Energy, What Now?

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By Alec M. Wodtke, presented as an address to the Humboldt Club of Göttingen April 8, 2011

The purpose of this talk is to open a conversation with you and to stimulate a conversation amongst you about a topic that we have all been thinking about at various levels of rigor for years. Furthermore, it is a topic that requires our attention – I would argue regardless of our particular area of expertise. That is the topic of energy. Why do we need it? How much do we need? Who is using it? Where do we get it? Where could we get it? What are the consequences of energy consumption? What does it mean to have sustainable energy consumption?

Energy: Why do we need it and how much do we need?

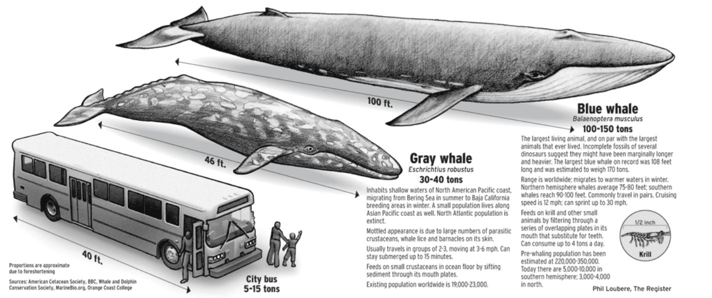
*In a very real sense the human body needs energy. To give you an idea of how much, consider that one must typically eat about 1000 kilocalories per day to survive – 2000 in rich countries where everyone gets fat. This actually means 8.000.000 Joules and the day has about 80.000 Seconds in it. So after the dust settles on this little math problem, we are talking about **100 Watts**. This is the 100 Watt survival level for human existence. This is equivalent to the energy consumption of a really good bright incandescent light bulb. That's what you need. Now ok you might say I need more that just that. I need my car. I need my house with indoor heating (and cooling – even refrigeration). I need my television. I need my laptop. I need my Ipod, Ipad, Iphone. And and and …. But no, you don't need those. Once upon a time, people walked or ran instead of driving. They rode horses. They built their own shelters without indoor heating or cooling or refrigeration or saunas or televisions or laptops or Ipods.*

The human body needs about 100 Watts of power to run: some need more than others...

So what happened? The short answer is: we got greedy. And greed appears to be an evolutionary advantage. Put another way, it seems to be an empirical fact that societies that can harness large amounts of energy destroy or absorb those that do not. And after a few thousand years of evolution, we are left with what "the survival of the fittest" leaves you with: a bunch of competing societies that all use extraordinary amounts of energy[1].

Energy: How much are we using?

Average energy use in so-called developed countries is between 10.000 Watts per person (in the US) and 5.000 Watts (in Germany). That is to say it is about 50 to 100 times the survival level. Putting that in the energy units of a prior age, that is to say in units of human energy consumption, the average American has the equivalent of 100 Slaves worth of private energy consumption, In Germany only 50 slaves. A simple question- Why do we all need so many slaves? Again, I think it must be true that over the last 5000 years or so societies with large energy consumption stomp out those with lower ones.



The size of things: The mass of coal needed to produce the annual energy for a family of four in the US today lies between that of the gray and the blue whale. This roughly approximates the amount of CO_2 produced by that family in a year.

To get an idea how much energy this really is lets think about the US (my home country) which uses 25% of the worlds energy. By the way, if you want world levels, just multiply by four. US energy consumption in 2004 was 10^{11} *GJoules. How much is that? Well the amount of coal you have to burn to get that much energy is on the order of 10.000 million tons. Physical scientists would say 10 Gigatons. So for every single one of the about 75 million families of four in the US, one would have to burn a mass of coal equal to about 130.000 kilograms. That is to say 130 Metric Tonnes. That is equivalent in weight to the largest living animal on the planet… the Blue whale. In Germany it is not so bad. It is only a gray hale worth of Coal. Imagine if each of those families had to be responsible for dealing with the Carbon waste of that combustion – that is imagine it didn't just go up in smoke into the air. Imagine the conversation that might ensue.*

Carbon waste Dealer: Excuse me ma'am, we've just picked up your gray whale and we'll be taking him off to our gray whale storage facility. By the way the upkeep charge on that will be a little higher next year. It seems everyone has a gray whale they want picked up and taken away. Let me tell you, business is terrific. We're just literally swimming in Gray whales this year.

Customer: Oh dear.

Carbon Waste Dealer: By the way, have you considered what you'd like us to do with your gray whale next year? We are offering a limited special discount for our regular customers, which I'd advise you to consider seriously. The price of loading and storing gray whales is going up and I don't expect that to change any time soon.

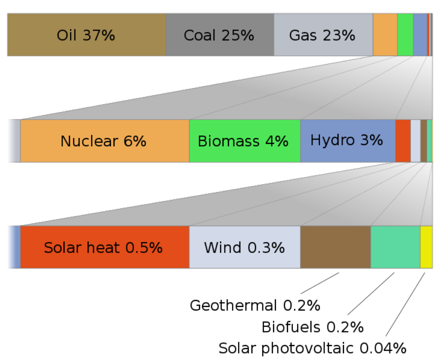
Customer: Oh dear.

Carbon Waste Dealer: In fact, we've just established our China division and I can't even get enough trained gray whale transport and storage specialists to hire. There is some chance we'll have to turn some people down next year.

Customer: Oh dear.

Carbon Waste Dealer: You might consider our 'do it yourself special'. We install a deep back yard pit and every year you dispose of your gray whale without us. Course, it does tend to smell up the place a bit. But it's all part of our keep the customer happy service plan.

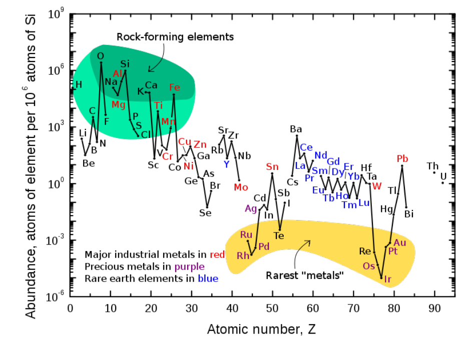
Customer: Oh dear.



