The Game Plan.

A solution framework for the climate challenge.

Many contributors and thanks.

Many people are to thank for this document. Most of them I have never communicated with personally. Many of them lived long before me. Those people are all of the scientists, philosophers, artists, writers, videographers and engineers who have contributed to an understanding of the issues both technical, social, and environmental that pertain to the challenge of climate change.

Some explicit thankyous should go to a shorter list of people. To Wes Hermann for his important work at GCEP (Stanford) in quantifying global exergy flows.

To David J C Mackay who is writing a book with similar themes called "Without Hot Air" who appears to be the rare but important combination of good scientist and good communicator. After an invitation to meet with him we had to mutually agree that videoconferencing is the only conscionable way.

To all of my colleagues at Makani Power for their great feedback on this talk, and their tireless efforts to produce more ways of making carbon free energy.

To Google for their efforts in promoting clean energy sources.

To OReilly publishing company for the many oportunities they have given me to communicate these messages publicly.

Most importantly I need to call out Kirk Von Rohr and Dan Benoit who worked tirelessly to put together the graphics to communicate this story. I frequently realised throughout the production of this material that industrial design and graphic design will be incredibly important in our ultimate solutions. Quality design will never be un-important.

And of course to Jim McBride, a wonderfully irreverant and mischievous co-author of this document who epitomizes a classics education of a broad outlook enabled by strong readings in English, philosophy, mathematics, politics, and physics.

Resources

I was reading many books while preparing this document. Undoubtedly many of their ideas have flowed into this text. My philosophy is that this story needs to be told many different ways by many different people and we cannot have to much retelling and analysis of the challenge. My apologies to other authors who might feel their dominion intruded upon. I'll do my best to acknowledge all sources.

Saul Griffith Energy Literacy and climate change.

"If a path to the better there be, it begins with a full look at the worst." — Thomas Hardy

Special thanks to:
Jim McBride
Kirk Von Rohr
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Andrea Dunlap
David J C MacKay
Corwin Hardham
Emily Leslie
Wes Hermann
Makani Power

This is an old story, hopefully told in a new way.

Al Gore's documentary "An inconvenient truth" reached many people but his is just the most recent telling of a story that has been told many times before. At the peak of the energy crisis in the 1970's, Amory Lovins wrote a book called "Energy Strategies" that largely outlined the problem we have today.
In the 1950s Buckminster Fuller wrote many similar treatises on the dangers of over-consumption of energy and materials and its effects on the earth's ecosystems. At the turn of last century, Henry Thoreau wrote a beautiful book about simple living in the woods of Massachusetts as an antidote to the destructive lifestyle of modern living he perceived at that time. Walden has sold many copies and inspired the modern conservation movements. Muir and Carson should be attributed for their contributions also.
2 millenia ago, in his book "Critias", Plato wrote about the demise of the forests:
"What now remains compared with what then existed is like the skeleton of a sick man, all fat and soft earth having wasted away, and only the bare framework of the land being left...there are some mountains which have nothing but food for bees, but they had trees not very long ago, and the rafters from those felled there to roof the largest buildings are still sound."
There are many more books and speeches and documents beside these that are available today to further discuss humanity's influence on the environment.
Except for the fact that we now have better information thanks to the concerted efforts of modern science and the many tireless individuals that study the effects of humans on the environment, this document isn't telling you a story much different to the stories told by the individuals above, and many other visionaries besides. The principal difference here is that I've approached telling this story as an engineer would approach a challenge. "Tell me what I have to do and I'll make it work" might well be the call cry of engineers. This document is thus set out as a resource and an open document for other people to critique and improve until we can specify the task for engineers. Once we know what we have to do, we will certainly do it.

Resources

Energy Strategies : Amory Lovins.
www.rmi.org/images/PDFs/Energy/E77-01_TheRoadNotTaken.pdf
Winning the oil end game : amory lovins http://www.oilendgame.com/
Critical Path : Buckminster Fuller
http://bfi.easystorecreator.com/
http://bfi.org
http://www.imdb.com/title/tt0439521/
Walden : Henry Thoreau
http://thoreau.eserver.org/walden00.html
http://www.online-literature.com/thoreau/walden/

Critias : Plato http://classics.mit.edu/Plato/critias.html

Koyanasqaatsi : http://www.imdb.com/title/tt0085809/
Powaqqatsi : http://www.imdb.com/title/tt0095895/
Naqoyqatsi : http://www.imdb.com/title/tt0145937/
An inconvenient truth (DVD & webste)
http://www.climatecrisis.net/
http://www.imdb.com/title/tt0497116/

The revenge of Gaia, James Lovelock
http://en.wikipedia.org/wiki/The_Revenge_of_Gaia
http://en.wikipedia.org/wiki/James_Lovelock
http://www.ecolo.org/lovelock/

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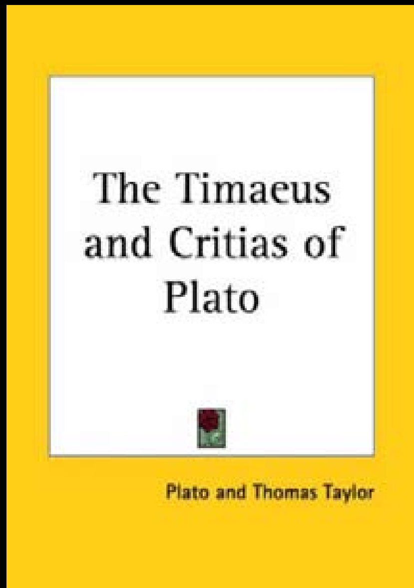

