and frame second floor. Because of geography, prehistoric lakes released huge amounts of water through the Toronto area cutting 50 – 100 meter gullies through the overburden of till, gravel and sand, exposing a large layer of clay in many areas of Toronto. When Europeans arrived with their mature brick making technologies, it was not long before many brick making factories were built right in the clay deposits. As a consequence double and triple brick walled houses became the overwhelming norm in a building boom that lasted almost 100 years. Double / triple brick is a good insulator, is very resistive to lateral and compressive forces and lasts over 100 years. As a consequence brick construction like our house is in the vast majority across all housing stock in old pre-WW2 Toronto.

The idea of heat management by using super insulation, revolutionary then, is standard practice today. Household retrofits including tight fitting windows and doors, insulation everywhere, double glazed windows, basement header sealer and external walls covered with insulation underneath siding are common. Unfortunately brick walls can't be encapsulated. Over a period of years as we upgraded our insulation each summer we measured our boost in heating efficiency the next winter. Our heating efficiency has increased by a factor of 33% since 2004 using our monthly gas utility invoices and daily

Mean temperatures from the local weather office to provide the inputs to the calculations.

Consider the following chart:



Let's unpack this chart. The left scale is the efficiency scale. Use it to read the magenta curve. On the right is the scale detailing the number of Heating Degree Days (HDD). Use it to read the blue line. The two straight lines give you an idea of whether the values of the two curves are increasing or decreasing. The heating seasons covered in the chart are listed on the bottom scale.

Heating Degree Days are calculated each day of the heating season in a two-step calculation. First, obtain the average daily temperature from the local weather office during the heating season from September 30th to May 31st. Second, for each day, subtract the average temperature from 18 degrees centigrade. Suppose the average temperature is 15 degrees C. Subtracting 15 degrees from 18 degrees returns the number 3. By convention then that particular day generated 3 Heating Degree Days and 3 is added to the running total for the season. If the result of the subtraction is zero or negative do not include that day in the total. For instance if the average temperature is 20 degrees then subtracting 20 degrees from 18 degrees will give a value of minus 2. The minus 2 will not be included in the running total.

So we can understand that the number of Heating Degree Days generated in each heating season is proportional to how cold that season was. Looking at the chart above we see that the coldness value bounces around a bit but the line through it shows us that the number of Heating Degree Days over the course of this chart has increased slightly. The slope of this line is slightly positive.

Now let's calculate the seasonal efficiency. We get the vast majority of our heating energy from natural gas. We track our monthly natural gas usage using our gas utility bills. We also track our daily usage of natural gas but that data is not included in this chart mainly because that data started on January 1st, 2007. We wanted to use earlier data that only our utility invoices could provide.

But we have a problem as you probably can see. We use natural gas all year long to cook our food, heat our hot water, dry our clothes and the like. So what part of the natural gas used in the heating season do we use for heating only? It's a good question. We solve it by calculating a baseline usage. Here's our reasoning. In the summertime we do not use natural gas to heat the house. It's all used for other purposes. In the wintertime we use natural gas for those very same purposes. So if we subtract out our daily natural gas usage for all the other uses what's left is the amount we used for heating only. We call this net cubic meters of natural gas. Note we have a good idea of our summertime use of natural gas on a daily basis because we have tracked our daily use of natural gas since January 1st, 2007.

The efficiency calculation is a simple division. We divide the total heating season's net cubic meters of natural gas used by the total number of Heating Degree Days to get a fraction. As you can see on the chart above during the first winter season the efficiency was about 0.76 cubic meters of natural gas burned for every Heating Degree Day. The last heating season used about 0.5 cubic meters of natural gas per HDD. The difference is an improvement of about 33%. If you look closely you see we've pretty much 'bottomed out' in our efficiency and it does not change much even though the winters get much colder as shown by the increase in seasonal HDD.

For a more thorough treatment of this topic see the link to our paper in the Appendix. In the paper you will get a timeline of the house modifications completed and the efficiency 'bump' we achieved with each modification. Note that the chart above has more recent data on it than the chart in the paper.

So as far as Lovins' ideas we are not there yet and quite frankly we do not have the resources to completely redo our house nor can we tear it down and replace it with a high tech house. The majority of our energy use is now and will be derived from natural gas. The only end in sight will be household decarbonization meaning we will convert our house to an all electrical house. In that way we will leverage a clean CO2 free Grid. This would entail modifications at the household level for one thing and another, the amount of carbon free Grid energy available would have to be increased substantially.

Cooling Efficiency

Cooling efficiency is a much harder to measure even with our robust datasets. We have a paper on that topic, "*Household Thermodynamics – Summer, Household Cooling in a Warming World*". See the Appendix for a link. We use electricity both for normal appliance use and cooling so figuring out what amount of energy we use for just cooling each day is a knotty problem. In the above paper on page 31, we successfully predict using an algorithm we developed the household's kWh usage over six seasons of 558 summertime days given only the mean 24 hour daily temperature as an input. Our calculated cooling efficiency is between **1.2 and 2.1 kWh used per Cooling Degree Day**. Note the Cooling Degree Day is the same calculation as the Heating Degree Day above except the daily mean temperature has 18 degrees subtracted from it.