At present our energy comes nearly exclusively from burning fossil fuels.

Where do we get our energy?

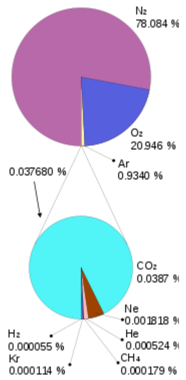
The short answer to this question is very short. We get our energy by burning things. Mainly, we burn coal, oil, natural gas and wood. In some sense we *also burn Uranium. We burn a lot of other things, but in much smaller quantities. It seems we like to burn things. So what are the consequences of so much burning going on?*



The chemical soup of the Earth's Crust produced life.

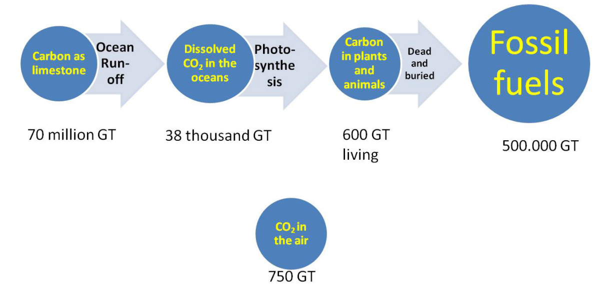
To understand this it is important to know a little bit about the Carbon cycle and carbon migration. The amount of carbon that exists on this planet is fixed. But it changes its form over time in response to large scale geo-events and this can have consequences. So here is how it works.

Once upon a time about 14 billion years ago there was a big bang and quite quickly (a millisecond later for protons and about 10 minutes later for Helium nuclei) subatomic particles formed. It took about 400.000 years to cool down but eventually these nuclei captured electrons and become the first actual chemicals (Hydrogen and Helium atoms). Eventually the Hydrogen and Helium atoms were attracted by gravitational forces and stars started to burn after about 100 million years. All the other elements in the periodic table come from nuclear reactions in those stars and that's why Hydrogen and Helium are the most abundant elements in the universe.



The chemical makeup of the earth's atmosphere. N_2, O_2, Ar and CO_2. Water vapor is not shown.

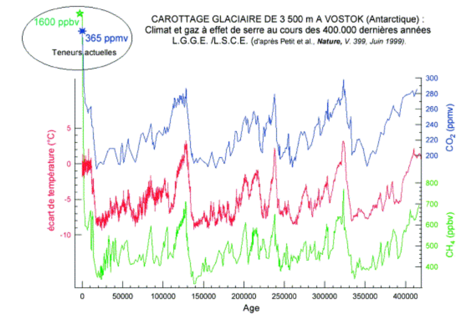
So eventually when the earth formed about 4 billion years ago there was an elemental distribution containing primarily Hydrogen, Helium, Carbon, Nitrogen, and Oxygen and a few other important elements. The Earth's crust has loads and loads of Carbon in it, mainly in the form of Carbonates. Think limestone. When limestone comes in contact with water – for example in the oceans or through rainwater runoff – it dissolves. Not all of it, but some of it. This dissolving of limestone actually puts a lot of CO_2 in the water and in the oceans. Scientists say there are 38.000 billion tons (we call this 38 GTons and it is about 400 Billion Blue whales!) of dissolved CO_2 in the oceans today and it has probably been something like that amount for a very long time. Now, no one really knows for sure but about 2 billion years ago this "biology thing" kicks in and something really amazing happens - photosynthesis. Some of the earliest living organisms figured out how to convert CO_2 and water into sugars and other energy containing compounds and use these for all sorts of important purposes that allowed life to really get diversified all over the planet. And by the way, as a side effect of photosynthesis was the production of O_2 leading to what we now know as our modern atmosphere, which in rough approximation contains nitrogen, oxygen, carbon dioxide, water vapor and (strangely enough) a little Argon.



The migration of Carbon that began with photosynthesis. It is not surprising that the relatively small carbon reservoir in the atmosphere responds to the others.

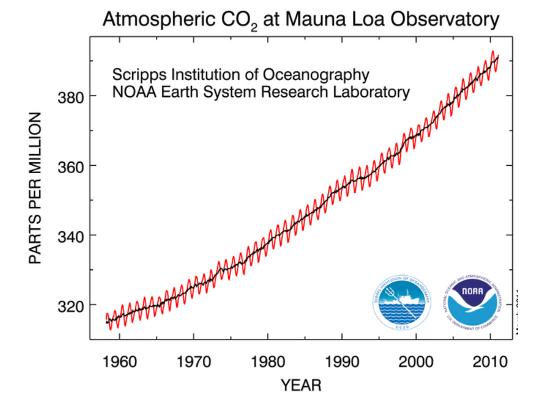
By about 500 million years ago life is also on land in a big way and oxygen breathing animals are getting going. Eventually the world settled into a really beautiful form of chemical equilibrium, CO_2 being consumed by plants which "exhale" O_2 and Oxygen breathing animals that breath out CO_2. But all the Carbon in plants and animals is still eventually derived from the limestone that dissolved in the sea. And of course the living organism prospered and multiplied and filled up the earth. And of course they all eventually fell down and died to make room for the ones that were coming after them.

And this has been going on for about 500 million years. And all that Carbon that made up the bodily tissues (proteins in mammals and cellulose in plants) was buried in the ground or in the seabed or anyhow it was buried somewhere. And over 500 million years or so, this led to a net movement of carbon from limestone in the earth to this buried carbon in the earth's upper most crust. This is now what we call fossil fuels. If you like, the fossil fuels buried in the earth are essentially 500 million years worth of solar energy collected by photosynthesis and stored in the ground in the form of a chemically active form of Carbon – something chemists would call an energetic form of carbon – something that burns.



The CO_2 (and methane) record over the last 400.000 years. CO_2 has varied by a little less than a factor of two. The global temperature has been strongly correlated with atmospheric CO_2 and methane.

