Household Decarbonization

The Electrification of Household Heating

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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

Household Decarbonization

Introduction

We are of the opinion that decarbonization of our civilizations is critical to their survival in anything more than their simplest form. The science tells us we have to decarbonize rapidly in the first half of the 21st century in order to have a livable world in the 22nd century. This is a huge challenge.

We 'tip our hats' to Joseph Tainter and Jane Jacobs. The reader might recognize several of their ideas embodied in this essay.

In the year 2016 our household used a total of 29,039 kilowatt-hours (kWh) of energy from all sources including: natural gas, grid electricity and solar generated electricity. Home heating consumed 15,812 kWh of natural gas, or 54.5% of our total energy use, and released about 2,900 kilograms of CO_2 into the environment.

The first big step on the pathway to decarbonization at the household level, after efficiencies like insulation are completed, is to reduce as much as possible the use of natural gas in energizing household heating. Here in Ontario, Canada we have one of the cleanest electrical grids in the world because of our use of the '**big three**' clean energy production technologies: wind, hydro dams and nuclear. So the logical thing for us to do would be to energize our heating from the grid rather than from natural gas. To do that we need to convert our hot water radiator based heating system from natural gas to grid electricity. The technology required is available and off-the-shelf.

In this essay, using our data, we will build a simple model of our heating season in 2004-05 and build another using data from 2016-17. Between these heating seasons the house was modified to become 30% more efficient to heat. We will contrast and compare the two heating environments and estimate the cost of heating with grid electricity at today's electricity prices. We will attempt to estimate the further increase in heating efficiency, such that the cost to heat our house with electricity after conversion, is more or less the same as heating with natural gas today.

And finally we will look at how the percentage of decarbonization at the household level is affected by electrification and how the role of further efficiencies affect that percentage.

The heating season 2004-2005

We will use the heating season from October 1st, 2004 until the end of May 2005 as our first year in this discussion. Below we list in chart form the utility gas bills for that heating season.

Reading date	Oct 25/04	Nov 19/04	Dec 21/04	Jan 25/05	Feb 23/05	Mar 24/05	Apr 25/05	May 25/05
Number of days	32	25	32	35	29	29	32	30
M^3 used	124	242	500	675	556	515	264	148
Total Invoice	$76.50	$124.01	$242.45	$312.14	$274.06	$254.93	$121.54	$71.56
$/M^3	0.62	0.51	0.48	0.46	0.49	0.50	0.46	0.48
M^3/day	3.88	9.68	15.63	19.29	19.17	17.76	8.25	4.93

We will concern ourselves with the third line in the above chart, the number of cubic meters of natural gas used. The total for the season is 3,024 m^3. We can convert this natural gas usage in cubic meters to kilowatt-hours (kWh) of energy by using the factor **10.35 kWh** for every cubic meter of natural gas. The total natural gas energy used is therefore 3024 x 10.35 = **31,300 kilowatt-hours (kWh)**. The cost per kWh of natural gas in 2004-05 is $1,477.19/31,300 kWh = **$0.04719/kWh.**

We have one more modification to this total amount to factor in. We have calculated the total amount of natural gas used from our utility invoices but we also use natural gas for our domestic hot water, our clothes drying and our cooking. In order to isolate this non-heating usage we look to the summertime usage when the home heating is turned OFF. We'll call this our baseline natural gas usage. Note that it will be slightly less than the actual usage in the wintertime because in the winter we use our natural gas energized clothes dryer much more than in the summertime plus we cook hot food more often [no wintertime BBQ … ;-(( ] and may even take hotter showers. So bottom line, our estimation of the baseline natural gas usage using this method will come up a little light.

If more gas is used for wintertime non-heating functions there will be less used for heating. That means the heating efficiency will increase. But unfortunately we don't make that correction because we just can't measure the difference. So the best we can do is to use our method realizing that the household efficiency as shown in the numbers will be less than reality.