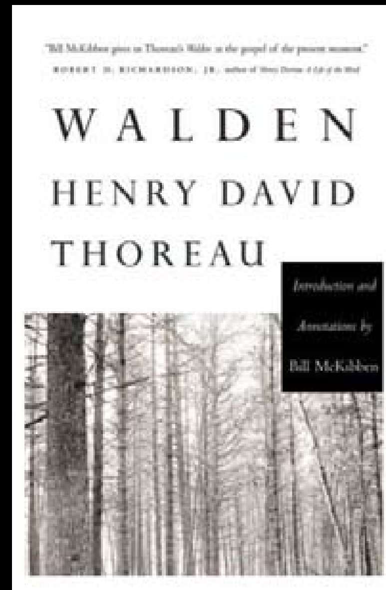

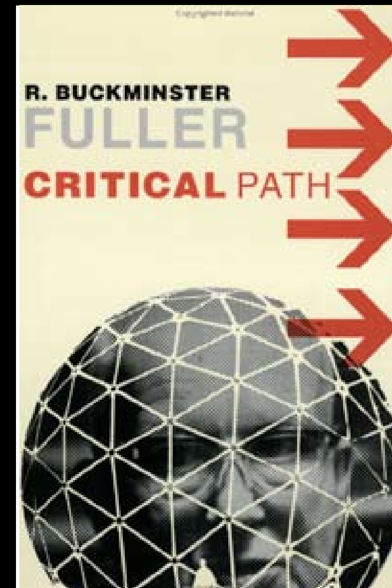

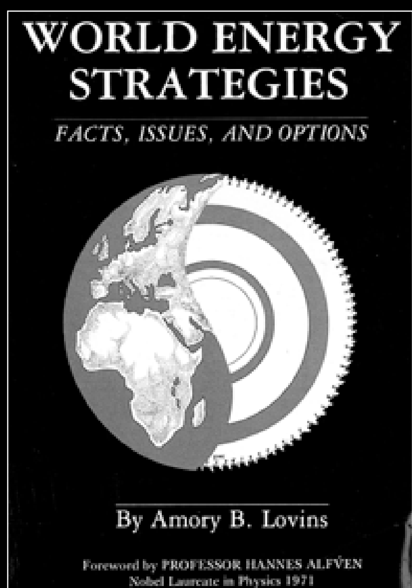

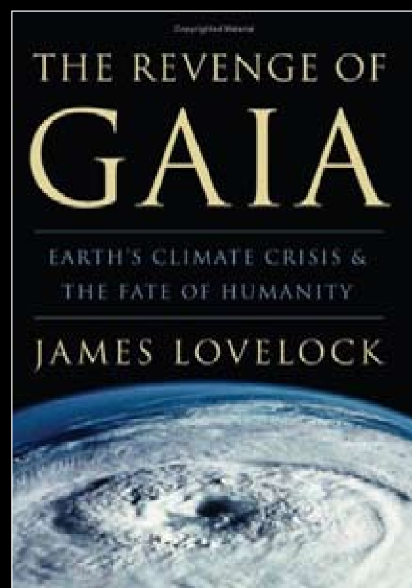

The big and the small of it.

This document started out as a very cold and impersonal look at the physics, and the thermodynamics of Earth's energy systems. It was clearly apparent that while audiences enjoyed that conversation and it provided valuable perspective, the numbers were too large, and the issues so impersonal, that it was difficult to understand the implications.

In an effort to remedy that this document now has two stories intertwined: The larger, global energy picture, and the more personal energy accounting for all of earth's individuals. The larger story is about very big numbers and very big implications. The personal story is about each of us living and working in this shared planet, and the cumulative effects that each of our lives make.

I remember first watching Al Gore give a tremendous, and important, presentation at a conference with his climate change talk. The immediate questions from that audience were "How does this effect me?" and "What can I do to make a difference?".

A few years later the answers to these questions ended up in the credits of his documentary "An Inconvenient Truth". Because the answers to those questions are the only way we as individuals can understand our global challenge, we have tried to bring them into the center of this conversation rather than the appendix. This isn't meant as a gross criticism of Gore, just that I personally want a deeper understanding of the consequences, and to know what to do.

Without doubt, the only way to move forward is to know what the target is, know how to measure progress towards that target, and have the data and information to make good personal decisions as well as good global decisions.

Resources

Two very good books on large scale challenges humanity has faced and conquered before are "The making of the atomic bomb - Richard Rhodes" and "choose an apollo book"
http://www.apolloarchive.com/
http://www.richardrhodes.com/
BBC's documentary on the space race is another great piece of media on big challenges and how they are solved. http://www.imdb.com/title/tt0461887/
WWII Home Front Efforts
http://en.wikipedia.org/wiki/United_States_home_front_during_World_War_II
http://www.historyonthenet.com/WW2/home_front.htm
http://americanhistory.si.edu/victory/

Disney's propaganda:
http://www.amazon.com/gp/product/0835713105/qid=1150917204/sr=1-1/ref=sr_1_1?s=books&v=glance
http://en.wikipedia.org/wiki/Walt_Disney's_Production_of_Propaganda_for_the_US_Government_During_World_War_II

The big and the small of it

There are two intertwined stories here key to an understanding of the energy challenge.

The first is the **impersonal story** told in very big numbers **about climate change, global energy consumption, and fossil fuels.**

The second is the **personal story** about how **every decision you make** in your life **impacts everyone you share the planet with**, and just how big the scale of the energy challenge is.