During this remarkable flow of hundreds of thousands of Gigatons of Carbon[2], the CO_2 in the atmosphere – which is an extremely small part of the overall carbon in the world – just served as a temporary holding station for that migrating Carbon, passing from the oceans to the earth's upper most crust. There never was very much carbon in the atmosphere and there never will be. But because the atmosphere holds such little carbon when enormous amounts of Carbon are migrating from one part of the earth to another, the atmosphere responds, soaking up some carbon when there is extra and giving it back when there is less. So we shouldn't be surprised that the Carbon in the atmosphere bounced around by a factor of 2 when there was so much Carbon moving in the world.



The CO_2 record over the last 50 years. CO_2 is about 30% higher than ever in the last 500.000 years.

Now none of this really caused any problems until someone realized you could mine this stuff – the fossil fuels I mean - and you could burn it. Remember burning things? Very big amongst humans. We just love it. And in the course of the last 100 years or so we have unintentionally been reversing this natural migration of limestone-based to buried-dead-animal-and-plant-based Carbon. By burning all this dead animal and plant based Carbon – what we call fossil fuels - we are sending the Carbon that was stored in the earth back into the atmosphere.

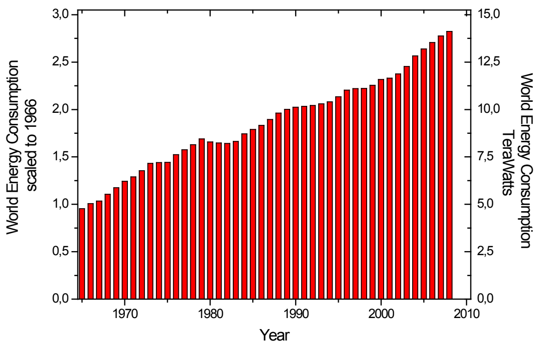
Now again no one really knows, but I suppose it is reasonable to think that if we wait long enough, the oceans will reabsorb the CO_2 and various processes will eventually turn it back to limestone. So you might not think we have a problem. We are just sending things back where they came from, aren't we? But the problem is we are doing it much, much, faster. The fossil fuels formed over ***a few hundred million years***. We are presently burning fossil fuels back to CO_2 so fast, that we might accomplish the reversal in only a few hundred years. That's a million times faster. So then we should not be too surprised if the oceans cannot absorb the CO_2 and run in reverse as fast as we need them too.

This means that there is a traffic jam of CO_2 in the atmosphere. We are just putting the CO_2 back into the atmosphere much faster than it can be taken out by natural processes. There is of course very clear evidence that this is happening. Here you can see the CO_2 in the atmosphere measured over the last 50 years. You can even see the Earth breathing with the seasons. What this traffic jam of CO_2 is going to do to the planet is still argued about. Many people are now convinced that the increased CO_2 leads directly to an increase in the Earth's temperature near its surface and in its atmosphere. The consequences of this heating are also a matter of intense discussion and we may not really know for many decades to come what the truth really is. But there is no question that we are doing a major planetary scale experiment, the outcome of which is completely unclear. And since we only have one planet it seems that most people nowadays agree that this experiment is probably a mistake and should be stopped if possible.

What are the trends in energy use?

As I said the aim of this talk is to give you some facts and background so that you can really dig into this important problem. So, it's important to understand where we have been if you want any chance to know where we could be going in the future.

In this diagram you can see the world's rate of energy consumption over the last 40 or so years. In 2008 we needed about 15 Terawatts of power for humanity. The rate of Human Energy consumption is described in terms of Terawatts (TW). If you want to know what a Terawatt is, you have to imagine all of the people of the world - and I mean every single one - going to their own private 25" color television set and simultaneously - all 8 Billion people- turning it on. And then leaving it on. Not watching in groups. Alone… separately…. Each with their own TV... That's a Terawatt rate of energy consumption. And the world needs about 15 of those going 24 hours per day, every day of the year!! In other words, if you imagine every single person on the planet turning on a 25" Color TV, then leaving the room without turning it off and going one by one to 14 more rooms and turning on 14 more 25" Color TVs and leaving them on, then you are starting to get an idea of how much energy we are using and what 15 TWatts means.



Energy consumption world-wide has tripled in the last fifty years reaching ~15 TWatts in 2010.

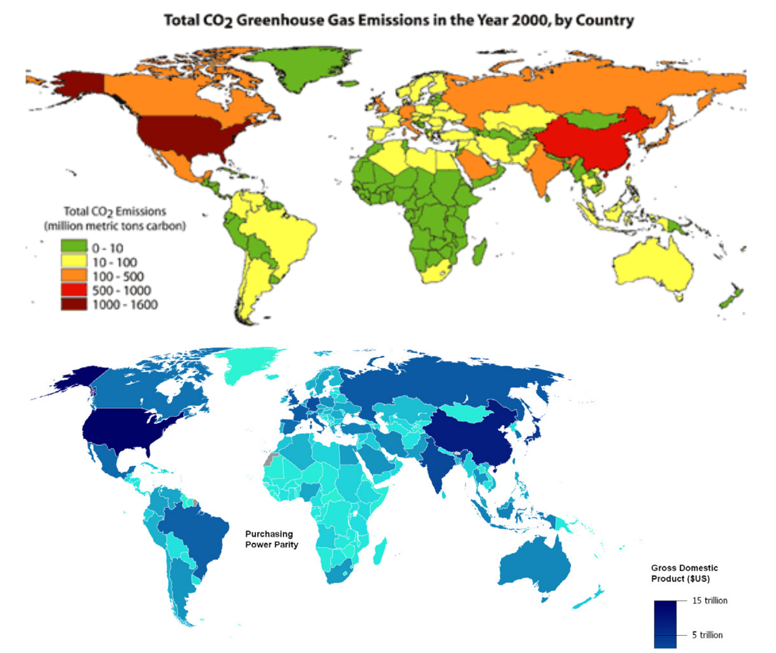
More disturbing than the large rate of energy consumption is the rate of growth of energy consumption. Between 1965 and 2008 (43 years) the rate of energy consumption about tripled. So we have to really think hard about changing our means of energy production for the future. As much as we would all like to convert to renewable energy sources and shut down Nuclear and all the rest, there is really no way to handle this problem – at least in my humble opinion – without simultaneously working to control the growth of the rate of energy consumption.

