The Ravina Project

A Carbon Free Household

Can we get there from here?

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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, totaling over 100,000 pieces of data. They allow us to validate or falsify various speculative hypotheses. It also allows us to anchor our published papers in data rich analysis. Some of our papers rely upon the analysis of several thousands of observations from our databases.

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 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 in 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, for instance. Refurbished and reconfigured used electric automobile batteries may provide a key piece among the technologies included in the future 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. And further, the load leveling required when massive amounts of renewable power are withdrawn from the Grid requires that loads be manipulated to maintain critical Grid parameters. Renewables especially solar PV power supplies tend to supply power in bursts rather than continuously like, for instance, hydro based power supplies.

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 lifestyle part of the experiment unfolds we are living a future lifestyle today 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 Gord

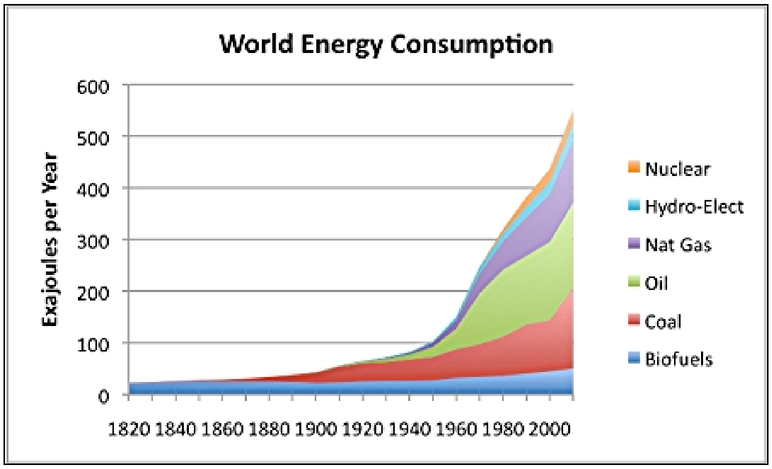
A Carbon Free Household

Abstract

Our working definition of a carbon free household is: a household that does not use fossil fuels to power itself. Since we can't do that in reality this paper builds a model of our household with a clean power supply. We take some time in designing the household power supply to ensure it satisfies the needs of the household. We expand the model to include 100,000 similar households and their clean power supplies. We look at the implications of the results and finally make a few comments regarding the policy implications of our model.

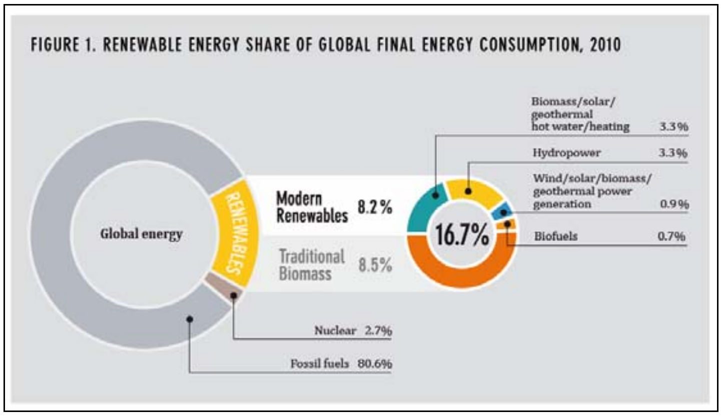
Fossil Fuels – Where are we now?

The graphic below gives us an appreciation of the exponential growth in world energy consumption up to 2010 broken out by energy source.



Source: World Energy Consumption by Source, Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent

Look at the fossil carbon component to this graph and imagine what the graphic would look like without the coal, oil and natural gas. If we keep nuclear, biofuels and hydro we are left with 100 Exajoules of energy to run the world at a 2010 energy consumption of five times that much.



Source: REN21 Renewable Energy Policy Network for the 21st Century

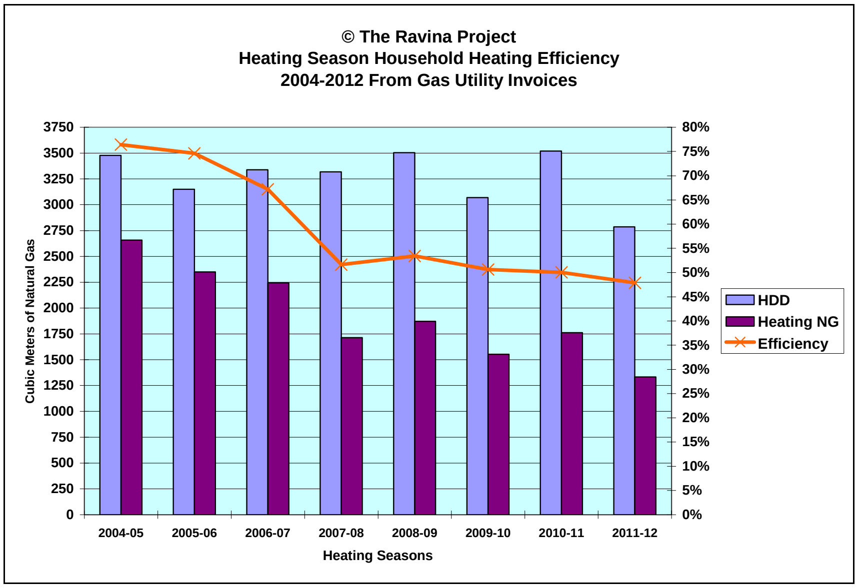
The graphic above details the energy gap to be filled with renewables in order for the world to turn off the carbon fuel tap. Current thinking involves the ideas of cutting back on fossil energy consumption by using high technology, changes in lifestyle and efficiencies at the consumption end coupled with a monster rollout of all forms of non-fossil energy technologies like: wind, solar (PV and Thermal), ocean wave, hydro, geothermal and biomass just to name a few. The second graphic above gives us a good understanding of where we are now using these new technologies and the generation mix we had as of 2010.