A logical framework for solving the climate challenge : Step 1.

In laying out the logic of this document we hope to give you the tools to rebuild this story as it relates to you. If you disagree with any specific assumption or piece of information, you have the approach outlined here to return to. If you believe global warming isn't happening at all, this logic is still valid for you. You will merely conclude that nothing needs to be done immediately, and you will walk away with a greater understanding of your own energy consumption, ways to save money, and ways to increase the security of energy supplies as fossil fuel supplies slowly dwindle.

If you believe that we should return to pre-industrial levels of CO_2 this story is still valid - you will reach more drastic conclusions about the urgency of action, and the things we must start to do.

The real point here is that this is an approach which really lays out climate change for what it is. A collective choice for humanity. A choice that determines the aesthetics of our future planet, the way we live, breathe, work, eat, and play

The first step in the problem is understanding the relationship between greenhouse gases (principally CO_2) and climate change. This is very well studied and the IPCC has been at the forefront of collecting and vetting this information for humanity.

The other goal of laying out the logic this simply is to push the conversation forward for climate change. It is going to have to come down to a choice, where we set a real goal - not a diluted percentage of industrial output goal like the Kyoto goal - but a global CO_2 concentration and emissions goal and consequent clean energy production goals. People will do what they need to do once they have a goal in place. We all love challenges.

Resources

Intergovernmental Panel on Climate Change : http://www.ipcc.ch/

http://en.wikipedia.org/wiki/Carbon_dioxide

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

http://www.gcrio.org/ipcc/ar4/wg1/faq/ar4wg1_FAQs_Full.pdf

A logical approach to a conversation about energy:

Step 1 CO_2 = Climate
Understand the link between CO_2 concentration and climate change. Understand the models, their predictive power, their accuracy.

Step 2 Temperature Choice
Choose the temperature at which you would like to stabilize the earth. Acknowledge the implications of your choice.

Step 3 Allowable Carbon
Determine from your choice of climate change the amount of carbon you are allowed to release into the atmosphere annually.

Step 4 Useable Fossil Energy
Determine from the amount of carbon you can release to the atmosphere the amount of energy available to us from fossil fuels and carbon emitting sources and therefore what "new clean power component" we need to generate.

Step 5 Clean Energy Sources
Analyse from what sources we can possibly make "the clean power component"

Step 6 New Energy Mix
Choose a mix of technologies to make "the clean power component" and estimate the industrial and engineering effort to meet the challenge.

A logical framework for solving the climate challenge: Step 2.

As we increase CO2 concentrations in the atmosphere, the temperature rises. By halting or reversing the rate at which we emit CO2 to the atmosphere we are in effect choosing the CO2 concentration that the atmosphere will eventually stabilize at. This concentration determines the temperature that the world will stabilize at.
The idea is that once you have an understanding of the relationship between CO_2 and temperature (with all of its uncertainties) you can make a choice of what temperature you would like to live at, and what effects that has on the environment. This is a choice that nobody seems to want to make. No-one wants to be wrong. No government wants to say "3 degrees more heat is OK", and then find out that it isn't. It's hard not to conclude that the safe and sane choice is the conservative one. Act now, and if we over-estimated the threats and consequences then the next generations can change our estimates and resource use because they will know more than we do now.

Step 2: Choosing a global temperature target.
This choice of temperature is obviously going to be the most difficult choice humanity has ever made.

Resources
http://dotearth.blogs.nytimes.com/2007/11/11/more-heat-on-ways-to-lower-the-thermostat/

The first time I publicly gave this talk it was at a technology conference for the programmer / hacker community. The temptation was to say that "Earth's climate is humanity's operating system" and that "what temperature we choose determines what functional calls we have, how stable the platform is, and what chances there are that we crash the OS and have to reboot". That mightn't be the best metaphor for general audiences, but the point of bringing it up here is we need to find the metaphors for every audience. Everyone needs to develop an intuition for what this means to us all.

One principal reason the temperature choice will be difficult is that at different teperatures you have a different set of winners and losers. This is probably only true for small temperature changes where the argument is about how this wine producing region increased in productivity while this rainforest dries out. At larger temperature changes, like those beyond +2 degrees celsius, I think there is a compelling argument that noone wins. The world changes so much and the struggle for resources for survival will become so great, that no-one can hide, and no-one wins.

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A logical framework for solving the climate challenge: Step 3.

Having chosen a temperature, we can infer what CO_2 concentration we should aim at for creating equilibrium on the planet. This is a number measured in parts per million (ppm) of CO_2. This talk largely ignores the other green-house gases of CH_4 and NO_2, methane and nitrous oxide respectively. Methane is produced in large quantities by our livestock (sheep and cows in particular) and our landfills, as well as natural sources. Nitrous oxide is a by-product of our nitrogenous fertilizers for agriculture and produced in air travel through the jet-fuel combustion process. The concentrations of these gases is sometimes measured as CO_2 equivalent. Methane per molecule is a 21 times more absorbing greenhouse molecule than CO_2. Nitrous oxide is even worse, with an effect 310 times that of CO_2. Obviously we need to address all of the molecules that contribute to climate change, and work to reduce the concentrations of all of them. This conversation will however focus just on CO_2. We need to also reduce methane and nitrous oxide emissions, but I'm assuming that if we develop the awareness of climate implied by this document, that will happen in parallel to our focus on the largest contributor, CO_2.