Who is using all this energy, anyway?

Of course, we know the answer to this question even before we ask it. The rich countries are the ones that have all the slaves. The developing countries are the ones that are trying to get more slaves. And the third world countries are mostly

So-called primitive cultures live closer to the 100 Watt survival level than we are accustomed to.

left on the outside looking in, hoping they won't become slaves of the apparently unquenchable energy thirst of the rest of the world.



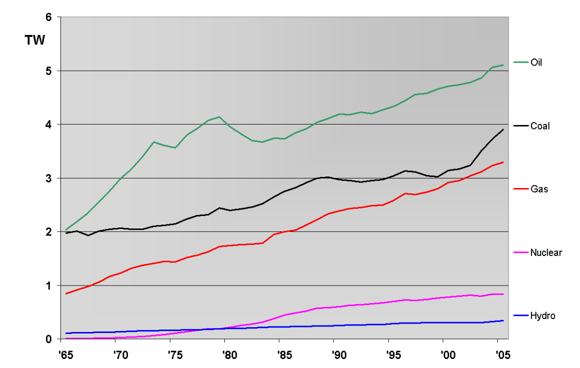
Carbon Pollution and GDP are closely correlated.

What's also quite interesting to notice is that this is not simply a population problem. So-called primitive cultures are living much closer to the 100 Watt per capita lifestyle than are we in the so-called developed countries. So, this means that energy consumption and CO_2 production doesn't simply track population. It's not just a question of how many people there are, it's a question of "What's your lifestyle".

In fact, if you compare each country's GDP to their Carbon pollution, you get a pretty good correlation. This is a really scary fact. Roughly speaking there are 300 million people in the US using 25% of the worlds energy. Meanwhile 1.3 Billion people in China and a little over a billion in India are working like crazy to recreate the AMERICAN DREAM in their own countries. Do the math. It ain't gonna work. Of course, this is a vast oversimplification. There are four billion in Asia, another billion in Africa, and 400 million in South America with similar hopes for their futures. We have all heard of the population bomb. What we should really worry about is the affluence bomb.

All Fossil Fuels are not created equal: And coal is a real threat

Now if you look at the major sources of energy that we are presently using you will immediately realize that fossil fuels make up by far the lion's share. Now it is important to understand that all fossil fuels create CO_2 when we burn them. And in that sense they are all contributing to keeping this uncertain planetary experiment going. But it is also important to understand that not all fossil fuels produce the same amount of CO_2 while providing the same amount of energy. In other words, while all fossil fuels are "bad", some are really worse than others. So when we look at the advantages of using fossil fuels and weigh them against the disadvantages we shouldn't lump them all into one category. This is actually easy to get your head around. If you are using Coal it is about twice as bad as natural gas or oil. In other words we could still produce 15 TWatts of power and dramatically reduce the CO_2 pollution, if we just stopped using coal and switch it all over to oil or natural gas.



Coal burning releases twice the carbon for the same amount of heat in comparison to methane and oil, yet it is the fastest growing source of energy production.

How much CO_2 reduction would we achieve? Well to figure this out you have to see how much CO_2 is being produced *now by burning coal. This turns out to be about 4 TWatts- in other words everyone on the planet watching four 25" color TVs simultaneously. To get 4 TWatts of power from coal, we presently produce ~500.000 Kilograms of CO_2 …wait for it... per* ***second*****. *That's four blue whales per second!!*** *Natural gas produces about half that much CO_2 while producing the same amount of energy. So should we manage for example to remove the coal and replace it by natural gas, we would reduce the CO_2 production by about two blue whales per second (250.000 Kg/Second). That's a lot of reduction. Total man-made CO_2 loading of the atmosphere is about 2.000.000 Kg/Second. So that's about a 10% reduction – without any loss of power production. Imagine if we actually start doing things more efficiently. By the way that is twice the requirements of the Kyoto protocol, which called for a 5% reduction.*

How can we cover our future needs? A hypothetical scenario.

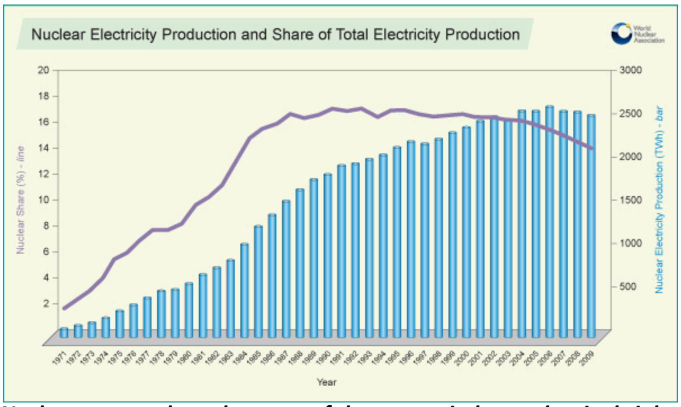
To get a clearer idea about this let's imagine a hypothetical scenario to convert the world's energy production to one of the most established forms of Carbon free energy production - nuclear power based on Uranium fission with High pressure water reactors or something of that nature. This is a good example because it is (at least hypothetically) possible. And we get to see what we are really up against in converting away from our present energy mix. Of course, we have to ignore all of the arguments against nuclear power. We have to imagine that security is no longer a problem, storage of spent fuel is not a problem, atomic weapons proliferation is not a problem. But no matter. It's just a thought experiment.

First of all we have to realize that 15 TWatts is really an enormous rate of energy consumption. Another way to think about this is that the Fukushima-I power plant reactor I (until recently) produced about 500 MWatts. To get a TeraWatt you would just need to have 2000 of these reactors. This would mean that to cover 15 TWatts, we would need about 15.000-30.000 new nuclear reactors. Well how long is it going to take us to build them? Just to give you a baseline idea, at last count there were about 500 nuclear reactors in operation worldwide. And worldwide there are about 150 new reactors on the drawing board to be built and 300 more proposed. Even people who are huge fans of nuclear power say that these are 3-5 year building projects. So if we generously say that we are presently building nuclear power plants at a rate of 150 reactors /year, we would get our 15.000 new reactors in about 100 years. These are what the numbers look like during a time the World Nuclear Association calls a Nuclear Renaissance.