The first graphic emphasizes that the target is constantly moving upward and is probably non-linear meaning that each year brings an increased rate of energy use from fossil carbon sources. This phenomenon is caused by several factors including: many in the Third World moving into the Second higher energy consuming World, many people in the Second World moving into the much higher energy consuming First World and population increases right across the board. At this time of writing, there is no consensus as to what the end point of this expansion will be. We have seen estimations of the world's population from 9 Billion to 15 Billion people before the rise levels off. What we know for sure is that the energy consumption powered by fossil fuels will increase in perpetuity if nothing is done on this issue between now and 2050.

Lifestyle, Efficiencies and Energy Consumption

Since most of our consumption of natural gas is heating related here in Toronto at 43 Latitude, we have focused our main efforts in reducing the need for household heating. We have several papers on our WEB site that detail our efforts in this area. In short, we have looked at the heat flow through the house and built barriers to that heat flow so that more heat is trapped in the house and less fuel is used. As well, we have used electrical energy (25% carbon) to warm certain critical areas in the house so that our use of natural gas (100% carbon) is reduced.

The results are shown below.



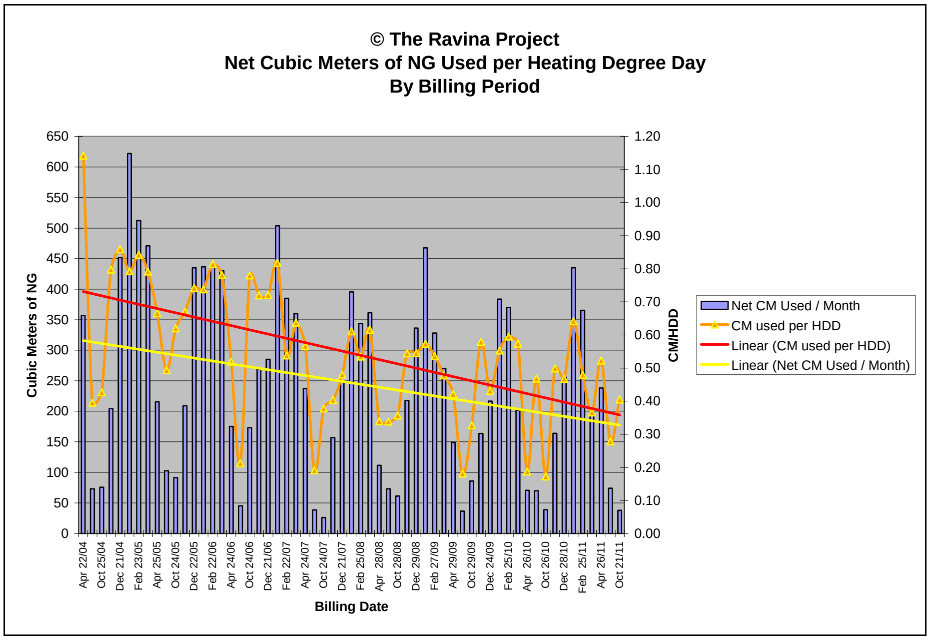
Let's unpack this first graphic. The natural gas consumption numbers come from our utility bills. The heating degree days are calculated using the local Environment Canada's average 24 hour temperature for each day. The Heating Season for Toronto starts October 1st and ends May 31st. Summertime use of natural gas is not considered in these graphics. Efficiency is calculated as the total number of cubic meters of natural gas used for each Heating Degree Day. Heating Degree Days are calculated by subtracting the day's average temperature from 18 degrees centigrade.

So on a day where the 24-hour average temperature is 5 degrees C, that day would generate 18-5=13 Heating Degree Days.

Why are Heating Degree Days so important? They are important because they provide a baseline of 18 degrees Centigrade as a constant by which the household efficiency can be measured. Every house will use more energy on a colder day but so what and compared to what? If you have a standard for comparison, you can compare the house from day to day or season to season and get some idea of whether your efficiency efforts are paying off. For example, if 15 cubic meters of gas are used on a day which generates 15 Heating Degree Days then the household has an efficiency of 15/15=1.0. Since we want to use less natural gas for every Heating Degree Day, an improved household efficiency will mean we use less gas for the same number of Heating Degree Days. The fractional number representing the household efficiency should decrease in magnitude.

Let’s say we added some insulation to the house. The next heating season on a day that was cold enough to generate 15 Heating Degree Days we used 10 cubic meters of gas. Our household efficiency increases to 10/15=0.67.

Note in the above graphic, the number of Heating Degree Days have remained more or less constant until the heating season of 2011-2012. That means of course the temperature during those heating seasons was more or less constant. As we made more and more efficiency upgrades to the house, adopted a different lifestyle, and changed the way heat moved around the house, we were rewarded by real demonstrable changes in household efficiency.