Carbon has an atomic weight of 12. Oxygen has an atomic weight of 16. Each time you combust, or burn, a carbon molecule, it is oxidised to become CO_2. Some people measure carbon input into the atmosphere in terms of C, others in terms of CO_2. To convert between these values multiple Carbon by 3.67, or divide CO_2 by 3.67.

$C : CO_2 = 12 : (12 + 16 + 16) = 44$ hence $44/12 = 3.67$.

Resources

http://en.wikipedia.org/wiki/Carbon_dioxide_equivalent
http://en.wikipedia.org/wiki/Avoiding_Dangerous_Climate_Change

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A logical framework for solving the climate challenge: Step 4.

Knowing the concentration we wish to stabilise at, we know how much power we can make burning carbon based fuels, over what time frame we need to reduce it, and to what ultimate value. This is an extremely important number to determine because it sets us our target of how much non-carbon power we will need to produce to support the lifestyles we want to live.

With these choices and their consequences, we can now understand the grand challenge of renewable (or non-carbon emitting) energy, or indeed whether it is a challenge at all.

My personal interpretation of the information laid out here is that this is the biggest engineering challenge ever faced by mankind. That barely implies that it is also the biggest social, economic and political challenge in history!. I personally would conclude that you should support a concerted effort to meet this challenge in every way possible whilst also learning to live your personal life in healthier and happier ways.

Every choice you make is important here: your choice of how much climate change you can tolerate; your choice of lifestyle and the power generation it implies.

Resources

http://bioenergy.ornl.gov/papers/misc/energy_conv.html

The other intent of laying out this logical framework and making this an open document is that this story needs to be told in different ways by different people in order to tell the story as far and wide as possible. The wisdom of many eyes on this document interpreting it in better ways will surely help humanity face and conquer this challenge. - This is after all about our collective choice, not the choice of any single player in the game. The coal companies get their vote, the environmentalists get their vote, middle Americans get their vote, Indian peasants get their vote. It's everyone's climate. Thats what we have to realise. It's everyone's climate. It's everyone's choice.

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A logical framework for solving the climate challenge: Step 5.

This step allows us to know where all of the earth's energy resources are, how they can be tapped, and what we can expect of each of them. Even which secondary effects each of those choices might have: how much land area we devote to this or that, or what ecosystem effects solar panels and wind farms have. The important thing here is to know what the possibilities are and to inform wise investment choices in the potential of each one.

Resources
http://gcep.stanford.edu/
http://gcep.stanford.edu/research/exergycharts.html - this is an excellent chart of energy (or exergy) flows in earth's system.

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If this really is a problem, what is the challenge?: Step 6.

Finally we get to the really fun part. This is where the challenge turns to engineering. This is where we get our hands dirty, put our shoulders to the grindstone, and solve the problem. Pick your new energy mix, how much wind, how much solar, how much coal, how much gas, how much petroleum, how much nuclear, how much wave, how much tidal, how much geothermal. Once picked we are only a bunch of good new jobs and fulfilling work-days away from meeting our challenge.

"The sun pays all the bills"
 - Kim Stanley Robinson.

Resources
http://en.wikipedia.org/wiki/Kim_Stanley_Robinson

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The personal side of the story: Step 1.

No one is exactly like anyone else. That's part of why it is fun to be human. We all live in different ways. How we live determines the impact we each have on the environment. In recent times this has led to a public conversation about "Carbon Footprint". I personally prefer to think about it as your own personal power requirement. Carbon and power are like the chicken and the egg. It is hard to figure out which came first and which one we should think in.

I am definitely unusual. As I write this I am a 34 year old scientist, inventor, and entrepreneur living in California. I have my own company that is trying to invent new ways of harnessing renewable power sources. I live in 'the Mission', a small yet colorful district in the city of San Francisco. I rent a small stand-alone house with two bedrooms that I share with my partner. I fly a lot, both for business and pleasure, and generally those trips are combined. I don't drive very much, and when I do it is mostly in a very efficient Hybrid, or a reasonably efficient vintage VW beetle. I am an omnivore - I eat meat - regularly. I try to commute by bicycle and public ferry most days. I like to think of myself as environmentally aware and as motivated to building a better future for the planet. In spite of all these things, preparing this document has shown me that I am a major part of the energy problem. I don't buy as many things as most other people, but the things I do buy (like laptops and cell phones) are particular energy intensive products.

I have a strong background in mathematics and physics and engineering and a PhD from MIT to show for it. Even with that I find it very difficult to calculate my own ecological footprint to the accuracy I would like, and during the analysis I found myself repeatedly stumbled for lack of information. I am sure it is hard for everyone. I have every modern resource available and I still find this whole issue extremely challenging to understand and deal with.

By calculating in detail my own energy consumption I hope to make more people aware of their own personal environmental impacts. I hope also to induce an improvement in the reporting of personal environmental impact by the companies that provide us with our material goods.

Resources

www.saulgriffith.com
www.makanipower.com
www.howtoons.com
www.squid-labs.com

The personal side of the story: where does your energy go?.

Step 1 My Lifestyle
Calculate my own current energy consumption as a result of my lifestyle.

Step 2 Carbon Calculators
Compare to other people's "Carbon Calculators"

Step 3 My Share & Energy Demographics
Make it personal: give everyone an equal share of the current total energy resource. Compare my equal share to world's current demographics.

Step 4 My New Life
Re Evaluate my own personal footprint to see what impact an equal share would have on my lifestyle.

The personal side of the story: Step 2.