And now comes the real kicker. 150 reactors per year is just not fast enough and not by a long shot. Nuclear reactors only last about 50 years before they have to be decommissioned, so we would only get about half of the reactors we need before they have to be shut down again. So you have to build twice as fast to get all the reactors you need in 100 years and four times faster (600 reactors / year) to get the reactors you need in 50 years. And then look at the energy consumption trends. The world energy consumption is growing so fast that even if you can produce 15 TWatts of Carbon neutral nuclear power 50 years from now, the world will probably then be consuming 25 TWatts or more.

And it turns out that these estimates (600 reactors per year – !!2 per day!!) are completely unrealistic because the political and economic climate is really still very anti-nuclear. People and now governments are really concerned about safety, proliferation and waste storage. If we are really thinking about 30-50 times more reactors than we have now, we have to completely revolutionize what we mean by nuclear reactor safety. Just based on past experience, you can see that in less than 50 years of nuclear power, we have had at least three major accidents. Some people say we shouldn't count Tschernobyl, because there is simply no way such a stupid design would ever be built again. So let's take two. Now imagine you want to have 50 times more rectors for the next 50 years to try to maybe cover one-half of the worlds present energy needs. Ask yourself the following. What are we going to have to do to make

Nuclear Reactors at least 50 times safer so that we will only have two major nuclear disasters in the next 50 years? Do we have any idea what that means to make a nuclear reactor 50 times safer? Now let's not just forget the spent fuels storage problem. There are 2 million pounds of spent nuclear fuel at Fukushima right now accumulated by 1% of the world's reactors operating over about 50 years. With 50 times more reactors, we are talking about 1.000.000 million pounds of nuclear waste that would be accumulated over the next 50 years.



Nuclear power: the only sector of the energy industry that is shrinking. Nuclear power's share of electricity production has been falling for 25 years and the absolute electricity production from nuclear has been falling for 5 years. This during a Nuclear renaissance.

These are big unanswered questions and we only need read the newspaper these days to see that the questions are well justified. Who is it that might be building these 15.000-30.000 reactors that we need? Is it even remotely possible that we could build 500 per year for the next 30 years even if we wanted to? The answer is no. No one is even dreaming about ramping up nuclear in any kind of magnitude like 600 new reactors per year. Quite the opposite is true. The World Nuclear Association [3]says that in 2011 there are all of 60 reactors under construction world wide – most in Asia. China has a plan to build about 50 and China is by far the most ambitious country in the world with respect to nuclear. And those plans are at least temporarily on hold thanks to Fukushima. Japan was planning to have 5 under construction this year. Not gonna happen. India is building 4 in 2011 and there are significant protest movements against the nuclear industry in India. The US, which has more nuclear reactors than any other country in the world, doesn't seem to be building any. Germany is shutting theirs down.

So, I think it is really a fair statement to make that nuclear may well be a part of the energy mix for some time to come, but it is unlikely that nuclear's net share of the energy production rate will even be maintained. This is borne out by the facts. Here you can see a plot of nuclear power production which peaked out in 2006. Think about that. We are making less electricity world-wide from Nuclear now than we did 5 years ago. I think this must be the only sector of the energy industry that is actually shrinking. Furthermore this is not a new trend. The percentage of electricity derived from nuclear peaked in 1986 and is gently falling over the last 25 years. This means nuclear is losing out to economically more competitive forms of electricity production. And take a wild guess what that is. The oldest, dirtiest, form of all. BIG BAD COAL.

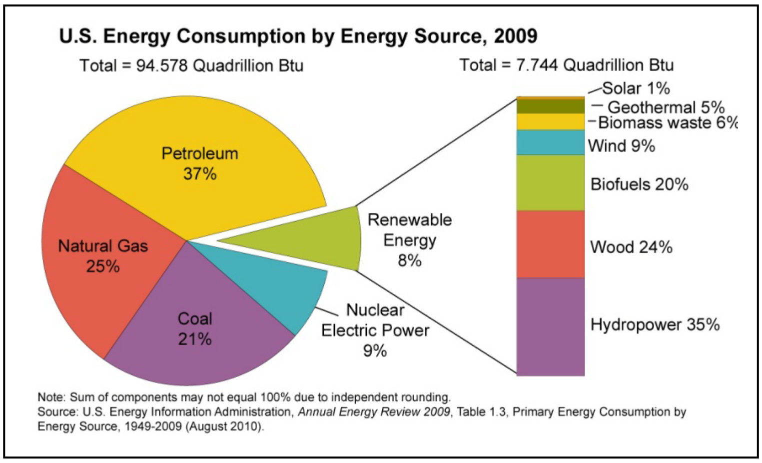
Honestly, it is extremely unlikely that this trend will reverse in light of Fukushima and consequently it is not foreseeable that nuclear is going to be a major part of the solution. The nuclear age came and went. Economically people were giving up on it for a long time before Fukushima. Fukushima just put the lights out after the party was already over.

And ultimately it will probably be politically impossible to have Nuclear at all. So, for example in Germany it is now pretty much a consensus opinion to get rid of nuclear. But we have to think about this responsibly. We have to think about what we are sacrificing in giving up Nuclear. Well for all its faults nuclear does not produce CO_2. So if we give up 1 TWatt of nuclear we have to think how we will replace it without producing lots more CO_2.

Renewables: which ones make sense?