On a practical level, we are using other methods of cooling all covered in the paper. Our use of air conditioning has been very limited over the last several years because of the success of our insights into low energy cooling techniques.

It is in the summertime cooling that we most closely embody Lovins' ideas regarding passive heating and cooling. Our use of exhaust fans at critical places and curtains to contain heat especially in the kitchen, allows us to cool with minimum energy use.

Electricity Use

Lovins makes the point that with the dropping cost of solar photovoltaics it is possible that a detached house like ours could generate enough electricity for our use all year 'round. We have authored several papers on this issue. The bottom line is we generate about 30% on average with the new panels.

As it is right now, the Grid is our load of last resort. If we can't use the power from the panels, our inverter dumps the excess to the Grid through our bi-directional meter installed by the utility. It meters both the incoming and outgoing energy. Last year we exported over 1.5 MWh to the Grid.

Off-Grid Living and Energy Waste

We strongly suspect that Lovins ideas on household generation of electricity will lead to huge waste of energy because of: over supply, limited size of battery and of course an optimized household that is frugal in its electrical energy use. It's ironic that the more insulation your off Grid house has installed the more potentially harvested energy remains just that. In fact, the solar charge controller will limit the power coming from the panels to the amount of load the house is currently providing plus any extra energy required for battery charging / absorbing / floating no matter how much power can be harvested.

This may be a bit murky so here's a concrete example. Just recently we celebrated Earthday 2016. For this special event we went off-Grid for 24 hours. In the afternoon we noticed that sun was pristine and powerful so we expected the solar harvest to be about 2,300 Watts. I looked at the Outback MX-60 solar charge controller and it told me it was harvesting at a rate of about 750 watts. It told me it was using power to do battery charging plus powering the house.

I was suspicious of the 750 Watts because after watching the sun closely for 9 years I knew the 'proper' power we should be harvesting given its position and sky conditions. I strongly suspected that the MX-60 was shutting down the array's power output because there was no place for the power to go. I turned on a 1,200 Watt heater that was plugged into one of the 'protected' circuits that remains ON even if we are off-Grid. The MX-60 immediately increased the energy input from the solar array to 2,200 Watts.

Why did this increase occur? Simply put, the power had another place to go. The MX-60 opened the gate and let in more power from the array to compensate for the heater's load on the battery. Technically, the battery voltage dropped signaling to the MX-60 that more power should be harvested.

Is Off-Grid Even Possible?

Firstly, before we discuss our success in electrical sustainability and Grid independence a short explanation of our circumstances are in order for no other reason that to orient the reader to the technology we have employed here. The project was initially designed to include a 1,500 Watt array of 12.5% solar PV running through an Outback MX-60 (60 Amp) solar charge controller into a 48 Volt bank of eight, six Volt lead acid batteries with 14 kWh of usable energy in them. A new distribution panel was installed into which we connected all the house circuits we wanted to be independent of the state of the Grid. The new panel is powered by our Xantrex 4048 inverter from the battery. The Xantrex and Outback themselves are powered from the battery. The inverter takes power from the Grid during the night and in bad weather such that the battery does not discharge. So bottom line, the Grid power can disappear for hours or more, the circuits connected to the new distribution panel cannot be interrupted because they are constantly getting their energy from the battery.

During the summertime when the house uses little electricity the total amount of power being harvested by the array may be several times that amount. It is not uncommon for the summertime house to be using 300 Watts of power and the array to be harvesting 3,000 Watts. Where does the energy go? This is where the Grid attachment comes in handy. If the battery is full and the house is not using much power, the inverter routes the extra power back to the street through our bi-directional utility meter. Each day we read our meter and get two running total values: energy we have brought in from the Grid and energy we have pushed out to the Grid. Thus we can maintain tight energy accounting. That along with knowing how much energy is generated by the solar array plus the amount of natural gas we have used, provides us with a total energy accounting package. Our solar array was upgraded in September 2013 to ten 280 Watt panels at 17.1% efficiency for a total nameplate harvesting power of 2,800 Watts. Our battery was replaced with eight Trojan L16E-ACs in January 2016.

You now have the background to understand our data.

So can our house be independent of the Grid? That is, can all our summertime electrical needs be supplied by our solar PV array and the battery?

In order to answer this question we will have to build a model of the household power usage and generation. We certainly have enough daily data to make a determination.

Battery Dynamics

Firstly we have to take a detour into the physics of batteries when integrated into a household electrical power system. It’s not complicated but will allow you dear reader to better understand the dynamics of the argument below.

The first thing to understand about a lead acid battery is that the battery’s voltage indicates the battery’s level of charge. So low voltage implies low charge. There are subtle variations in all of this but they are not needed to understand how the basic system works. Every battery manufacturer publishes the high voltage the battery should have when it is being charged up and another lower voltage called the ‘float’ voltage which keeps the battery in a state ready for action when called upon. The float voltage does not harm the battery such that the float voltage can be maintained for years at a time. Our first battery lasted for nine years.

Our Power Generation Station

Our household power station has several major parts: the solar panels, a solar charge controller, an inverter, a battery and a Grid connection.