By now nearly everyone is aware of the concept of a "Carbon Calculator". There are many freely available on the web. Critiques of the system already get air-time in the press. I will compare a large set of them here to see how they compare using the same data I used myself. The bad news : the results are more variable than they are accurate. Why would I want to show this? If these are going to be the principle tools for the average person to figure out their progress in helping the world, then let's make them precise, and accurate. As all engineers know (and athletes!), you can only improve if you measure well and if you have benchmarks.

Resources
http://www.lowcarbonlife.net/

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The personal side of the story: Step 3.

It's worth here looking at the demographics of humanity's energy use, and the way our collective behaviour is the contributor. I include this quick study of demographics not to point the finger at any country in particular, but to put things in perspective, to help plan the future. We have to remember that our lifestyles and cultures changed and went in these directions before we knew a lot about climate change and the relationship with personal consumption. Rather than have Europeans thumb their noses at Americans and say "Look how much better we are" it would be hoped everyone says "OK, here we are, how do we all improve"... "what do you know that can help me improve, what do I know that can help you". The thing about living on the same planet tied together with the same atmosphere is that we can't simply ignore our neighbours. We are all in it together.

Resources

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The personal side of the story: Step 4. My new life.

I found it very powerful to look at the global power consumption, and the global population, and determine the average global power consumption per person. I then used this number to re-evaluate my life. Can I reduce my lifestyle to this average? Will it be hard? Easy? will it improve my life or make it less interesting? I'd recommend everyone go through this exercise and make your own choices: it helps you think about what is important to you. I still choose some portion of international travel because my family lives overseas. You might not. What really surprised me is that my new life actually looks a lot better for my health. I can also imagine that it will really improve the quality of my life. People will call me an optimist. I am!

I'm not trying to imply that equal distribution of the earth's energy resources is the right solution, I'm merely using it as a starting point for perspective. It certainly can't hurt to use this as your target.

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Science and the scientific method.

Science is interesting. In modern day life we are bombarded with scientific study headlines. "Study shows (insert bizarre phenomena and conclusion)." Because of this, the public might be forgiven for becoming complacent to, or innoculated against, the latest "scientific" finding. Next week's study will likely contradict this week's. In part this is because the modern media does a fairly poor job of communicating science, and mostly because it tries to "dumb it down" or "sensationalize" it. I think the majority of the problem is that there isn't a wide understanding of the difference between "science" and "the scientific method".

Science is the study of some sort of phenomena accompanied by an effort to explain it with a theory. Because of this, great scepticism does and should meet any single scientific study. That scepticism by the rest of the scientific community is really what the "scientific method" is. As a scientist you are obliged to question every assumption and conclusion, and to test and retest them until an established truth emerges. With enough time, and enough questioning, we can build a lot of confidence that the theories are correct. This has been a proven method for generating the incredible amount of knowledge that humanity taps to construct modern life.

This method is particularly easy for easily measurable things like the mass of a neutron or the size of the moon, or for the motions of the planets. More recently it has gotten harder because the complexity of the things that we study has greatly increased. In biology it is very difficult to reach simple conclusions and knowledge because the entire system is so complex and interconnected. This is also true of climate change. The earth's climate is not completely understood. That is true and will likely always remain true. In the science of complex systems we build models. These models explain large data sets by simplifying the problem for us. We can test these models by measuring reality and comparing it with our models. It takes quite a long time to draw strong conclusions, but in the end, through the scientific method, we can have high confidence that the conclusions are generally correct, even if we do not know the exact details.

At right is a paper by Arrhenius, a great scientist of the late 19th century. He is most famous for the Arrhenius equation, but also studied the chemistry of our atmosphere. His study on "Carbonic Acid" (now referred to as CO_2) is one of the earliest studies that links climate change with CO_2 in the atmosphere. A century later the scientific method has concluded with great confidence that our CO_2 and other greenhouse gas emissions are heating our world and endangering our lifestyles and the future of our children. While it remains wise to continue to doubt the headlines of each new "scientific study" it would be very unwise indeed to ignore the results of the collective wisdom of thousands of scientists working together through the scientific method. The conclusion now reached is that our behaviour with regards to how we produce our energy and therefore generate CO_2, must change. And now.

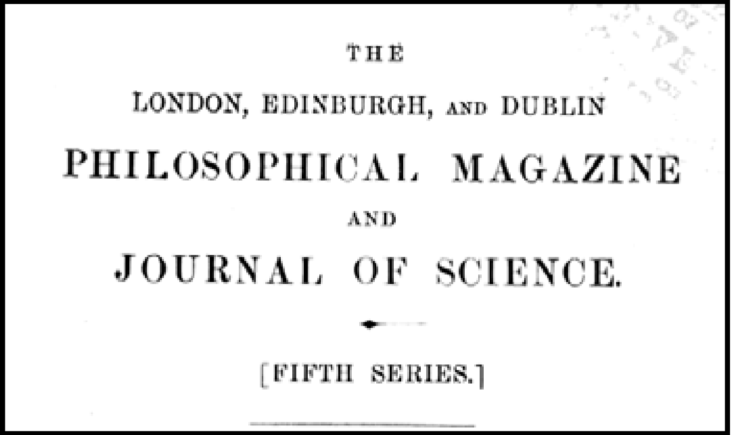
Resources

Phil.Mag.S.5.Vol.41.No.251.April 1896.
http://www.globalwarmingart.com/images/1/18/Arrhenius.pdf
http://en.wikipedia.org/wiki/Scientific_method