The graphic above breaks out the efficiencies by the month. Only months that are heating months are considered and the natural gas consumption is modified each heating season to subtract the natural gas used for domestic hot water, cooking, clothes drying and the like.

The bottom line here is that both graphics demonstrate that we have made huge strides in upgrading our 1920s era house to become much more efficient in the use of fossil carbon for heating. Back-of-the-envelope calculations indicate we have increased our household efficiency by more than 33%. All the above demonstrate that we have done our ‘homework’ in reducing our overall energy usage. This is important because we, in this paper, are ‘building’ a power supply for the household. It makes more sense to build for an efficient household.

Data Collection

One of the designed-in strengths of The Ravina Project is its set of robust and high fidelity data bases. Even though neither of us, Susan nor myself are scientists we do believe that data collection and observations are essential to scientific/engineering progress. Our hero is Tycho Brahe who collected marvellous data and built models with it. His data are well known for their accuracy and quality even to this day. In short, he had a nose for data. ☺

Each day we collect the following numbers:

- kWh of electrical energy used by the household
- kWh of electrical energy sent to the Grid
- Total kWh generated by the solar panels
- Cubic meters of natural gas used by the household
- A weather report centered upon the sky conditions for the day
- The time in EST of the observations
- The peak power in Watts recorded from the solar array
- Battery voltage in Volts.

This data collection effort has been ongoing without missing a single day since November of 2006. We believe we have captured a picture of the household's use of energy, its thermodynamic profile if you like, because we have covered off all of our energy sources and sinks.

These data are augmented by daily data from Environment Canada. There are other data we collect but these above are mentioned specifically because they are pertinent to the argument we make below in this paper.

Characteristics of the Carbon Free Household

What do we mean by a carbon free household in the confines of the thought experiment / model described in this paper? Well, the short answer is we use no fossil fuels to energize our household. Can we use Grid energy? Yes we can if it is 100% carbon free … but ours is alas, only 75% carbon free, so Grid energy is not to be used in our experiment.

What fossil carbon free sources are available for us to use?

The usual list includes: solar PV, solar thermal, wind, micro-hydro, geothermal, biomass and the like. We have investigated all these sources for our use here. We even wrote an RFP for a wind project that is still on our WEB site. We had several engineers visit us from different companies who were interested in seeing the property and location. Bottom line wind power is not an option for us. Ditto for all the other forms of fossil free energy generation except solar. This is not surprising considering the house is located in a densely packed neighbourhood in Old Toronto. Solar is only an option because the huge trees are in the right location and the designer of our solar array got creative with the installation. Solar thermal is not an option because it would harvest way, way more energy than what we could ever use with negligible fossil fuel use impact.

So for this experiment we will use only solar PV for our energy source. Solar PV is great because it harvests photons at the Quantum level and emits electrons, one of the fundamental particles in the Universe. It seems fitting therefore that a high tech, complex civilization would energize itself using a fundamental entity.

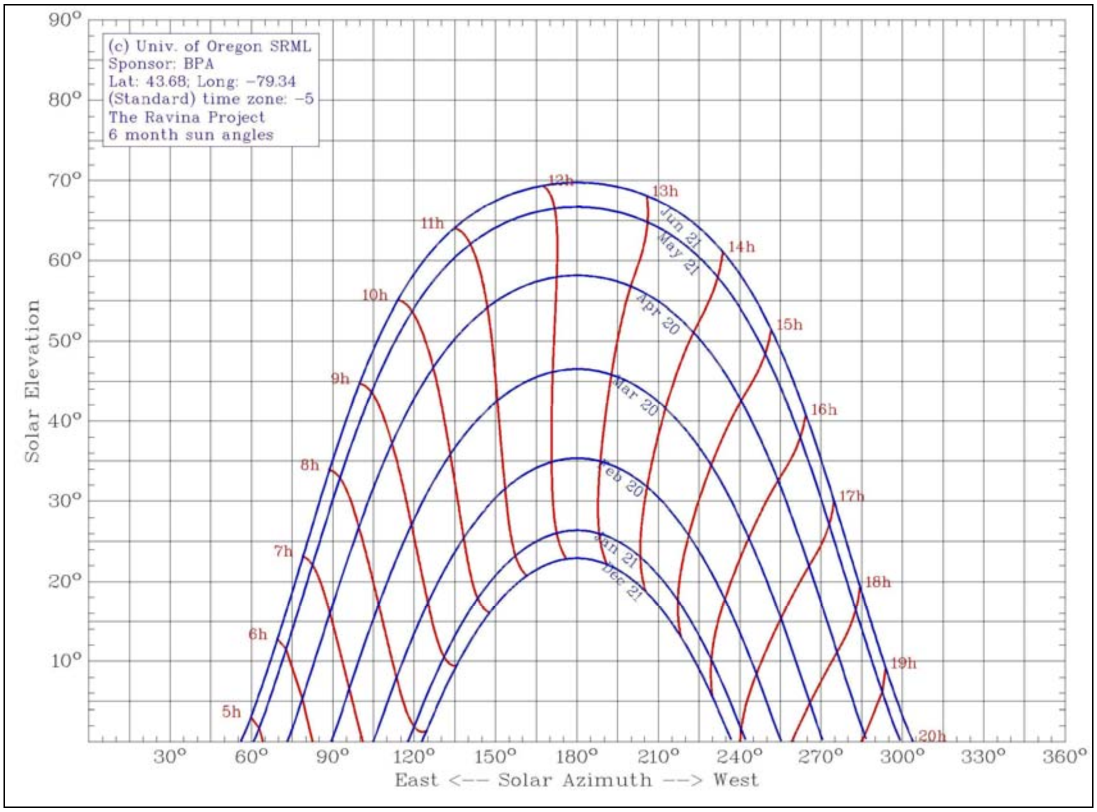
The Four Seasons of Solar Photovoltaic Power

We have been watching the sun and its angles for seven years now. We have also generated papers on many aspects of energy harvesting using solar PV including: inventing a new energy efficiency standard that we use and calculate on a daily basis, and modeling the power being harvested at any time of the day in relation to the sun's angle upon the solar array's surface.