Consider the following charts consisting of our natural gas invoices from our utility:

We will look at two summers to calculate our baseline gas usage, the summer of 2004 below.

Reading date	**Jun 23/04**	**Jul 23/04**	**Aug 24/04**	**Sep 23/04**
Number of days	29	30	32	30
M^3 used	46	48	41	48
Total Invoice	$29.90	$32.10	$29.64	$32.84
$/M^3$	0.65	0.67	0.72	0.68
M3/day	1.59	1.60	1.28	1.60

And the summer of 2005 below.

Reading date	**Jun 22/05**	**Jul 25/05**	**Aug 24/05**	**Sep 23/05**
Number of days	28	33	30	30
M3 used	92	53	12	30
Total invoice	$49.42	$35.10	$17.43	$25.51
$/M^3$	0.54	0.66	1.45	0.85
M^3/day	3.29	1.61	0.40	1.00

The numbers from the invoices are the: gas meter reading date, number of days in the billing period, total cubic meters of gas used and the total billed amount. There are two other derived numbers: the cost per cubic meter and the number of cubic meters we used each day on average during the billing period. Looking at the third line in the charts for the total amount of natural gas used we calculate that we used a total of 370 cubic meters. To get an average daily usage we divide 370 cubic meters by the total number of billed days (the second line in each chart) which is 242 days to get an average of **1.53 cubic meters of natural gas used per summer day**.

Other than the reason mentioned above, what further reason do we have to make this extensive calculation? We make it to isolate any change in lifestyle we may make that may change our usage of natural gas. In this way we can ensure that the net amount of natural gas used is as close as possible to what we actually use for home heating. Note for two years we had another person in the household. It would be inaccurate to ignore that extra load on the household's energy inputs. The resulting efficiency calculations would be skewed.

After these cooling seasons' natural gas usage calculation, we can change the total daily amount of natural gas we used for the wintertime of 2004-05. There were 244 days in the winter billing cycle where we, on average, used 1.53 cubic meters per day for purposes other then heating. So we must subtract 244 x 1.53 = 373 cubic meters from our total wintertime gas usage which becomes 3024 – 373 = **2,651 m^3**. We can express this volume of natural gas as energy in kilowatt-hours by multiplying each cubic meter of gas by a factor of 10.35. We used: 10.35 kWh/m^3 x 2,651 m^3 = **27,440 kWh** of heating energy for the winter of 2004-05.

The wintertime of 2004-05 generated **3,475** Heating Degree Days according to Environment Canada's local Toronto Center weather station. The resulting household efficiency is calculated in cubic meters of natural gas used for every heating degree day (HDD) in 2004-05 as: 2,651 m^3 of natural gas/3,475 HDD = **0.7629 m^3 used per HDD**.

We can also express the above efficiency as the amount of energy used for heating per heating degree day as: 27,440 kWh/3,475 HDD = **7.896 kWh/HDD**.

Decoding our natural gas Utility invoice

We know how many cubic meters of natural gas we used in the winter of 2004-05 but we have no idea of how much that gas would cost with today's prices. So what we will do in this section is to deconstruct our recent natural gas invoices such that we will be able to 'generate' an invoice for the 2004-05 season's total gas usage but at today's gas price.

The chart below shows several months of natural gas invoices at today's prices.

Date	7/22	8/22	9/22	10/24	11/23	12/20	1/23	2/21	3/23	4/21	5/24
# of days	30	30	30	31	29	26	33	28	29	28	32
Gas used m3	47	40	48	72	188	285	372	341	314	207	147
Customer Charge	20	20	20	20	20	20	20	20	20	20	20
Delivery	5.11	4.62	5.51	7.15	17.16	25.49	42.3	42.66	39.4	26.3	18.9
Site Restoration Clearance	-0.58	-0.49	-0.59	-0.89	-2.32	-3.51	-4.31	-3.85	-3.54	-2.3	-1.66
Transportation	2.6	2.25	2.7	4.06	10.59	16.06	20.2	18.17	16.7	11.2	7.98
Gas Supply Charge	4.46	3.85	4.62	7.8	21.02	31.86	42.3	39.03	35.9	23.6	16.7
Cost Adjustment	0.59	0.1	0.11	-0.14	-0.56	-0.85	-2.38	-2.69	-2.48	-1.2	-0.7
HST	4.18	3.95	4.21	4.93	8.56	11.57	15.4	14.73	13.8	10.1	7.97
Total	36.4	34.28	36.56	42.91	74.45	100.62	133	128.1	120	87.6	69.2