*Well of course, we can make wind and geothermal and bio-fuels and all the renewables and that all sounds wonderful. But 1 TWatt is a lot of energy. Remember all the renewable energy we have now is about the same as all the nuclear. So that doesn't sound so bad. All we have to do is double the renewable and we can phase out nuclear. Right? **It's not that easy**. You can see that about 60% of all the renewables presently in use (for example in the US and it's not much different in Germany) is in the form of wood burning and hydroelectric. While incremental improvements can be made on this we cannot double renewable by cutting down twice as much forest? Quite the opposite, we need to find a way to move a few hundred GTons of carbon from the atmosphere to the biosphere by replanting our forests on a scale that has never been attempted before in order to help relieve the traffic jam of CO_2 that we presently have in the atmosphere. Hydroelectric is not going to help us much either. It turns out pretty much every place the world has to offer where a good dam can be built has already been used. Biofuels also have their own problems because you have to spend energy (think tractors running on diesel and big factories churning out fertilizer) before you can get it. So that appears at the moment to be a bit of a wash.*

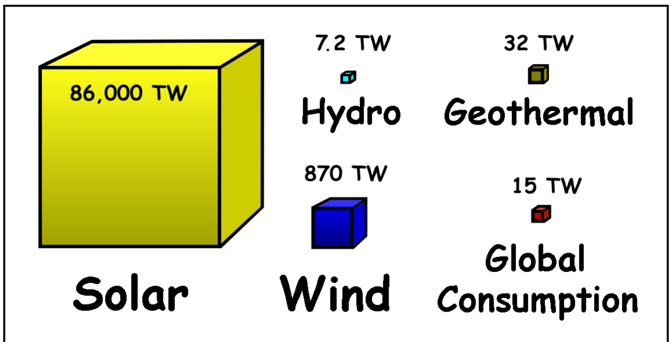
When it comes to renewable and what can be expanded, the real answers are: Wind, geothermal and solar including solar thermal. This picture shows the amount of energy available from various sources in comparison to global consumption. All of these sources have the potential to provide energy at a rate that dwarves present energy consumption.



But these now make up a grand total of 15% of the renewables. That's 15% of 8%- So we are talking about 1% of the total. We need about a factor 10 growth in these forms of energy production just to cover our desire to turn off nuclear.

Then we need a factor of 10 growth beyond that to get to cover the present energy needs or about 15 TWatt. That's 100x growth. Can we do that in 50 years? I am convinced that it is possible but it will require real effort. And don't forget that in 50 years we may well use energy faster to the tune of 10-15 TWatts in comparison to today. So, then we could maybe shoot to have 50% carbon neutral renewable with such a fast expansion.

So a possible scenario might be to shoot for 15 TWatts from wind, solar and geothermal and get the remaining power we need from natural gas, which burdens the atmosphere a factor two less than coal. Remember coal is the enemy. Then we have to try to get consumption under control especially when it comes to electricity and transportation. But I am coming to that. So, I think you will by now certainly see that it is really not a small problem.



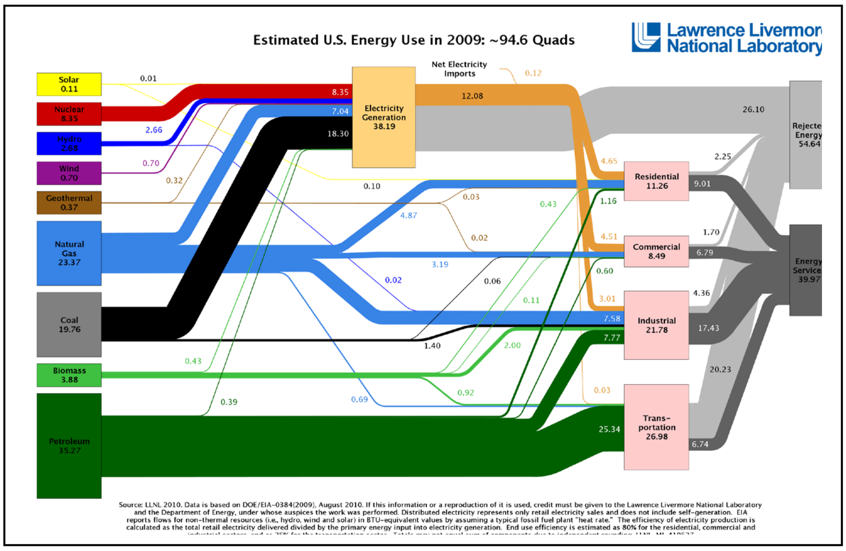
Where are the big energy reserves? Solar, Wind, Geothermal have potential to be dramatically expanded.

Now, before you go out and start shopping for your next 15 TV sets *to continue the human tradition of wasting energy like crazy. It won't be easy. All of these energy sources have their problems. And any restructuring of the energy world on the TWatt scale will cost a lot of money and require a lot of cleverness. Probably more than anything else it will require a lot of political cleverness and cooperation between many countries.*

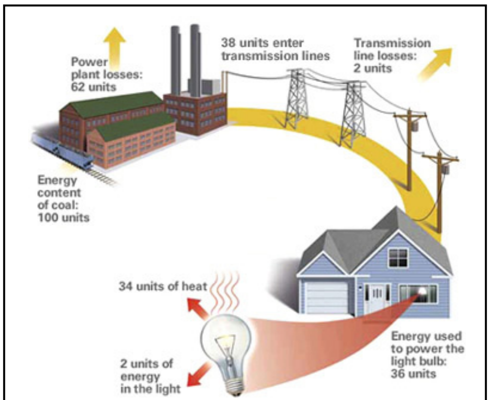
So, to review we have looked at world that has a rate of energy consumption increasing by about 10 TWatts every 40 years. We need to undertake a massive restructuring of energy production to deal with global warming and that won't happen overnight. Fifty years might be enough time to make a big impact on this. In the meantime we have to see that we make the best of what we already have. We have to analyze how we are doing things with our present resources and see if we have any short term options. And that brings me to the next really important topic.

Efficiency: A revolution waiting to happen

I hope we have learned enough in the course of this discussion to now know that we will need 50 years of hard and clever work to solve this problem and it will require a level of international cooperation that is unprecedented. So, if we are really smart and work hard in 50 years things can look really different. And by different I think it is realistic that we might have 10-15 TWatts from real renewable forms of energy and another 5-10 TWatts from natural gas. If things go well we won't be using coal anymore at all and the liquid petroleum will have run out. Of course at the heart of our energy future is how well we use the energy we have. And that requires a look at how we are using it now.