We are at 43 degrees 40 minutes of latitude. So all our comments regarding the sun must be understood in this context.

And further, our solar array is moveable such that it can compensate for the sun's altitude in the sky. This allows us to make observations regarding the effect of sun angles upon the collecting surface of the array. We have several papers that demonstrate those effects. However, the bottom line for this paper without getting too technical is that the more acute the angle of the sun's rays upon the collecting surface, the less power harvested. Maximum power occurs when the sun's rays fall at an angle of 90 degrees upon the array surface. Our tilted array structure allows this orientation to occur by design as the day progresses even in the depths of winter.

If we look closely at the sun's journey across the sky on a six-month basis we can make some interesting observations.



Consider the sun chart above generated by the University of Oregon.

It is a six-month chart of the sun's location in the sky based upon what a person observes from a fixed location upon the earth's surface. As you can see the chart mentions our latitude and longitude as the set location. The solar elevation scale on the left side of the chart is a measure in degrees of the sun's altitude above the horizon. The sun's azimuth scale on the bottom of the chart is a measure of the sun's location on a great circle on the horizon with 180 degrees being due south. Each hour in the day when the sun is above the horizon it has a location in altitude and azimuth on this chart. The time of day is shown in standard time and the dates are written on each of the curves. Note that noon does not mean that the sun is directly south of us. This is not an error. Because of the great Canadian, Sir Sanford Fleming we have time zones on a world wide basis. Our time zone ticks over to 12 noon as a whole corresponding to the sun being directly south when viewed from the far eastern end of the time zone. However, here in Toronto the sun has to travel for some time to get to us before it is directly south of us.

Anyway, technicalities aside, observe that the sun climbs higher in the sky for half the year and the other half is a mirror image but opposite of the first. I did not include the sun chart for the other half of the year but you can imagine it. Nevertheless, note as well that the sun spends a few months lower in the sky and a few months higher in the sky. Note as well that the sun travels quickly from the lower daily sun altitudes to the higher daily sun altitudes in about the same number of months as it does lingering at the high or low daily altitudes in the sky.

Here at the Ravina Project we call the months the sun lingers at its maximum altitude in the sky, summertime. Similarly, we call the months where the sun lingers low in the sky, wintertime. When the sun races from the low angles to the high angles we call this time spring and finally, when the sun races to the lowest angles, we call that fall. These dates are related only loosely to the seasons as we know them. Our ‘seasons’ are based entirely upon the sun’s daily power output as a function of its angles upon the earth here at this latitude.

The actual dates are:

- Winter, from November 6th to February 5th
- Spring, from February 6th to May 5th
- Summer, from May 6th to August 5th
- Fall, from August 6th to November 5th

From our data each of these periods has a distinct sun power and energy harvesting characteristic. As well, normal solar arrays are not moveable so they are held hostage by the sun’s angles. There are only four variables that a user of solar panels has control over: the physical size of the solar array, the type of panels installed, the angle/azimuth of the collecting surface and its location. Everything else is beyond the user’s control. From our experiments we have found the sun’s location in the sky and sky conditions (clouds, haze, smog, jet vapour trails, the amount of atmosphere the sun’s rays have to travel through and the like) are the two greatest determinants of the sun’s power at any moment in time. The lower wintertime sun angles are solar energy killers even for us, with an array that can make the wintertime sun’s rays hit the surface at 90 degrees on one axis, for no other reason than the amount of atmosphere the sun’s rays have to travel through. This long journey attenuates the very light frequencies that are critical to harvesting power from the sun using solar photovoltaic collectors.

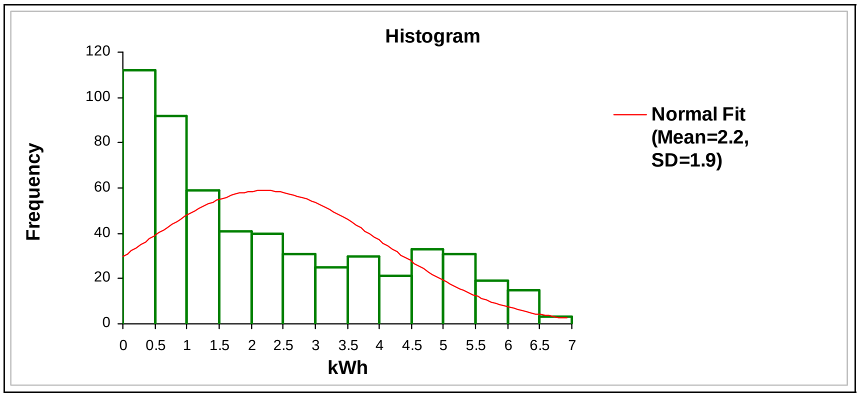
For the rest of this paper we will concentrate on the poorest energy harvesting part of the year … the wintertime. Why do we concentrate on wintertime? It’s because we need energy in the wintertime probably more than at any other time in the year. Here at this latitude, lack of household energy in the wintertime would be deadly and trash the house with burst pipes and the like. So our model, if it does nothing else, must incorporate enough generation to cover the wintertime household energy use … 85% or more of which is consumed by heating.