The reading dates in the chart above start on July 22nd, 2016 and go through May 24th, 2017.

As you can see there are lots of extra charges that vary linearly with the amount of gas used except for the 'customer charge' which is a constant each month.

So with all charges and taxes taken into account, for a total of 2,061 m^3 of natural gas used, we paid a total of $863.32 or **$0.4189 a cubic meter**. Converting 2,061 m^3 of gas to kWh gives us **21,330 kWh** using the same 10.35 kWh/m^3 conversion factor we used above. The cost per kWh of natural gas is $863.32 / 21,330 kWh = **$0.04047/kWh** at today's gas prices.

Evaluating winter 2004-05 heating using today's natural gas pricing

In the 2004-05 heating season our efficiency expressed in kWh per heating degree day was **7.896 kWh/HDD** over a winter which generated 3,475 heating degree days. We also know from the above calculation that using today's natural gas prices the cost per kWh of heating is $0.04047. The cost of heating at the efficiency of 7.896 kWh/HDD is 7.896 x $0.04047/kWh = **$0.3196/HDD** at today's natural gas prices. At the old 2004-05 prices the cost per kWh is $1,477.19/31,300 kWh = **$0.04719/kWh.** At the same efficiency using old prices the cost per HDD is 7.896 kWh/HDD x $0.04719/kWh = **$0.3726/HDD**.

For 3,475 heating degree days generated in the winter of 2004-05 the estimated total cost of natural gas is: $0.3196/HDD x 3,475 HDD = **$1,111** at today's natural gas prices. At the old prices it would be $0.3726/HDD x 3,475 HDD = **$1,295**. That's about a 14% drop.

Decoding our electrical utility invoices

Let's take a year of utility invoices, calculate the total number of kWh used and the total amount paid for that energy to find a good estimate of our current cost per kWh of electrical energy delivered to our meter. In the chart below we have recorded a year of invoices from Toronto Hydro. We include a year to get a better estimation of the cost per kWh of energy rather than just an estimation over a few months.

Meter reading date	Days	kWh used	kWh gen	Net kWh	Invoice total	$$/kWh
Mar 31/17	100	2053.409	207	1846.409	$365.60	$0.20
Dec 21/16	21	421.265	30	391.265	$82.89	$0.21
Nov 30/16	30	453.431	93	360.431	$86.75	$0.24
Oct 31/16	31	293.64	131	162.64	$55.95	$0.34
Sept 30/16	30	219.971	178	41.971	$36.05	$0.86
Aug 31/16	31	267.7	222	45.7	$38.12	$0.83
July 31/16	31	198.181	226	0	$26.20	$0.00
June 30/16	30	139.038	299	0	$4.76	$0.00
May 31/16	31	170.166	279	0	$13.72	$0.00
Apr 30/16	30	367.31	186	181.31	$57.97	$0.32
Mar 31/16	31	626.71	81	545.71	$115.20	$0.21
Totals				3575.44	883.21	$0.247

Note a few anomalies with this chart taken directly from our Toronto Hydro invoices. There are three months where we send back to the grid more energy than what we use yet we were still charged for usage. For those months the marginal cost for delivered product is infinite.

So bottom line, over the last year we paid: $883.21 / 3575.44 kWh = **$0.24702 per kWh** for electrical energy.