The energy flow map shown here is for the US in 2009 and gives a clear picture of how we presently waste energy. You don't have to really understand everything here and there is a lot of information in this chart. But basically, on the left hand side you see all the primary energy sources for the US in 2009 and on the right hand side you see what we did with it. There are some remarkably simple things worth noticing here. First of all, the US consumed 95 Quads of energy. You don't really need to know what a Quad is (Quadrillion BTU is about 10^{15} kJoule). Of those 95 Quads, 55 Quads was "rejected energy". Rejected Energy? I wonder if its feelings were hurt? Why don't we call it what it really is – WASTE. Lost opportunity. It becomes even more interesting if you look where all this waste is taking place. It happens primarily in two places: electricity production and transportation fuels. For these two human activities huge inefficiencies are simply "normal." How can that be? It's very simple actually and here is an example to show you really how this works. Boiling it down, a lot of energy went up the smokestack.



Big Opportunities for improved efficiency.

Look at this cartoon of how the incandescent light bulb in your home works – or if you live in Europe used to work. Now they are illegal. The purpose of a light bulb is to light your house. For that you need a certain amount of energy in the form of light. With an incandescent light bulb we get that light energy by heating up a tungsten wire – that is heat energy is converted to light energy – you are acquainted with the idea of really hot objects glowing red and even hotter objects glowing white. That's heat energy being converted to light energy. And the hotter things are, the more light energy comes out of them. Now an incandescent light bulb makes the tungsten wire hot by passing electricity through it. This works because whenever you pass electricity through an object – so long as it is not a superconductor – it produces heat. So, old fashioned incandescent light bulbs use electricity to produce the heat which produces the light. Now how did we get the electricity? We burned coal to make heat!!! So, think about it. We burn coal to make heat so that we can turn it into electricity. Then we use the electricity to make heat so we can turn it into light. Seems pretty complicated doesn't it. Well it is. And it is also really wasteful. Typical coal fired power plant produce electrical energy with about 35% efficiency. So for 100 units of heat energy produced by burning coal, you get 35 units of electrical energy. Then you lose a couple of units because some electricity ends up heating the cables that carry the electricity to you house. Once the electricity arrives at your house you use it heat your tungsten and as a side product get some light. Well the heat energy from the light bulb is about 20 times more than the light energy. So putting it all together you get 2 units of light energy (what you really want) from 100 units of heat energy produced by burning coal. Boy is that BAD.

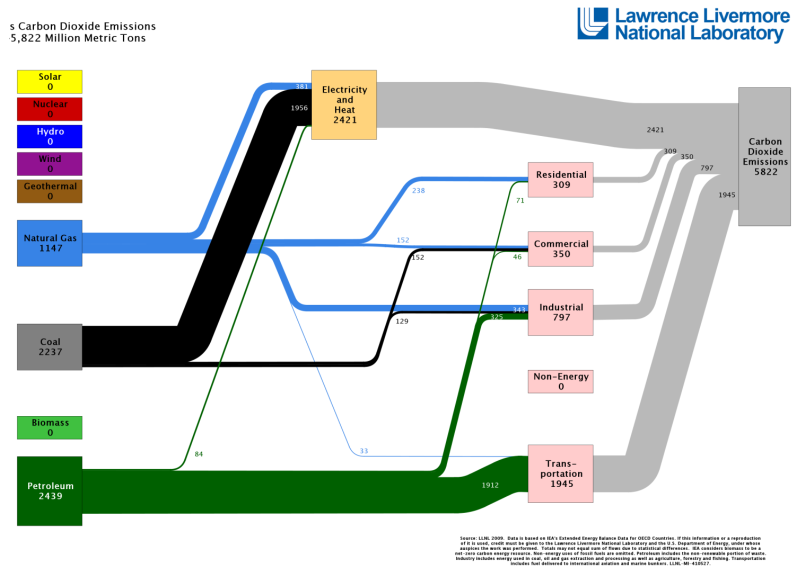
Now I don't want to get into the argument about whether outlawing incandescent light bulbs is good or bad, but this example shows you an important principle. When you convert energy from one form to another, you never do it with 100% efficiency. So, these issues of energy form conversion efficiency become really important technical questions where there are enormous opportunities for improvements.

The "rejected energy" from transportation is a similar problem. Here you are also usually burning something (usually liquid petroleum fuels) and you are using the heat from the burning to drive a piston and convert the heat energy into mechanical energy of motion. This energy conversion efficiency is also limited. In fact these limits are not just because engineers are too stupid to do it better. Quite the contrary, today's engineers are very aware of energy efficiency and are constantly thinking of ways to improve these things. It's important to realize however, that when it comes to heat engines, there is an important limit set by nature as to how efficiently you can convert heat energy into mechanical energy. It depends on a lot of things, but most fundamentally it depends on the temperature. At temperatures we are used to working with, 35% is pretty close to the limit set by the natural laws.

Of course, for transportation there are a lot of efficiency opportunities besides the engine design. If you drive your car, the actual service you would like to have is to have your @ 100 kg body transported from point a to point b. But on average each of us does that by bringing along about 2000 kg of metal and plastic. So making cars lighter obviously helps. Wind resistance and lost energy due to braking are the other big issues. These problems are actually solved. The 1 Liter auto is a reality. Imagine driving Coast-to-coast in the USA on one tank of gas. It can be done. It has been done. Google "Hypercars" and "hypermiling" when you have some time to kill.

So there is a fundamental efficiency problem when we talk about heat engines which turn heat energy to energy of motion or to electrical energy. And at least based on our present heat engine technology, this means an energy conversion efficiency of about 35%. The other 65% goes up the smoke stack or out the tail pipe of your car in the form of heat.

Now this really matters for the Carbon traffic jam we have in the atmosphere. Since we are basically relying on heat engines that use fossil fuels, we are locked into a technology that is fundamentally about 35% efficient and the rejected energy is heat produced by burning Carbon which produces CO_2. So if you look at a Carbon flow map which is very similar to the energy flow map I just showed you, you won't be surprised to see that it is electricity production and transportation which are most responsible for burning CO_2 back into the atmosphere. Here is where we have the most lost energy and all the lost energy was mainly created by burning fossil fuels.