The inverter has four jobs to do. The first job is to use energy from the Grid to float the battery at a certain voltage and very importantly, not letting the battery stray above the float voltage. The second job is to use the Grid energy to charge the battery if required. The third job is to transform the energy in the battery into energy that the household can use. The household is constantly drawing power from the battery. And fourthly, the inverter sends any excess energy back to the Grid.

The solar charge controller has two jobs to do. It takes the power coming from the solar panels and changes it into power that the battery can use. The voltage coming from the panels is seldom a voltage that can be used by the battery and in many cases the solar panel voltage will harm the battery. The second job of the solar charge controller is to ensure that the battery does not get overcharged. From above we know that the battery's voltage is proportional to its state of charge. The solar charge controller is programmed to ensure the battery is kept at the proper float voltage among other things. It monitors the battery voltage and if the voltage gets too high it shuts down the solar panels to a point where the float voltage is restored as detailed above. The voltage will drop in value because the household circuits are constantly taking energy from the battery and thereby dropping the voltage.

The battery can store energy and provide power as the situation demands. Its capacity is 14 kWh of usable energy. It can be overcharged but that will reduce its lifetime from the expected 10 years. Similarly it can't be totally discharged for the same reason. Our battery has about 18 kWh of energy in it of which we can use about 14 kWh.

You probably noticed the subtle interplay between the solar charge controller and the inverter. How does the inverter know when to send power to the Grid? The solar charge controller may shut down the panels because of high battery voltage even though the inverter is ready and able to send excess power to the Grid.

These two devices are not attached in any way even though they both have computers in them. Interesting as it may seem they talk to each other via the battery voltage. In the best situation the solar charge controller provides maximum power to the battery at all times and never deviates from that function all day long. Similarly, in the best situation the inverter provides power to the house and any excess is directed to the Grid.

So how do they work via the battery voltage to maximize the energy harvested? It's very simple, the solar charge controller is programmed to float the battery at a slightly higher voltage than the inverter's float voltage. As the battery voltage gets too high, the inverter withdraws power from the battery and sends it to the Grid thereby reducing the battery voltage. This interplay between these devices goes on throughout the generation day and guarantees that the solar panels harvest maximum energy because they are never shut down by the solar charge controller.

Our Electrical Energy Accounting

We can measure/calculate/imply the following electrical energy amounts:

A. Energy imported from the Grid via meter reading,
B. Energy exported to the Grid via meter reading,
C. Energy generated from the solar panels via meter reading,
D. Energy to and from the battery is implied,
E. Energy used by the household calculated from meter readings.

On a daily basis we account for all the energy flows in our household. At the end of the generation day we take amount A, subtract amount B and add in amount C. That math gives us amount E. If we add in the energy used from natural gas, that gives us a total household energy accounting for the day. We are in our 10th year of data collection.

On-Grid Power Dynamics

Let's follow the energy when we are in a normal state of being on-Grid. As I write this we are harvesting over 3,000 Watts from our 2,800 Watt array. The house is using well under 1000 Watts so we have a power difference of about 2,000 W we have to account for. The battery is being floated by our inverter at the temperature compensated voltage recommended by the manufacturer, Trojan.

So where does the power go? So far we trace the power from C being placed into D. But the inverter wants to bleed off power from the battery to reduce its voltage. The extra power has no place to go except to B and E. The household provides a power load for this process bleeding off energy that drops the battery voltage. But when there is extra power to deal with, the power must be pushed back to the Grid B.

Off-Grid Power Dynamics

When off-Grid, flow A and B do not exist. A and B readings are not available. Reading C is available but it only shows us the energy harvested from a shut down or partially shut down solar array. It certainly does not tell us how much energy would be harvested if the Grid was attached.

The energy flows D and E can't be calculated.

In order to get some idea of household usage when off-Grid a new meter would have to be installed between the inverter and the protected power distribution panel. We do not have that meter installed.

Bottom line, when off-Grid we do not have any way of doing any accurate energy accounting.

Off-Grid Calculations

We have a problem. In order to demonstrate the viability of our off-Grid living, that is, how close we can get to Lovins' ideals we have no off-Grid data to crunch and to make an assessment.

What shall we do?

Let's build a model using our extensive on-Grid database and see if it gives us insight into a possible answer to our question.

An Off-Grid Model

Firstly we have to acknowledge the 2nd Law if thermodynamics and indicate that there will be no losses accounted for in our model.

As we have discussed above when off-Grid the solar array must partially shut down so that we leave energy untapped. So accurate generation readings, that is, readings that reflect the true daily energy harvest would only be true in an off-Grid scenario if the battery was huge, far bigger than what we have now. In that case the solar charge controller would never reduce the solar energy harvesting rate.

Our data tells us how much energy the household uses each day and how much is sent to the Grid. In our model the amount sent to the Grid will be sent to the battery. Our model has only two power sources, the solar array and battery. It also has two power sinks, the household and the battery. We set the battery parameters as 14 kWh completely charged or 0 kWh, completely discharged.

On a regular day to calculate our household usage we add the amount we brought in from the Grid, subtract the amount we sent to the Grid and add in the generated total. In our database we have a 'regular day' total for each day. We will use this 'regular day' total in our off-Grid model to represent the total daily energy draw by the house. So how does that 'regular day' usage fit into our model? For each day we know how much we sent to the Grid plus one other parameter, we know how much energy was left in the battery from the day before. So now we have all the components to build our off-Grid model. We subtract the total energy used for the day from the amount left in the battery from the day before plus we add in the amount we sent back to the Grid for that day. In the off-Grid situation the only place to store the surplus energy is the battery.