Wintertime Solar Energy Collection

We have been collecting data on our solar array for seven complete years and we are into our 8th year at this time of writing. We therefore have six years of wintertime data. You might ask where did the seventh year go? We organize our data from January 1st to December 31st each year. So even though our data started on November 1st 2006 we organize the data over the calendar year. From this point of view the seventh year is not completed yet.

So we go with six years of data. That amounts to 552 days of generation numbers.

The chart below is a histogram that shows you the distribution of the daily energy collected in kWhs over 552 days of wintertime. You can see the poor collection with a huge number of days below 1 kWh (200?) using the frequency scale. From a solar PV energy point-of-view this is an ugly graphic but it's real. Maybe a better term is 'really' ugly graphic. ☹



The details are provided below.

n	552				
Mean	2.20		Median	1.60	
95% CI	2.04	to 2.35	95.5% CI	1.30	to 1.90
SE	0.080				
			Range	6.8	
Variance	3.50		IQR	3.10	
SD	1.87				
95% CI	1.77	to 1.99	Percentile		
			0th	0.00	(minimum)
CV	85.2%		2.5th	0.00	
			25th	0.60	(1st quartile)
Skewness	0.66		50th	1.60	(median)
Kurtosis	-0.84		75th	3.70	(3rd quartile)
			97.5th	6.09	
Shapiro-Wilk W	0.90		100th	6.80	(maximum)
p	<0.0001				

Note the following in the above chart. At the 50th percentile … at the midpoint in the data sorted from lowest value to the highest value, we only generated 1.6 kWh that day. This means that we generated less than this amount half the time. Did I say ugly? Note as well that the Median (the mid point in the data) is lower than the Mean or average because there are so many lousy days with no generation at all. Look at the 2.5th percentile with zero generation. Of the 552 days, 2.5

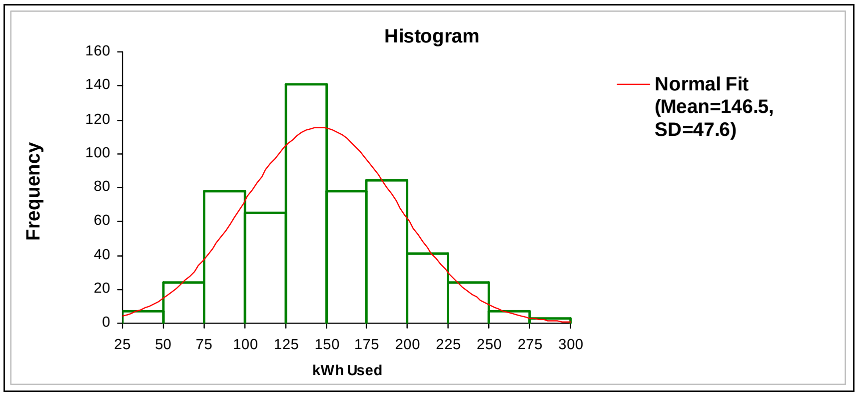
percent of them or 13 days we did not harvest one kWh of energy. And finally note as well that there is one chance out of twenty (1/20) that the Mean or average does NOT lie between 2.04 and 2.35. And going forward, this CI range will hold, more or less, no matter how many more days we add to our database.

This statistical description is produced via our purchased stats package:

Analyse-it ©

So there are the numbers … we generate on average in the wintertime only between 2.04 and 2.35 kWh each day. These numbers, bad as they are, are much better than a fixed array because we can compensate for the sun’s lower altitude in the sky. Fixed arrays can’t do this.

So now let’s look at what the household used in kWh each day. The natural gas volumes are converted to kilowatt-hours at the ratio of 10.35 kWh equals one cubic meter of natural gas at standard temperature and pressure (STP).



These data include the marginal amount generated from the solar array and the converted amount from natural gas to represent the total energy used by the household over the 552 wintertime days.

The difference is staggering. And we see the details below in the next chart.

n	552					
Mean	146.476		Median	144.766		
95% CI	142.496	to 150.456	95.5% CI	139.580	to 148.121	
SE	2.0262					
			Range	257.37		
Variance	2266.157		IQR	65.276		
SD	47.604					
95% CI	44.952	to 50.591	Percentile			
			0th	32.797	(minimum)	
CV	32.5%		2.5th	63.821		
			25th	114.486	(1st quartile)	
Skewness	0.23		50th	144.766	(median)	
Kurtosis	-0.23		75th	179.762	(3rd quartile)	
			97.5th	244.042		
Shapiro-Wilk W	0.99		100th	290.172	(maximum)	
p	0.006					

Even on the lowest day of energy consumption in a modified household focused on energy savings, we use 32.8 kWh of energy whilst generating virtually nothing from the solar array. Over the 552 days of wintertime there is one chance in twenty that the average daily use of energy is not between 142.5 and 150.5 kWh. The median is lower than the Mean so we know that there are more lower numbers in the data than higher.