Carbon flow in the US in 2009. Carbon loading to the atmosphere is strongly associated with electricity generation and transportation, the main places we use heat engines to produce mechanical and electrical energy.

So for global warming it is really important to think about how we behave with respect to electricity production and with respect to transportation.

But these problems are not ridiculous ones. We have now the technology to run 1 L automobiles; that's about a factor of five improvements over what we actually use. We have the technology to produce electricity from wind and solar thermal and geothermal and while we are making a transition natural gas. So even without nuclear we can make big improvements both in how we produce energy and how we use it. So there is no question that we are in a position to take a big bite out of CO_2 pollution.

So let's collect all of the tidbits we've touched on and sum them up to see what the ingredients to the solution of the energy problem might look like. Over the next 50 years, we need a 100x growth in Solar/Wind/Geo to produce about 15 TWatts. We need to make up the difference with Natural Gas that will probably become the most important transportation fuel. We need major improvement in energy consumption habits especially as they relate to electricity and transportation. We don't really have to worry about liquid fuels since they will run out over the next 50 years. We need a major effort to reforest the planet. Doubling the earth's forests – which means going from 80% deforested to 60% deforested - would remove 100's of GTons of Carbon from the atmosphere. Finally we need an international enforceable treaty outlawing Coal similar to what was done with CFC's.

What is our concept of sustainability?

In today's world this word – sustainable – no longer has any meaning. Culturally we have kept this word in the language only as a matter of convenience, that is to say it can still be used in sentences in combination with the word "not". If you don't believe me when I say how short term our cultural perspective is, consider some other cultures. For example, the Iroquois nation – the real Americans – established principles of democracy in the so-called Great law of Peace in 1720. This was the written culmination of a democratic league of Indian nations that began 200 to 300 years earlier. Part of the Iroquois thinking was to base decisions on what would benefit the 7th generation into the future. That's a couple of hundred year's perspective. This is nowadays in our western culture – to say the least – a minority view point. There are remnants of this thinking in our culture. We all agree in principle that the welfare of children – usually this means my children and not necessarily your children – is important and modern politicians can be successful with such ideas. But, the concept of looking seven generations into the future is for all intents and purposes lost from our consciousness.

The Iroquois considered the interests of the 7th generation. Perhaps, we can learn something from them about the politics of sustainability.

The energy crisis if it can be called that is something that requires 50 years of real cooperation amongst peoples of many nations. But our election cycle thinking is 10 times shorter than that. Some of the really big problems we need to think very hard about are political ones that have to do with how we imagine decisions that reach just 50 years into the future. Perhaps the Iroquois have something to teach us.

Are Eco-freaks protecting the planet?

The declaration "save the planet" seems to have originated in the late 20th century with the rise of the environmental movement. Variations abound, one of the most well known being "save the whales". While these utterances are primarily political in nature they do shape our thinking and we must think carefully about the rational value of such ideas. At the risk of diminishing the importance of preventing the over fishing of whales, I always liked the slogan "save the humans". And there is a very simple reason for this. The planet doesn't need saving. The humans need saving. Seen as a holistic ecological system, the planet is not at risk. The planet will go on and it will have life and sun and rain and snow and glaciers and mountains and earthquakes and everything else that make the Earth the Earth. With one exception, it might not have humans. Or if there are any humans they will have relearned how to live near the 100 Watt survival level.

The planet doesn't need saving. The humans do.

The Earth has been around an awfully long time. Humans just a blink of an Earthly eye. As soon as we are so foolish as to catastrophically eliminate our potential to survive on this planet, the Earth will yawn and say "So what". Once humans are gone it might take a few thousand years before all trace of human civilization is erased. And in that time the Earth will manage to get back to its healthy condition. Reforestation might take 500 years and in that time the 500 GTons of excess carbon we now have in the atmosphere will be tied up again in trees. So that is really a small problem for such an amazing planet as the Earth. We should not delude ourselves about being altruistic for the sake of the Earth. It is a simple matter of long term survival of humans. We should not lose track of that fact.

Collapse of civilizations has happened before many, many, times in the history of the world. And it appears one symptom of collapse is that the afflicted civilizations never saw it coming. The Easter Island Collapse is one of the most instructive. What started as a rich and successful society which fished Marlins and other large game fish from the sea for feasting ended with people eating rats they caught in their garbage piles as the last remaining source of protein on the island. The pattern is simple. A successful society always expands. More success… more people… more people… more success. But the ever increasing load of a successful civilization on its environment and on its basic material resources – especially on an island – eventually reaches a limit. And then, very quickly, from one harvest season to the next, something changes. For the Easter islanders it was the fact that they had completely deforested the island for agriculture speeding up soil erosion, which led to the near complete loss of their farm land and food supply. When environmental limits are nearly reached, there might still be time to react. Reforesting Easter Island would have been possible and other Island cultures facing similar problems did not die out because they did react. The question then becomes can the previously successful civilization change.

The Easter Islanders may have collapsed due to a lack of imagination. They could not imagine that their civilization might fail.

Now it turns out the Easter Islanders couldn't. They were probably like many successful civilizations that simply couldn't believe they could ever fail in a fundamental way. After all, they had been so successful for so long… Maybe they even thought that it was a kind of a law of nature (God's chosen people) that they should always do well.

They never saw it coming.

Now our island is reaching some of its environmental limits. We need not be as short sighted as the Easter Islanders. Indeed science allows us to think in amazingly clear ways about how things could go. And it certainly cannot be as big a danger for us that "we won't see it coming".

Endnotes

[1] An interesting evolutionary question is what will happen if there is a real energy crisis, where societies adept at energy efficiency are at an evolutionary advantage. In that case, one might speculate that the 100 Watt per person societies might slowly come to dominate as they did only a few thousands of years ago.

[2] If one assumes that every O_2 molecule in the atmpshere resulted from photosysnthesis, one can calcuate that the entire reduced carbon that is somewhere to be found and might loosly be referred to as a fossil fuel is on the order of 500.000 GT

[3] This is a fascinating web page to look at now in the wake of Fukushima.