Evaluating winter 2004-05 heating using today's hydro pricing

The heating costs in 2004-05 can be calculated using electrical heating at today's pricing. From above we know that during that winter the energy efficiency was on the order of 7.896 kWh/HDD. From our invoices above we know that we will pay $0.24702 per kWh so in 2004-05 using today's pricing, we would expect to pay on average: 7.896 kWh/HDD x $0.24702/kWh = **$1.950/HDD**. Since there were 3,475 heating degree days in the heating season the total cost for heating then is: 3,475 HDD x $1.950/HDD = **$6,776 for wintertime electrical heating in 2004-05** using today's prices. Note again the household was 30% less efficient than today.

Calculate 2016-17 net natural gas winter usage in kWh, cubic meters

We will make our calculation for natural gas usage and estimation of the summertime average using our daily database. Note the heating season starts October 1st and ends May 31st of the next year in any year. Meter readings taken at the end of day September 30th and end of day May 31st will capture most energy usage between the start of day October 1st and start of day June 1st in any year.

On September 30th 2016 our end of day natural gas meter reading was 36,468 and at the end of day May 31st 2017 the same meter read 38,402. The heating season used 1,934 cubic meters of natural gas. We will look at the summer season of 2016 to calculate our baseline non-heating natural gas usage. The end of day gas meter reading on May 31st 2016 was 36,291 for a total usage of 177 cubic meters over 123 days between June 1st and the end of September for a daily baseline average use of **1.44 cubic meters per day**.

Over the 242 days of the heating season we used 242 days x 1.44 cubic meters per day or 348 cubic meters for non-heating energy. For heating during 2016-17 we used 1,934 cubic meters minus 348 = **1,586 m^3 of natural gas**.

The winter heating season generated 1,025 HDD in 2016 and 1,991 HDD in 2017 for a total of 3,016 HDD. These data are taken from Environment Canada Toronto Center weather station. The efficiency of the house is therefore 1,586 m^3 / 3,016 HDD = **0.5259 m^3/HDD.**

The efficiency in kWh per HDD can be calculated by taking the above efficiency of 0.5259 m^3 of natural gas/HDD and multiplying it by the conversion factor of 10.35 kWh/m^3 = **5.443 kWh/HDD**.

Based upon today's electrical prices the cost of heating is: $0.24702/kWh x 5.443 kWh/HDD = **$1.345 per heating degree day**. There were 3,016 HDD in the heating year 2016-17; the total cost for electrical heating for the winter of 2016-17 is: $1.345/HDD x 3,016 HDD = **$4,057**.

Note the difference between the efficiency in 2004-05 and 2016-17: 7.896 kWh/HDD vs 5.443 kWh/HDD is about 31%. Based upon the cost of electrical heating at today's prices the drop is: **$1.950/HDD** vs. **$1.345/HDD** which is again about 31% corresponding to the household's increased efficiency.

The electrical heating conversion target calculated

So we want to estimate how much more efficient our house must be in order for us to pay approximately the same amount for heating after electrical conversion.

What is the target? The target when heating with natural gas is $0.04047 per kWh x 5.443 kWh/HDD (our present efficiency) is **$0.2203/HDD**. Since our best and most efficient year has our electrical heating estimated to be $1.345/HDD and the target calculated from the present day cost of natural gas is $0.2203/HDD the house must become much more efficient. The efficiency increase can be calculated by the following: if an efficiency of 5.443 kWh/HDD produces a cost of $1.345/HDD and the target is $0.2205 the reduction must be then by a factor of $1.345/$0.2205 = 6.1. The efficiency in kWh/HDD must also decrease by the same amount from 5.443 kWh/HDD to 0.89 kWh/HDD an increase in efficiency over the present household of about **600%**.

Therefore if we want to electrify our house heating AND maintain the same energy invoice amounts we would have to make up a difference of over 600% in household efficiency. Such an increased efficiency is highly unlikely for the present structure.

Electrical conversion CO_2 release implications

The whole idea of conversion from natural gas to grid electricity for home heating is to drop our carbon release from our household by about 80%. Let's explore this idea further.