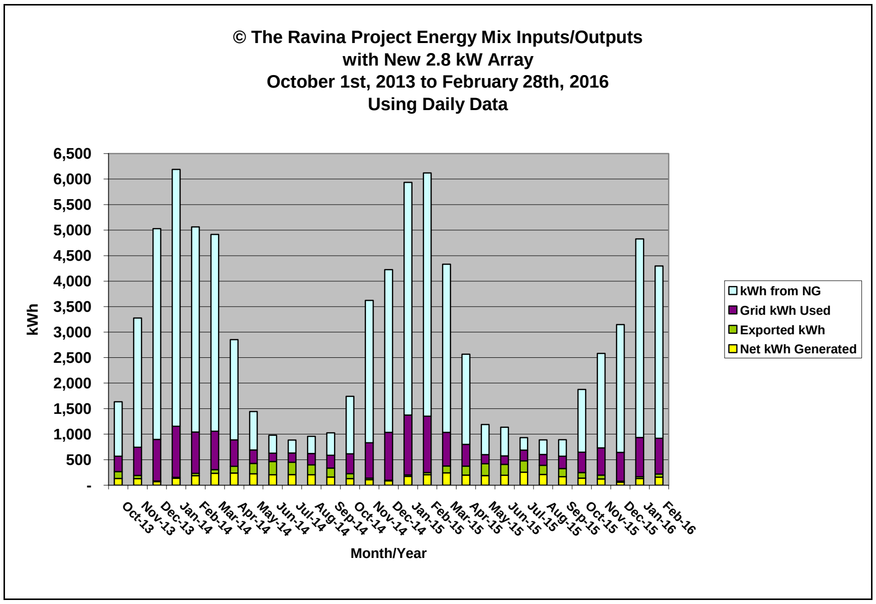
If the amount used from the battery plus any excess reduces the battery to zero or below zero, the battery charge for that day is set to zero and that zero charge carries over to the next day.

If the daily calculation raises the battery storage over 14 kWh, then the rest is treated as waste and the battery charge is set to 14 kWh to start the next day.

We will look at the summers of 2014 and 2015 because they have data from our new panels.

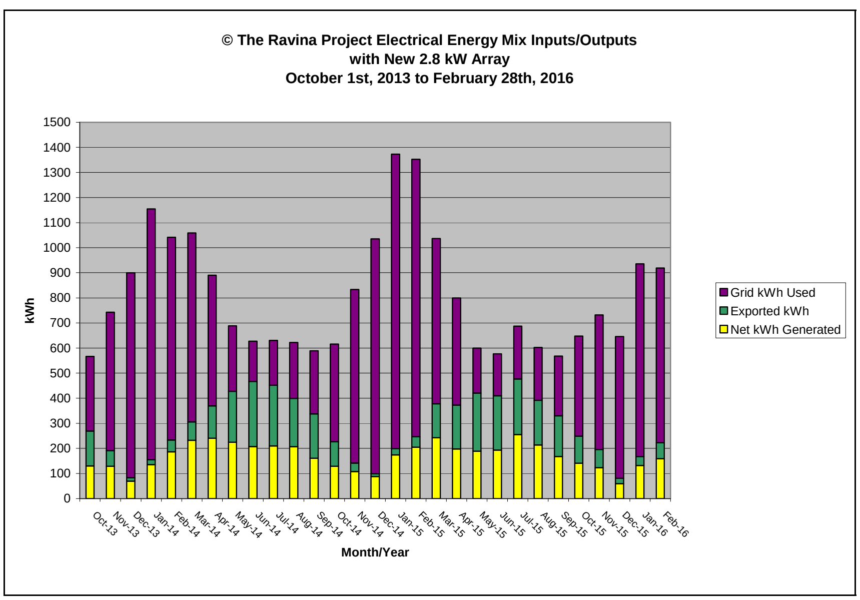
So what does the energy profile look like for those summers?

Consider the following chart.



Lets unpack the chart. This total energy input/export chart spans the range of our time with our new 2,800 Watt solar array. There is enough time to give you an idea of what amount of energy can realistically be harvested. We show this chart initially to demonstrate the huge difference between the energy we generate and the energy we use. Only in the summertime when carbon based energy is used only for cooking, domestic hot water and the like, does the electrical energy part of our usage become a significant part of our energy mix.