The distance between the average daily solar generation and usage is big by factors of:

- 142.50/2.04=69.9,
- 142.50/2.35=60.6 using the low value of the 95% Confidence Interval (CI) range for the total energy used in kWh and

- 150.46/2.04=73.8,
- 150.46/2.35=64.0 using the high value in the 95% CI range total energy used in kWh.

We get averages that differ between a low of 60.6 and a high of 73.8.

So as brutal as these numbers are, they give us a baseline that allows us to design and build our carbon free household.

Fossil Carbon Free Household Design

The Household here at The Ravina Project has been modified to be a prototype household. But the prototype design has not been directed towards household sustainability and total carbon freedom. We have focused on household resilience. Many of the areas overlap and as such we have a good chance of calculating what the characteristics of a carbon free household power supply should be.

Right off the top without going any further, providing household heating is the main energy hog at this latitude. So ripping out a wall, putting in a word burning furnace hooked up to our existing hot water heating system would cut back on the amount of energy required in the house. We can make some calculations on the energy equivalence in wood vs. natural gas, calculate the amount of wood we need in our back yard for use and the like over the wintertime. We would then multiply the amount by 100,000 which would expand the technology to 100,000 similar houses.

But such a project as a model would be dubious at best. It’s just too complicated with too many unknowns. So let’s design the power supply for an electrical solution to our energy problem. We know far more about such an effort because there are many fewer unknowns. Our years of working with solar PV have given us data and an insight into what needs to be considered when designing with solar PV.

But first let’s calculate how big a solar collector installation we will need.

Note the magnitude between what we generated and what we used is substantial. But we also note that our panels are only 12.5% efficient, that is, under laboratory test conditions 1 kW of spectral sun power per square meter of area at a Normal angle through a standardized atmosphere will produce 125 W of electrical output per square meter of panel. Let us use the latest high tech panel efficiency of 20% to re-build our household power supply. That allows us to calculate new numbers based upon a newer generation of technology. We will take each daily solar generation total and multiply it by a factor of 20.0/12.5. Since we are using existing numbers with the chaotic patterns of reality embedded within them, multiplying each by a constant preserves the randomness of the real world in the data. There are probably instances where in real life a daily total of zero kWh registered with the 12.5% panels would be non zero with the new ones, however in the grander scheme of things these few minimally changed values in a database of 552 datum would not be detected. So let’s proceed. Here are the new modified numbers.

n	552	
Mean	3.514	
95% CI	3.263	to 3.764
SE	0.1275	

Our new calculations become 142.50/3.26=43.7, 142.50/3.76=37.9 and 150.46/3.26=46.2, 150.46/3.76=40.0. The new panel technology closes the distance between the averages, the lowest being 37.9 and the largest being 46.2.

The wintertime daily household energy use in kWh are restated directly below.

n	552	
Mean	146.476	
95% CI	142.496	to 150.456
SE	2.0262	

Using a factor of 46.2 let’s see what kind of generation numbers we get. What we have done is to multiply each day’s solar generation total in kWh by a constant of 46.2. which is the difference between the largest value in the natural gas 95% Confidence Interval range and the lowest value in the same range for daily solar kWh output. (150.46/3.26=46.2)

n	552	
Mean	162.3294	
95% CI	150.7622	to 173.8965
SE	5.88876	

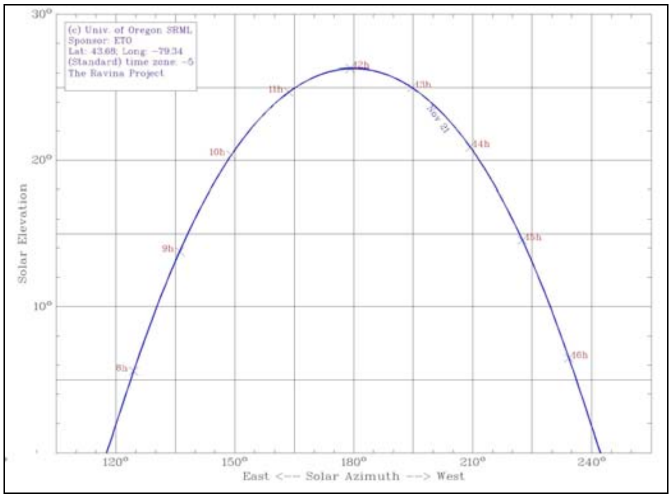
Our Mean is a little high, so let’s use our smallest difference between averages of 37.9 and see where that leads us. (142.50/3.76=37.9)

n	552	
Mean	133.1663	
95% CI	123.6772	to 142.6554
SE	4.83082	

Our Mean is a little low but that’s OK because we have bracketed the correct value or, better put, chances are the correct value lies somewhere in between these data sets. In our design we can use the values of both Means. They will give us two different designs which we are confident, or as confident as it is possible to be using chaotic data, that the true or proper value lies somewhere between them.

Here’s our goal. We will design a solar array using 20% panels that is 46.2 times larger than our present collector size of 12 square meters. We will call this design our **max design**. We will also design another collector using the 37.9 factor. We will call this design the **min design**. The max design works out to be 46.2x12=554.4 square meters in panel surface area. The min design works out to be 37.9x12=454.8 square meters.