HDD total for latest heating season is: 3,016
Total cubic meters of net natural gas used is: 1,586
Cubic meters of natural gas used per heating degree day is: 1,586 / 3,016 = 0.5258
kWh of natural gas used per heating degree day is: (10.35 x 1,586) / 3,016 = 5.443

We will assume that the same energy input will be required per heating degree day no matter what the energy source. This assumption can be criticized but it is the best we can do at the moment. Hopefully it will give us a 'ball park' estimate for the various factors we need to consider.

kWh of electricity used per heating degree day is 5.443

One cubic meter of natural gas releases 1,956 grams of CO_2
There are 10.35 kWh of energy in a cubic meter of natural gas
One kWh of natural gas releases 1,956 / 10.35 = 189.0 grams of CO_2
In Ontario the average CO_2 release per kWh of grid generation is about 43 grams

A kWh of natural gas releases 5.443 kWh/HDD x 189.0 gm/kWh = **1,029 grams of CO_2/HDD**.

If grid electricity is used the release is 5.443 kWh/HDD x 43 gm/kWh = **230 grams of CO_2/HDD**.

The percentage difference is: ((1028-230) / 1028) x 100 percent = **77.6%**. This means that just converting the household to electrical heating and leaving all else the same reduces the carbon footprint of the household by about 77.6%.

TransformTO's goal for Toronto is the elimination of 80% of the CO_2 it currently releases, over the course of 33 years. At the household level just converting to our clean Grid for heating will allow us to get the first 77% with a few percentage points remaining. So how much more efficient will the house have to be to make the 80% goal? Since both these rates of kWh usage are linear there is not much that can be done from efficiency to get to 80% because we are measuring a ratio.

For example, if the household were to reduce its heating energy usage from 5.443 kWh/HDD to, let's say, 4.000 kWh/HDD (about a 26% increase in heating efficiency) the resulting difference in carbon release will be

100%-((4.0000x43)/(4.0000x189.0)x100%) = 77.2%

We gain nothing because the increased efficiency in the household works in the linear way with both carbon sources. In order to change the CO_2 emissions per kWh used, the grid must become cleaner. Let's say the grid averages just 36 gm of CO_2 release per kWh. The above calculation becomes:

100%-((4.0000x36)/(4.0000x189.0)x100%) = **80.9%**

So at the household level after conversion to electricity, the CO_2 percentage reduction you get per kWh energy used is set and no more insulation or efficiencies used in the household will significantly improve the percentage reduction over natural gas usage. The efficiency affects both the natural gas usage and the grid usage in the same linear way and is defined by the ratio of CO_2 production for each of the energy sources: natural gas and the grid. The only way to get a decrease the in heating carbon footprint higher than 80% is to clean up the grid on average by about 7%. This seems to be quite a reasonable goal.

From a heating cost perspective using less energy for heating is a huge incentive if the heating costs per kWh are a factor of 6 larger. Note as well that the CO_2 overhead for a kWh of grid energy is so small that increases in efficiency of an electrified household will only save a marginal amount of CO_2 release. Again it goes back to the costs. While the environmental benefits are marginal for a saved kWh of grid electricity, the dollar savings are quite substantial.

So bottom line, after the initial percentage reduction in carbon footprint per HDD of energy usage from electrification no increase in the household's heating efficiency will affect that percentage further. Further increases in household efficiencies will decrease the cost of electrical heating after the conversion with only a marginal affect upon the household carbon footprint.

Conclusions, Comments and Insights

Note that these insights are skewed by our present grid CO_2 release per kWh. Our grid is one of the cleanest in the world at the moment so whenever we mention 'grid energy' that means, for all intents and purposes, 'clean energy'.

It is important to note that the goal for the world at this critical time in the history of our civilizations is to **dramatically reduce green house gas emissions**. So it follows that every effort must be made to promote CO_2 free energy generation where ever it may be and using whatever clean technology we have at our disposal. There is no hierarchy of carbon free technologies. Every one of them has its place in this fight. The only difference among them is the usefulness each has when used in various applications. Some applications make one more useful than another. For instance, it is hard to beat a solar panel/battery combination powering electronics that are very remote and can only be serviced at irregular times.