Consider the following chart:

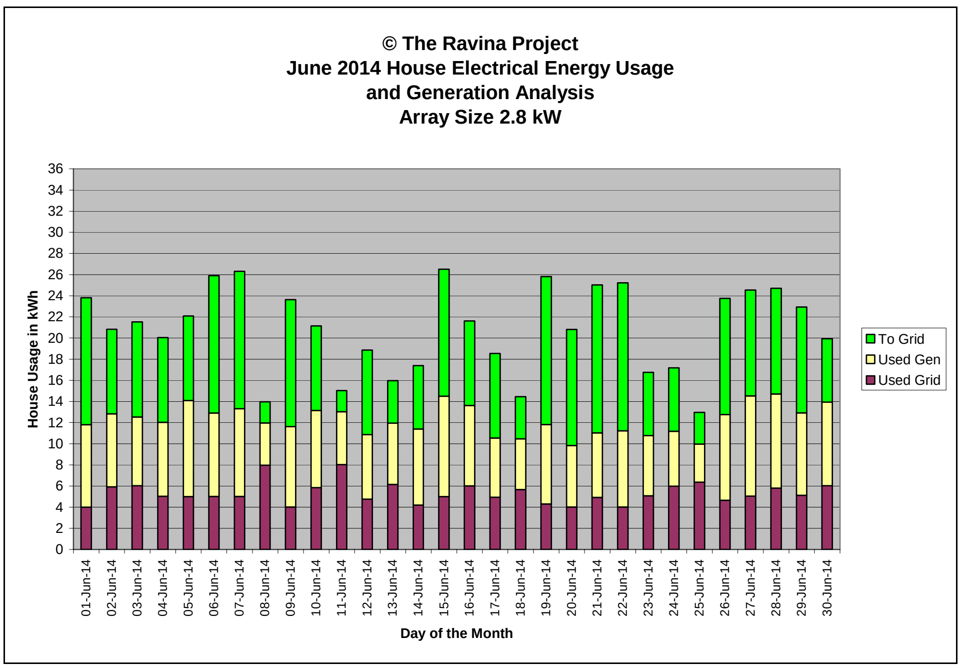


Let's unpack this chart above. It is identical to the previous chart with the energy use from natural gas deleted. This chart focuses on only electricity usage, generation and export. As you can see only in the summertime does the generation approach the amount of energy used from the Grid, marked as "Grid kWh Used" on the chart. We record this value every day from the bi-directional meter mentioned above. The Kelly Green part of each bar, "Exported kWh" is a measure of the amount of energy exported to the Grid. Lastly the yellow bar, "Net kWh Generated" indicates the amount of energy generated and consumed by the household.

Since the yellow bars represent the generated electrical energy used by the household in that month and the purple bars represent the amount of energy brought into the household from the Grid, then added together they represent the total household usage of electrical power for that month. The green bars show the amount we sent back to the Grid. Based upon that if the green bar is longer than the purple bar for a month, we were off-Grid in a net way. That is, we covered off all our Grid usage by pushing back at least as much or more than that we used from the Grid.

So from the above chart we are approaching Lovins' ideal of generating the majority if not all our own electrical energy but we are limited to the summertime with its good daily sun angles and longest days.

Consider the following chart from our WEB site and database:



Let's move down a level of detail to consider individual days. To recall our algorithm, the used energy each day is the combination of the bottom two colours combining used energy both from the solar array and the Grid. It is only the green part of the bar chart that indicates the amount of energy available to charge the battery. So on June 1st we generated 19.8 kWh but sent 12 kWh to the Grid for a net usage of 7.8 kWh. We used a total of 4 kWh from the Grid (at night) and for a total usage of 11.8 kWh for the day. If the battery was full at 14 kWh then the battery charge would be 14 – 11.8 + 12 kWh equals 14.2 kWh but the battery charge limit is 14 kWh so we waste 0.2 kWh.

On June 2nd we generate 14.9, send to Grid 8 and use 5.9 from the Grid for a total use of 12.8 kWh. The battery charge is 14 - 12.8 + 8 = 9.2 kWh. On June 3rd the battery charge becomes 5.6 kWh. On June 4th it's 1.6 kWh. Over the next 14 days the battery is exhausted for 12 days. This is not off-Grid living.

This is not looking good. June is our best month for generation.

You can, dear reader, make the calculations, back of the envelope style for the rest of the month as an assignment. We have been through the figures and we can be off-Grid only a few days of the summer given our normal summertime daily energy draw. The same dynamic occurs for June 2015. On our spreadsheet we doubled the daily solar generation amount and found we could live for many summertime weeks off-Grid. That would mean of course doubling the size of our array from 16 square meters to 32 square meters which of course cannot be done.