Of course there is a difference between the total panel surface area of an installation and the amount of ground space the installation inhabits. The panels if they are too close together will shade each other and cause a huge reduction in power output. From the sun chart below you can see that for 60 days starting with November 21st and ending with January 21st in the midst of the winter here, the sun at noon sun time does not get above 26 degrees in altitude. (both days have identical sun angle characteristics)



All days between these two dates have lower sun angles at noon sun time. Solar panels when they are installed here are angled to the south. On a flat surface with the panel's top edge 1 meter above the ground how close can the next row be packed in behind the first row? So how close can they be? The calculation is: 1/tangent(sun's altitude in degrees)

sun angle degrees	inter-panel distance in meters
5	11.4
10	5.7
15	3.7
20	2.7
25	2.1

Looking at the chart above and assuming that the solar array is built on the ball field behind our house we'd like to harvest energy all day long because the days are so short. What are the distances between the rows so that no shading occurs during the collecting day? The inter-panel distance varies from 11.4 meters to 2.1 meters as the sun rises from 5 degrees to 25 degrees. So we can't put the panels in rows unless it's all one row. The better design is one huge structure populated with panels with tilting capability like our array. To harvest the most from the winter sun the collector will need to be at a tilt of 70 degrees from horizontal every day. If the collector area is square it would have the dimension of either 23.5 meters or 21.3 meters on a side. Let's budget for a 10 meter area around the array for access, maintenance and fencing. So the footprint of these structures would be either 43.5 or 41.5 meters square which when multiplied out would be a footprint of 1,892.2 and 1,722.2 square meters respectively.

Note that here in the summertime the best orientation for the array is flat if certain conditions are met in its placement. We have a paper on our WEB site demonstrating this fact. So the footprint must include the full surface of the array when it is flat or horizontal with respect to the ground.

All the energy harvested in the short winter days needs to be stored for night time use and of course to cover poor generation days. How big will our storage capacity be? Well we know the maximum amount of energy we use. Let’s design to cover 97.5% of the maximum daily energy consumption which is 244 kWh of useful storage. Useful storage is typically 80% of maximum storage in lead acid batteries of the kind we have here. So if 244 kWh represents 80% of the maximum storage then 244x100/80=305 kWh of storage would be required for 100%.

Let’s look at the batteries.

Our batteries measure in cm 60x36x40 times 2 (we have two banks) to equal 0.1728 cubic meters. Our battery contains 18.6 kWh of total storage so one containing 305 kWh of total storage would be 305/18.6x0.1728=2.834 cubic meters of battery net any room for cables, ventilation and the like. So the container in which they sit would be much larger by a factor of 2 or 3. Now calculating the weight. It comes in at about 11340 kg/m3x2.834 m3/1000=32.138 tonnes give or take. We assume that the total volume of the batteries is lead at a density of 11340 kilos per cubic meter. This is obviously incorrect because the cells have we are incased in plastic walls and the dimensions taken incorporated the plastic walls. We acknowledge the error.

Let’s factor this up to a small city of 100,000 homes like ours, optimized for low energy use and each has this power supply and battery storage.

The area containing panels to support 100,000 homes would be 100,000x1,722.2 square meters or 172,220,000 square meters or about 172 square kilometers on the low side and 189 square kilometers on the high side. For a town of 100,000, the power supply could be larger that the area of the town in some cases.

The gross battery weight would be about 3,213,800 tonnes. Maybe used and reconfigured electric car batteries would be a better fit? But, you get the picture.

Both the generation and storage designs return very big numbers when scaled up to a small city.

Can we get there from here?

Where is ‘here’ and where is ‘there’?

‘Here’ is where we are, using huge and ever increasing amounts of fossil carbon to power our high technology, complex civilization.

‘There’ is where we have cut fossil carbon emissions way below the ocean’s ability to absorb CO2. ‘There’ is where we see a yearly decline in the CO2 content of the atmosphere … a signal on top of the yearly ‘breathing’ of the CO2 in the atmosphere.

The model we have developed in this paper is crude to say the least but we believe our numbers are in the right order of magnitude, which is good enough for us. They make our point.

So what is the solution?

Note that all the forms of so called ‘green’ energy come from diffuse energy sources. By diffuse I mean it takes a huge collector to harvest energy on a scale to support our civilization. Our solar collector of 179 square km is an example of lack of energy density writ large. Fossil based fuels are extremely energy dense, in fact, fuels are by weight the most energy dense storage we have. So instead of the batteries, we might use the solar array, all 1700-1800 square meters of it, to split water and run the house during the day time, and during the night time, the house energizes itself by burning the hydrogen in a fuel cell.

But then, as before, you have the problem of the 172-189 square kilometers of collector to deal with.

You can’t get away from it. Diffuse energy sources require HUGE collectors. The corollary of course is any time you see a huge energy collector you know automatically it’s harvesting from a low energy density source (hydro dams, wind turbines, solar concentrators, solar PV and the like)

Note as well, dear reader, that there are four forces of nature. Everything we see from the farthest galaxy to the smallest particle we sense in our colliders … everything is energized with only four forces: Gravity, Electromagnetism, Strong Nuclear Force, and Weak Nuclear Force. There may be a fifth but that is still being worked out as we write this paper. The important point is, if the fifth force exists, it is not something we could harness to energize our civilization even in the long term. So we are stuck with four forces … but Nature seems to work quite well within that limitation … and we should too.