One of the first insights we can make is that all kilowatt-hours of energy are not equal. They depend upon the carbon footprint of the energy source. If I save a kWh of grid electricity I save about 43 grams of CO_2 release. If I save a kWh of natural gas I save 189 grams of CO_2. So for my marginal dollar, what do I spend it on? Do I save grid electricity or do I save natural gas? It's a 'no-brainer', I get 4.4 times the CO_2 savings if I spend my energy reduction dollar on reducing natural gas usage.

If we convert our households to all electrical heating we get a fixed percent of greenhouse gas reduction. No amount of household heating efficiency will change that percentage. After conversion to electrical heating, efficiency is directly proportional to reducing heating costs rather than reducing the household carbon footprint. Why? The grid is clean. The CO_2 reduction per kWh for grid electricity is so low, huge energy reductions in this form of energy use are marginal at best, especially when compared to CO_2/kWh reductions in fossil fuel usage.

In order to get household heating electrified and get a CO_2 reduction of at least 80%, the electrical grid must be tweaked by about 7% from our calculations in order to get the 80% reduction required by the goals set out by **TransformTO**.

The current differential between the cost to the consumer of a kWh of grid energy and one derived from natural gas is so large, a factor of 6 by our calculations, any wholesale conversion of household heating will need a subsidy. If the Market makes the choice at the household level, electrification will never occur. The only non-subsidy future which allows for electrification then would be one where totally clean generation becomes ubiquitous such that the costs of consumption per kWh is on par with that of a kWh from fossil fuels.

Looking back at the wars humanity has fought. I stand to be corrected, but there is no war that I can remember or have studied that was won by using Market forces to determine both the tactics being used and strategies employed. We've seen wars of attrition but they are not the same thing. We are in the War to the death with greenhouse gasses and the resulting global warming. There are many who think we should leverage the power of the Market to win this War. I agree, however, in my view the Market should not determine the tactics and strategy used in our long march to victory. The Market is an enabler, a useful social construct to be leveraged.

Back in the mists of time when energy was very valuable because civilizations lived in energy poverty, squeezing the most out of any technology was important for civilization's growth in complexity. We can look at agriculture which, in essence, is an energy harvester and transformation technology which allows us to eat the sun's energy. Innovation in this technology allowed for increased yields, less waste and food production from hitherto marginal land. Note we are not arguing for the idea that innovation is a constant activity or that it occurs at the same rate through time. There may be a civilizational response to a problem, let's say an earthquake which changes the course of an essential river system, where innovation activity is ramped up in response.

We can look at sail technology or ship design and see the same trends, a more efficient idea quickly dominates. I remember the story of early European explorers sailing from point to point in the Arctic and remarking that they seemed to be observing the same people in kayaks at places 100s of miles apart. Such was the efficiency of the kayak as a means of transportation. These efficiencies were not present in the 'first' kayak built but successive refinement over generations produced a wondrously efficient watercraft.

And finally, I want to make the point that energy poverty is correlated strongly with civilizational collapse throughout history in my view. More available energy means a civilization can grow and become more complex. The Third World can join the Second and the Second World can join the First. **Our problem is greenhouse gas release and not energy availability** at a reasonable price. It is important to make that distinction because there are many in the green movement that equate available energy for a civilization with greenhouse gas emissions to such an extent that an overall reduction in energy use, energy poverty, is their recommended solution to the global warming problem. Their point of view is counter productive and totally wrong in my view. There are plenty of zero greenhouse gas producing energy production technologies available now along with a whole list in technical development. These technologies allow us to grow our energy use as high as we want plus curtail CO_2 production at the same time.

Nothing in Physics, which is the grand arbitrator in this issue, stands in the way of a clean, energy rich future for our civilizations.

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

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