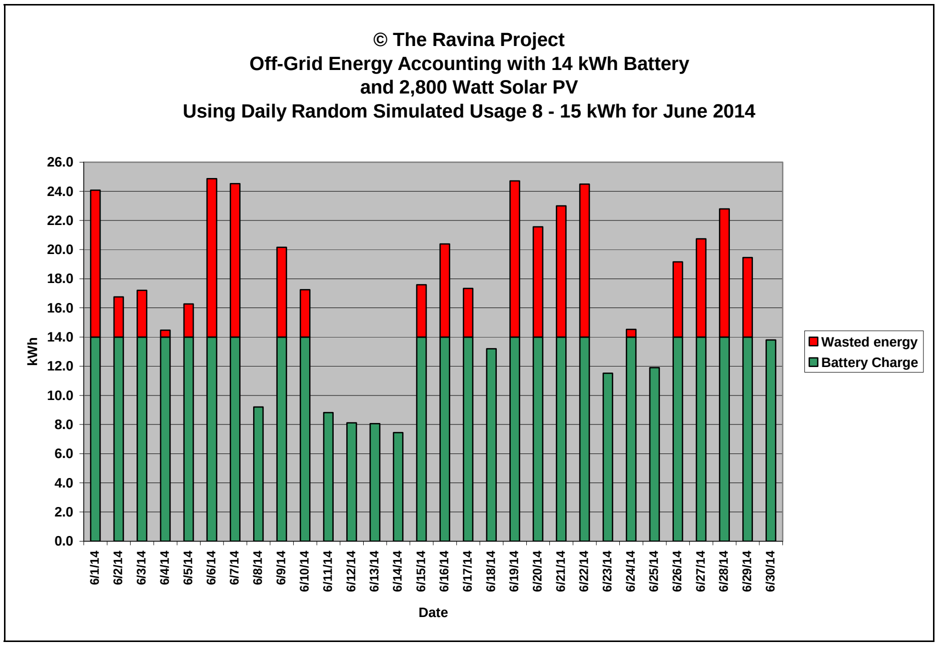
Earlier in the paper we said we have energy stored in our battery to give us enough for 2 days. That calculation is made assuming that the refrigerator and furnace are powered, some lighting, our internet, routers and one laptop computer. Everything is turned OFF when not used that is, nothing is on 'stand-by'. We assume the worst case conditions, in the dead of winter with little in the way of solar generation from an ice and snow covered array. We go into an extreme energy accounting mode where everything is turned OFF when not in use.

Since we have such extensive data, let's do a thought experiment such that we randomly generate daily household usage kWh amounts between 8 and 15. This exercise would simulate a middle ground of energy use between the under 7 kWh a day on battery alone and our current Grid attached summertime usage.

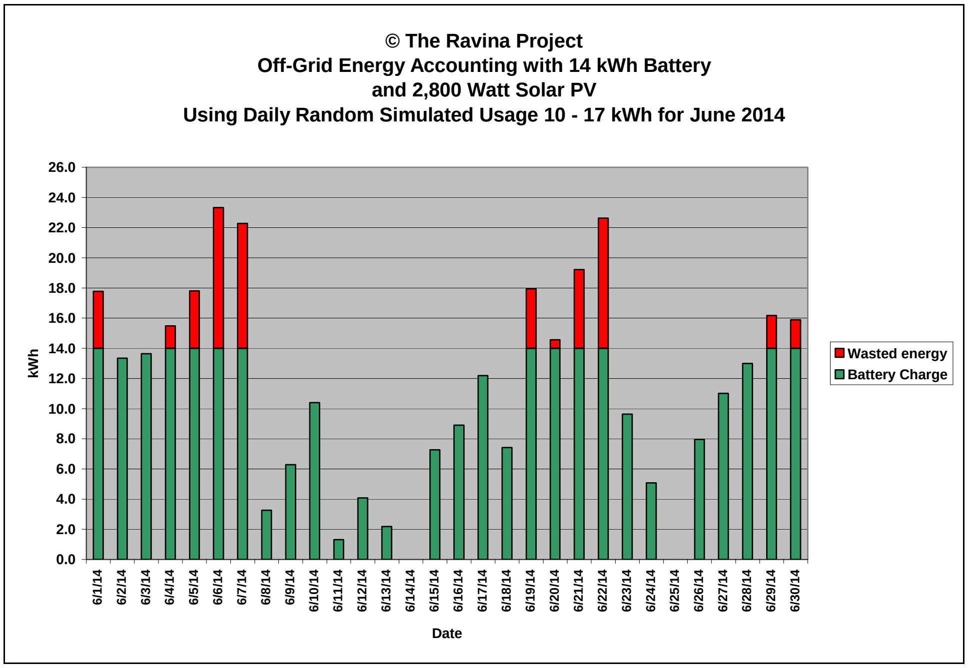
Just a note regarding this exercise, we are in contact through social media, with many households which are off-Grid entirely. One of their biggest problems is the amount of energy they can generate but their low energy use household plus their limited sized battery cannot absorb it all. Hence they know they are losing lots of energy. In their energy constricted off-Grid world, such waste is upsetting to say the least.

So using our actual generation numbers, a random spoofed daily usage and a 14 kWh battery capacity, what are the daily amounts in the battery and how much do we waste?

Consider the following chart:



Anything in red is wasted energy, generated but unused. Let's up the daily usage to a random number between 10 and 17 kWh.



At an increased random daily usage of between 10 and 17 kWh, we exhaust our battery twice in the month. On those days we are out of energy, the food in the fridge spoils and all of our electronics are down plus we still waste energy that very same month. Over the season we waste energy to the tune of 135 kWh in total for May 1st to September 31st using this 10 – 17 model.

The spoofed run for the 10 – 17 daily usage model is just one run. What we did is run the random number generator 20 times to see if having an exhausted battery was an outlier or mainstream. The result of our 20 runs indicated that we would be without battery energy nine times with one instance of two days in a row and one instance of three in a row without power. So a random daily usage of 10 – 17 kWh is well into off-Grid failure.

Off-Grid Bottom Line

What have we learned from our off-Grid model? And how close can we get to the Lovins ideal that we should self generate our electrical power?