We have taken off the table voluntarily, through our technology choices and ideologies, two forces that contain more than enough energy to power our civilization, the Nuclear Strong Force and the Nuclear Weak Force. And the kicker is that these nuclear forces are contained in the most energy dense materials we know about. So in a world where we desperately need carbon free sources with huge energy density to energize our civilization, we have taken the most energy dense substances off the table.

And until we put them back on the table ….

We can’t get there from here!

Policy Implications

We understand that this paper is crude in the calculations it makes. We also understand that some of our assumptions may have to be modified for all kinds of good reasons. The goal of this paper is not to write some definitive screed but to give the reader a sense of the magnitude of the problem going forward. Whether the city power supply is only 100 square kilometers or 999 square kilometers is of little concern for us, we just want to get the order of magnitude correct.

We are not policy analysts. Professionals reading this might get a chuckle at our inexperienced remarks and that’s OK from our point-of-view. We don’t claim to be experts in anything really.

Be that as it may, I do think we have made the case for the wholesale adoption of energy dense power sources into our civilization. The highest density we can achieve resides in technologies that harness the Atom.

So the question is; do we build Uranium and Thorium power reactors? There are no other choices when using the atom for civilian power supplies. Nuclear fusion reactors are still a ‘pipedream’ and, in our opinion for what it’s worth, they will not be a factor in the War on CO2 that will dominate the rest of this century.

Here is a story from history as we have heard it.

Alvin Weinberg, the father of the high-pressure water cooled Uranium reactor did all his design work for military use. His reactors were used in ships of various kinds (remember SSN 571 Nautilus?) and as the industrial infrastructure was built to support this technology, it moved into the civilian sphere and Uranium reactors became the template for civilian power generation.

Alvin Weinberg did not approve of Uranium based civilian power reactors. In the late 1950s he and his team were working at Oak Ridge National Laboratories in Tennessee. They were tasked with building a reactor to power huge bombers that did not have to land for weeks at a time. The high pressure steam Uranium reactors were too heavy by orders of magnitude to be placed into a bomber. He built a two Megawatt prototype reactor as proof of concept using an entirely new paradigm for nuclear power, liquid Thorium.

The development of the ICBM killed the nuclear bomber project but Dr. Weinberg continued with his work at Oak Ridge. He and his team continued operating his molten salt Thorium reactor.

It operated for 20,000 hours at two megawatts. It incorporated safety that cannot be built into any Uranium reactor that has ever existed or will ever exist … that is, if there is NO power available for safety systems to operate, the reactor will drain its contents into areas specifically designed to receive them. The reaction will stop. The key of course is that the reactor contents are liquid and therefore flow down hill. So really the safety of the reactor ultimately depends upon Gravity. At times the team would go home on weekends and shut the power down so the reactor would drain. On Monday morning they would heat the contents and pump them back into the reactor chamber to begin another week's work.

Dr. Weinberg was so adamant that his design was the proper and safe design for civilian power supplies that he went 'to the wall' to ensure they would be rolled out instead of Uranium based reactors. He was fired.

Now the amazing thing about this whole effort is the fact that this technology was developed in the 1950s and into the 1960s. The reactor was built and operated using almost ancient technologies on every scale. No one took up the mantle and brought this technology into our cities to power them. Why? There are many who point out that atomic bombs could not be made from Thorium reactor waste products unlike the waste produced in Uranium reactors. The Cold War was on and Plutonium for bombs was needed. The whole Thorium reactor effort was killed, mothballed and the technical drawings and papers were boxed away at Oak Ridge and forgotten.

They stayed there for many decades until Kirk Sorensen a NASA nuclear engineer went to Oak Ridge in the 2000s, copied all the papers to DVDs and kept a set for himself. He was working on building a power supply for a moon base among other projects and they all needed high energy dense power supplies. Kirk, who is quite engaging, has many, many videos on the WEB for you to see. He discovered the existence of the Oak Ridge papers by accident in an old textbook. It was a total surprise to him … a testament to how Thorium was erased from history.

A few years later a very high level Chinese delegation visited Oak Ridge, took copies of Kirk's DVDs, returned to China and set up a research institute in Shanghai, the Shanghai Institute of Applied Physics. They are investing 1 billion dollars so far in a crash program to develop Liquid Fluoride Thorium Reactors (LFTR pronounced 'lifter') to power their cities. They understand both the potential and safety of this technology. They also understand that they are choking on coal pollution and suffering dramatic climate change in many regions of their country.

Thorium development for city power supplies is going strong in India, Norway, UK and several other countries. There seems to be a new one joining the group every 6 months or so. There is much on the Internet for anyone who is interested. Ramping up on this issue is not an issue … to coin a phrase. See www.youtube.com/watch?v=N2vzotsvvkw for a short TEDxtalk by Kirk.

It seems to us that others have crunched the numbers and come up with the same conclusion, to wit, that our complex, high energy use civilization needs the energy locked away in the Atom to survive. Some of the world's top climate scientists (Drs. James Hansen, Kerry Emanuel, Kenneth Caldeira, and Tom Wigley) understand that our civilization is facing an existential crisis. They are calling for development of high energy dense atomic power for civilian use.

So I repeat myself in this section on policy. Until we put them (high energy dense technologies) back on the table ….We can't get there from here! … which means, of course, we will emit enough CO2 to change the Earth into a planet that is fundamentally hostile to humanity.

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

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