We have suspected for a while

GLOBAL STEP 1

Co_2 = Climate



THE

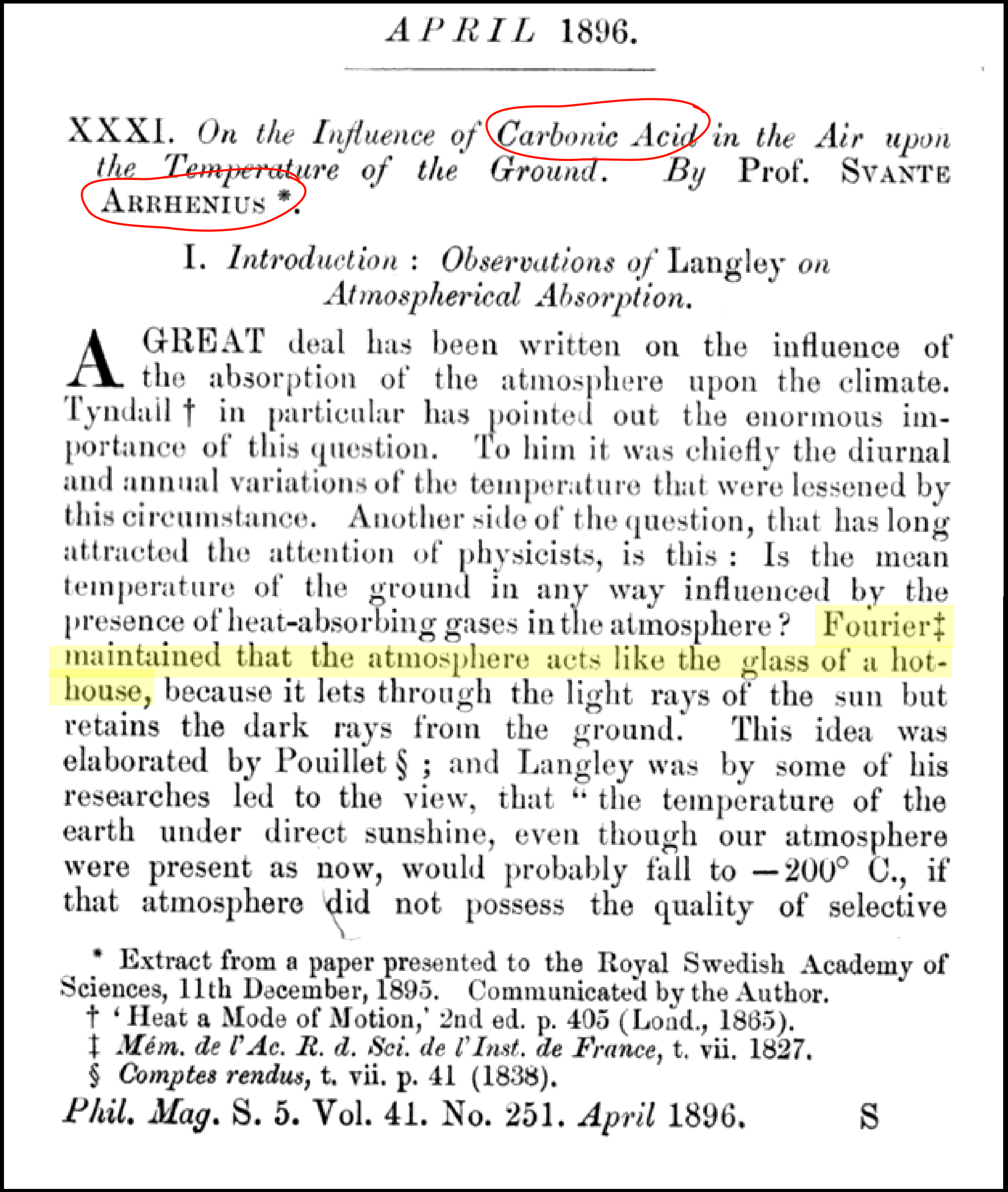
LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]



APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.

† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).

‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.

§ *Comptes rendus*, t. vii. p. 41 (1838).

The result of our energy use: Carbon Dioxide concentration in the atmosphere.

Scientists have now been studying the concentration of carbon dioxide in our atmosphere for more than half a century. They principally use two techniques. Direct measurement from research sites based (for example) in Mauna Laua, Hawaii, measure the current concentration direct from that atmosphere using highly sensitive instruments. Indirect measurement, requires inferring the concentrations from ice-cores taken from glaciers, and from ice-cores drilled into the antarctic ice-pack.

The graph at right shows the CO_2 concentration as measured by different methods for the last 1000 years.

This graph is the main reason we are all becoming increasingly aware of our environmental impact. This graph tells us about how we are risking our own future.

We need to keep looking at these graphs to see how we are doing. We also need to increase our confidence in the reasons for the historical variations of this graph due to natural climate cycles. This might be the most important plot of natural phenomena that science has ever produced. We should seek the deepest possible understanding.