1. given our normal June 2014 daily electrical usage, generation data and battery size we cannot stay off-Grid for more than a few days at best.
2. given a simulated random daily electrical energy usage of between 8 and 15 kWh we are able to stay off-Grid for the entire month of June 2014. However, we cannot use all the energy we harvest given the size of our battery. As you can see we waste many kWh.
3. given a simulated random daily electrical usage of between 10 and 17 kWh we exhaust our battery nine out of 20 random runs in the month and still we waste energy.
4. electrical energy waste is a problem in off-Grid applications.
5. battery size is critical to solving the energy waste problem.
6. the efficiency of the household electrical energy use contributes to the energy waste. As the household gets more efficient, for a given size of battery and solar PV array, the amount of energy waste increases.

The Lovins idea of being off-Grid is beyond us given our array and battery size. Note that in the summertime we use very little air conditioning because we have discovered cooling techniques that work well in a multi-story house by using well placed fans.

Comments about Decarbonization

Since the 1970s and ‘80s the amount of CO2 in our atmosphere combined together with the research especially in Paleoclimatology suggests that human complex civilization faces an existential crisis. It is now clear that humanity is locked into a ‘War on CO2’, a war we must start winning soon, like in the next 35 years. At the moment we are losing the war in a grand way.

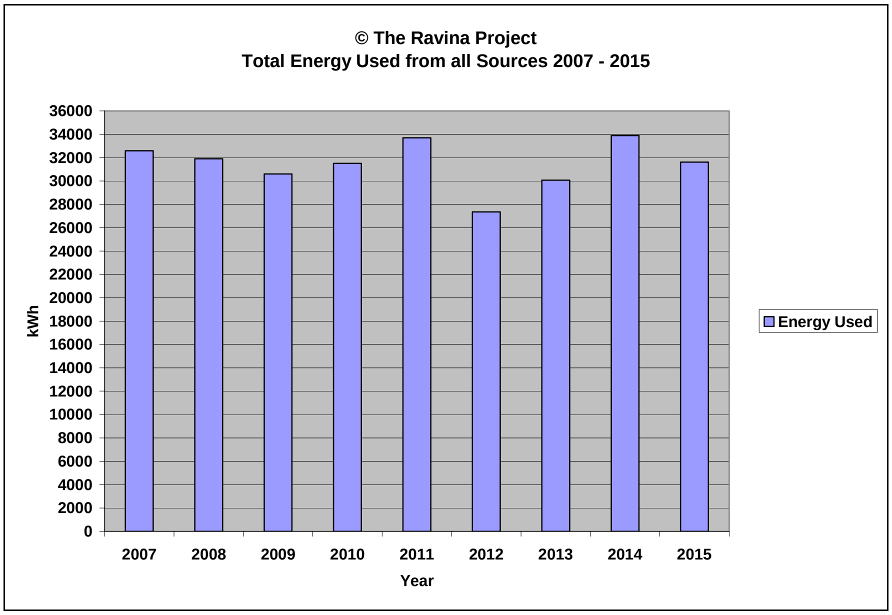
Looking at the data we have accumulated over the years and the improvements we have made to the household’s heating efficiency, we have reached an end with still about 65% of our energy usage from fossil fuels.

So how do we eliminate the use of fossil fuels at the household level?

Our data tells us the amount of energy we use on a yearly basis. It also shows us the breakout between electrical energy and fuels. So by extension it also shows us the amount of energy we would have to use from other energy sources if we were to eliminate the use of fossil fuels. Here in Ontario, Canada we have a very low carbon emission per kWh generated on our Grid of about 23 to 46 grams of carbon per kWh of energy produced. Clearly the Grid is much cleaner that our house. So for us the logical upgrade is to convert our house to an all electric home.

From our daily data we used a total of 283,239.6 kWh (857.66 GJ, 812.91 MMBtu) of energy between January 1st, 2007 and December 31st, 2015.

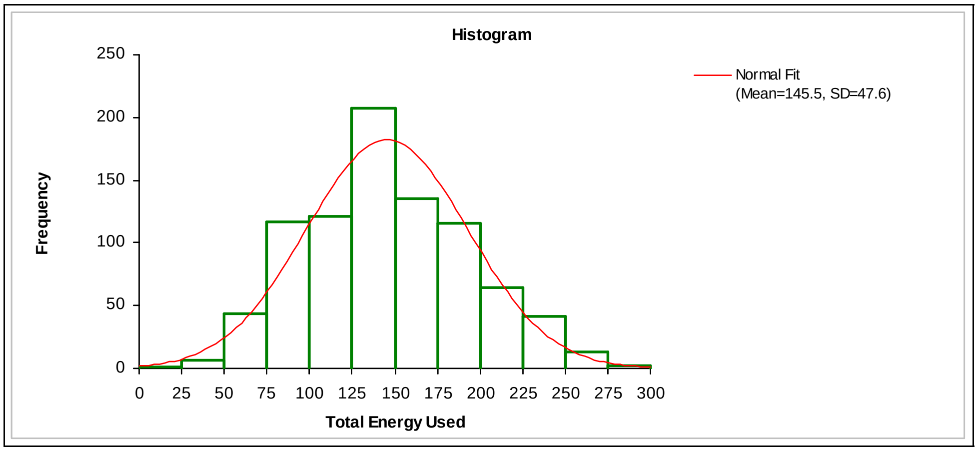
Consider the chart below:



The chart shows the energy load our house would provide to the Grid if all our energy came from the Grid. The clean generation provided by the Grid would have to be expanded to match our load. We have a 100 Amp service from the Grid. So we can pull a maximum of 120V times 100A times 0.707 equals 8,484 Watts or 8.484 kW at one time. Over the course of 24 hours we can receive 24 times 12 equals about 204 kWh. So that's the daily limit of our current Grid connection. Over the course of the winters what is our total daily draw?