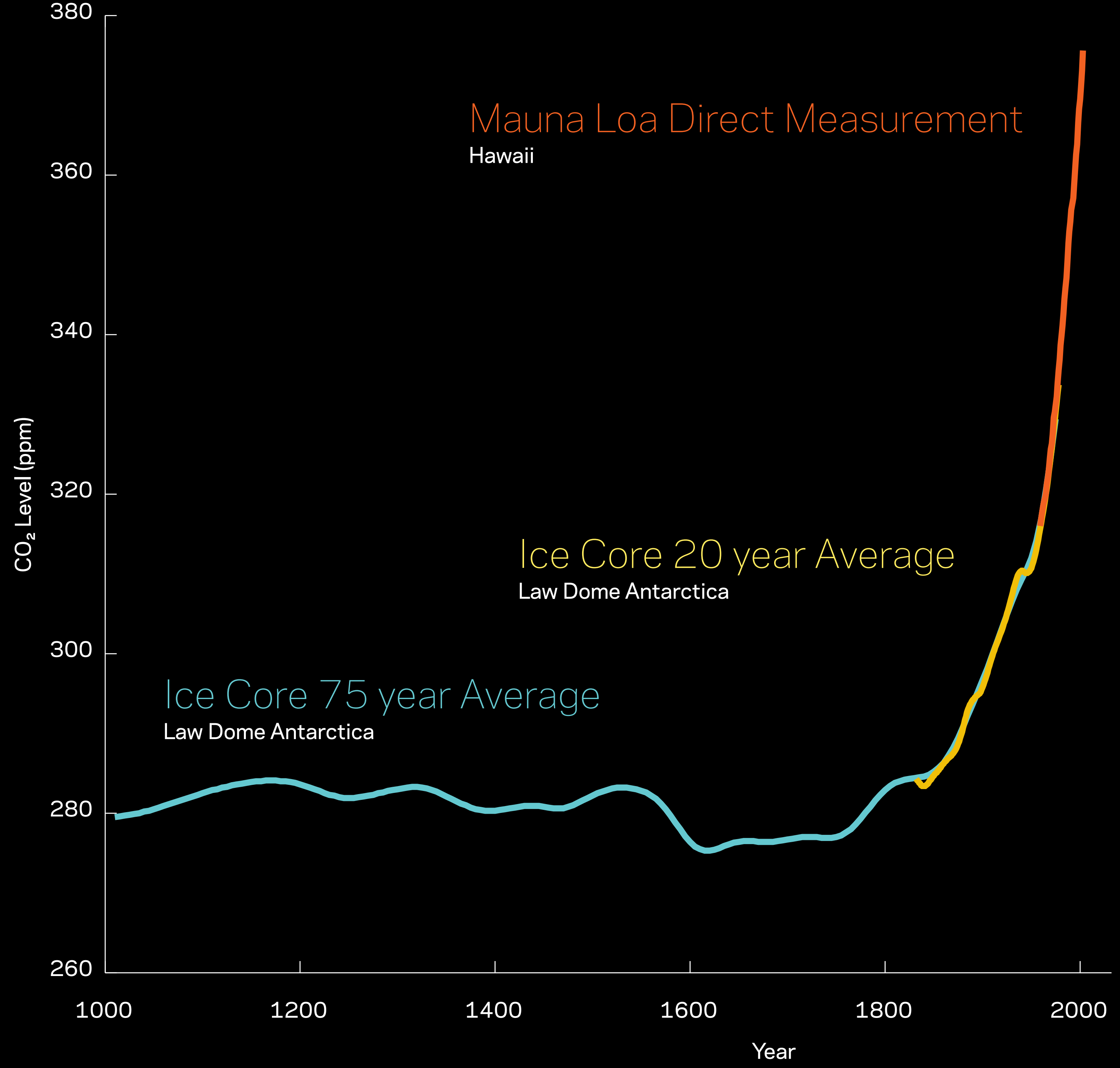
There is much earlier data: European Project for Ice Coring in Antarctica (EPICA) covers the last 650,000 years. CO2 is determined on bubbles enclosed in the ice. CO2 data from 0 to 420,000 years are from earlier measurements from ice cores from Vostok station [Petit et al., 1999], and Taylor Dome [Indermühle et al., 2000]. The isotopic records indicate the sequence of 6 full glacial cycles [EPICA Community Members, 2004]. New CO2 data measured at the University of Bern are from ice older than 420,000 years and extend the legendary Vostok record by more than 50% back in time. These data confirm that the present CO2 concentrations in the atmosphere are unprecedented for at least the last 650,000 years.

EPICA Community Members, Eight glacial cycles from an Antarctic ice core, Nature, 429, 623-628, 2004.
Indermühle, A., et al., Atmospheric CO2 concentration from 60 to 20 kyr BP from the Taylor Dome ice cores, Antarctica, Geophys. Res. Lett., 27, 735-738, 2000.
Petit, J.R., et al., Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, Nature, 399, 429-436, 1999.
Siegenthaler, U., et al., Stable carbon cycle-climate relationship during the Late Pleistocene, Science, submitted, 2005.
Spahni, R., et al., Variations of atmospheric methane and nitrous oxide during the last 650,000 years from Antarctic ice cores, Science, submitted, 2005.

Resources

Keeling, C.D. 1998.Rewards and penalties of monitoring the earth. Annual Review of Energy and the Environment 23:25-82. Annual Reviews Inc., Palo Alto.
Keeling, C.D., R.B. Bacastow, A.E. Bainbridge, C.A. Ekdahl, Jr., P.R. Guenther, L.S. Waterman, and J.F.S. Chin. 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. Tellus 28(6):538-51.
It is more complex than just CO2? : J. Hansen and M. Sato (2004) PNAS 101, 16109-16114 " Greenhouse gas growth rates."
EPICA data: http://www.ncdc.noaa.gov/paleo/icecore/antarctica/domec/domec_epica_data.html
Pales, J.C., and C.D. Keeling. 1965. The concentration of atmospheric carbon dioxide in Hawaii. Journal of Geophysical Research 24:6053-76.
Keeling, C.D. 1960. The concentration and isotopic abundance of carbon dioxide in the atmosphere. Tellus 12:200-203.