We use our commercial statistics package below to crunch all our wintertime days' energy usage. It looks like our 100A service will be up to wintertime heating if we were to be converted to a totally electrified household.

Of course it seems we will not have a problem but the Grid generators will have to deliver the energy. Since our house is a common structure in the Toronto Area it would not be out of the realm of possibility that there are 100,000 structures like ours with similar thermodynamic characteristics. Be that as it may, our wintertime load times 100,000 structures each at 179 kWh a day (the 75th percentile) would use 0.179 MWh times 100,000 = 17,900 MWh of daily Grid energy. The average wintertime daily use would be 14,600 MWh.



n	869				
Mean	145.50		Median	143.30	
95% CI	142.32	to 148.67	95.1% CI	139.27	to 146.22
SE	1.616				
			Range	260.5	
Variance	2269.91		IQR	66.10	
SD	47.64				
95% CI	45.50	to 50.00	Percentile		
			0th	23.41	(minimum)
CV	32.7%		25th	112.60	(1st quartile)
			50th	143.30	(median)
Skewness	0.25		75th	178.69	(3rd quartile)
Kurtosis	-0.35		100th	283.88	(maximum)
Shapiro-Wilk W	0.99				
p	<0.0001				

So given the nature of our energy use from various sources it seems that the best way forward for decarbonization is to electrify our household completely. Again we stress this is a local solution for us because our Grid generation is based upon nuclear, hydro dams and wind, which on a good day, accounts for over 95% of our generation.

Self generation is not an option for us.

Household Resiliency

One of the other projects here in the mix of projects that make up The Ravina Project is our prototyping of a Grid resilient house. We have batteries and solar to charge them when there is no Grid power. Since we have another energy source, natural gas, and since all our heating and cooling appliances plus refrigeration draw their electrical energy from our battery, we will never experience electrical energy poverty. Even in the coldest of wintertime days our furnace heats the house because the vast majority of the energy it uses comes from natural gas. In other words we are Grid resilient.

So how does this idea play out when we are totally bound to Grid energy such that if our local Grid is off-line we freeze in the winter. We'll have no energy source other than our generator and solar panels. But we are an outlier. For the normal home they certainly will freeze. The downside of household decarbonization at the household level is the loss of a totally independent and critical energy supply. This analysis means that the Grid will have to improve its ability to supply energy as more and more households turn to it for their only form of energy supply. It also means that the Grid will have to increase its reliability.

See the Appendix for a paper on surviving the 19th century.

Conclusions

The generalized conclusions we have reached are as follows:

1. Off-Grid living is not an option in a dense neighbourhood even in the summertime with the best solar generation. In rural areas where a large solar field can be deployed with a large battery, an off-Grid option is viable. Heating will still be accomplished using a carbon source of energy like propane.

2. Solar generation helps to offset Grid load at the local level but only in the summertime. For example, a moderately sized solar array could eliminate Grid draw for household air conditioning during the 10 AM to 2 PM peak generation times each summertime day.

3. Solar generation plus battery supply allows for household wintertime resiliency only if the main source of household heating energy supply is not electrical Grid energy.

4. Decarbonization at the household level will eliminate household resiliency. This situation will amplify wintertime disasters which include Grid failure. Household decarbonization will stimulate the carbon based generator market for emergency household electrical supply. This new generation capacity will be on average larger than what we use today because they will have to provide enough energy for minimal household winter electrical heating in excess of five kilowatts.

5. To offset a local Grid failure houses can be wired to make them into an appliance which would allow them to be 'plugged into' a neighbour's house.

APPENDIX

The Ravina Project - Household Grid Resiliency

The subtitle of this paper is “Surviving the 19th Century”. We look at the various threats to the household, identify the main issues and propose a simple and cost effective local solution to lack of Grid energy.

Household Thermodynamics Summer rev 6 04.pdf

The subtitle to this paper is, “Household Cooling in a Warming World”. We use several new methods for calculating our summertime cooling efficiency plus a section which tries to measure our differential response to heat and Humidex. Are we more responsive to heat or Humidex? Do overnight temperatures or Humidex play a role in our use of energy or are daily maximum temperatures and Humidex dominant factors in energy use? Our paper attempts to tease out these factors using our set of large databases.

The Ravina Project - Household Thermodynamics October 2011 12.pdf

The first part of this paper uses our database to tease out our energy saving due to increased insulation, various modifications made to the house’s internal heat flow plus changes made to the household itself. The second part of this paper is a subsumed by the above paper on summertime cooling.

The Ravina Project -Trinity T150 Boiler 01.pdf

Here's an overview of the boiler system in our house that operates as our furnace and domestic hot water heater.

"If we knew what we were doing, it would not be called research."
- A. Einstein

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