CO_2 concentrations last 1000 years



Recent rate increase in atmospheric CO2 concentration

In the last 50 years, the rate of increase in CO_2 has increased. The Mauna Loa studies by Roger Revelle were pioneering. The seasonal variation (uptake of CO_2 by northern hemisphere trees) can be seen at this detail. There is no denying that there is a very fast increase in CO_2 concentrations here. In fact in the last few years scientists are concerned that the rate of increase has increased again. This might be an indication of reaching the limits of the earth's ecosystems to absorb CO_2.

For reference, pre industrial concentrations were around 280 ppm.

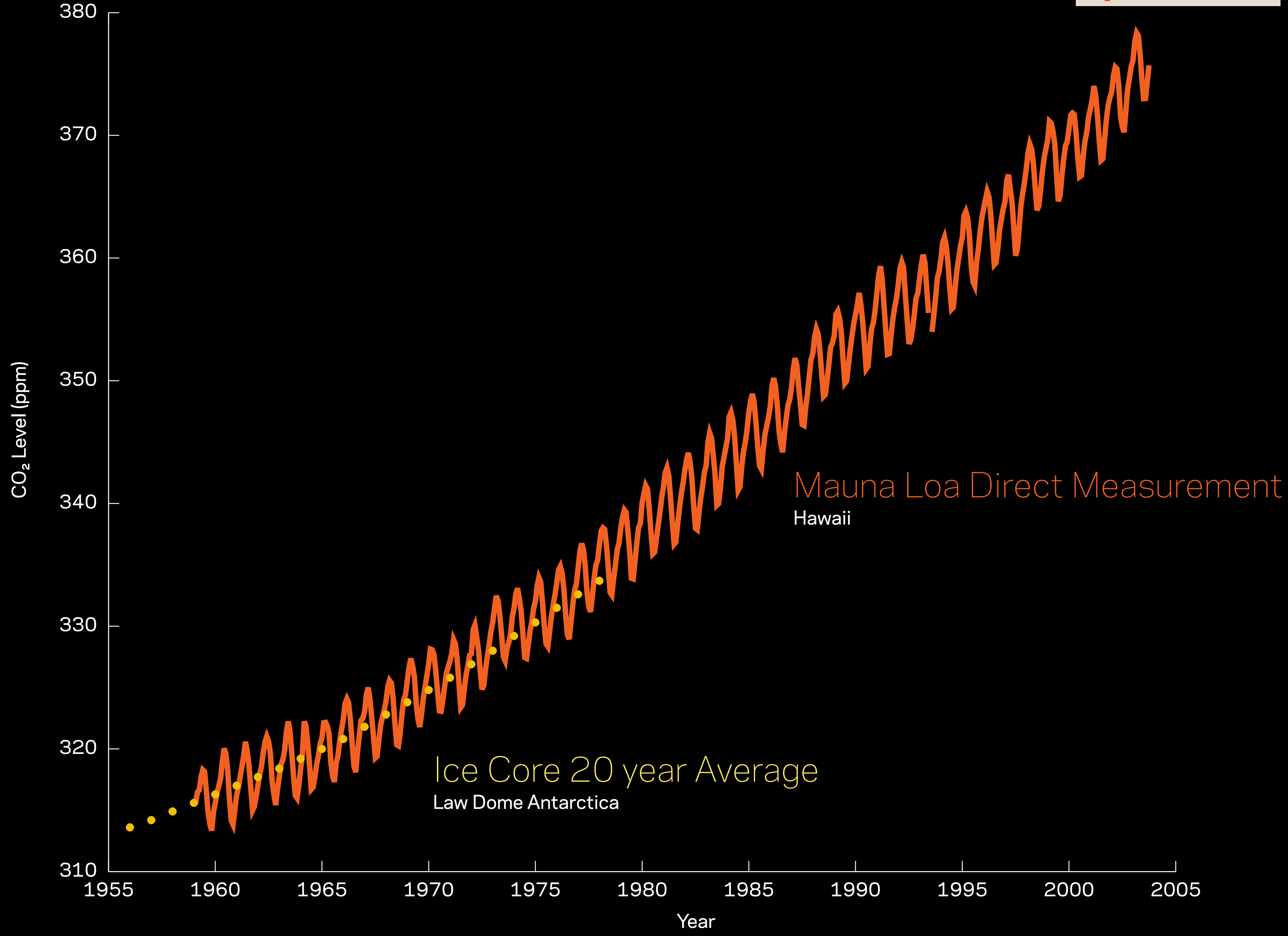
For those people who still doubt the scientific evidence of climate change, they should pause to note that despite the complexity of the system, we can in fact measure discrete things very accurately, and whats more, by multiple techniques. Presented here are two independent observations of the same phenomena that are in very close agreement. The observations were highly separated geographically, and geologically, and this increases our confidence highly in the conclusion of rapidly rising atmospheric CO_2 levels.

Resources

http://en.wikipedia.org/wiki/Roger_Revelle
Mauna Loa Observatory
Revelle, R., and H. Suess, "Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO2 during the past decades." Tellus 9, 18-27 (1957).

Inconvenient Truth, the movie, covers this point in some detail.
You can find the raw data set at: http://cdiac.ornl.gov/ftp/ndp001/maunaloa.co2

In detail

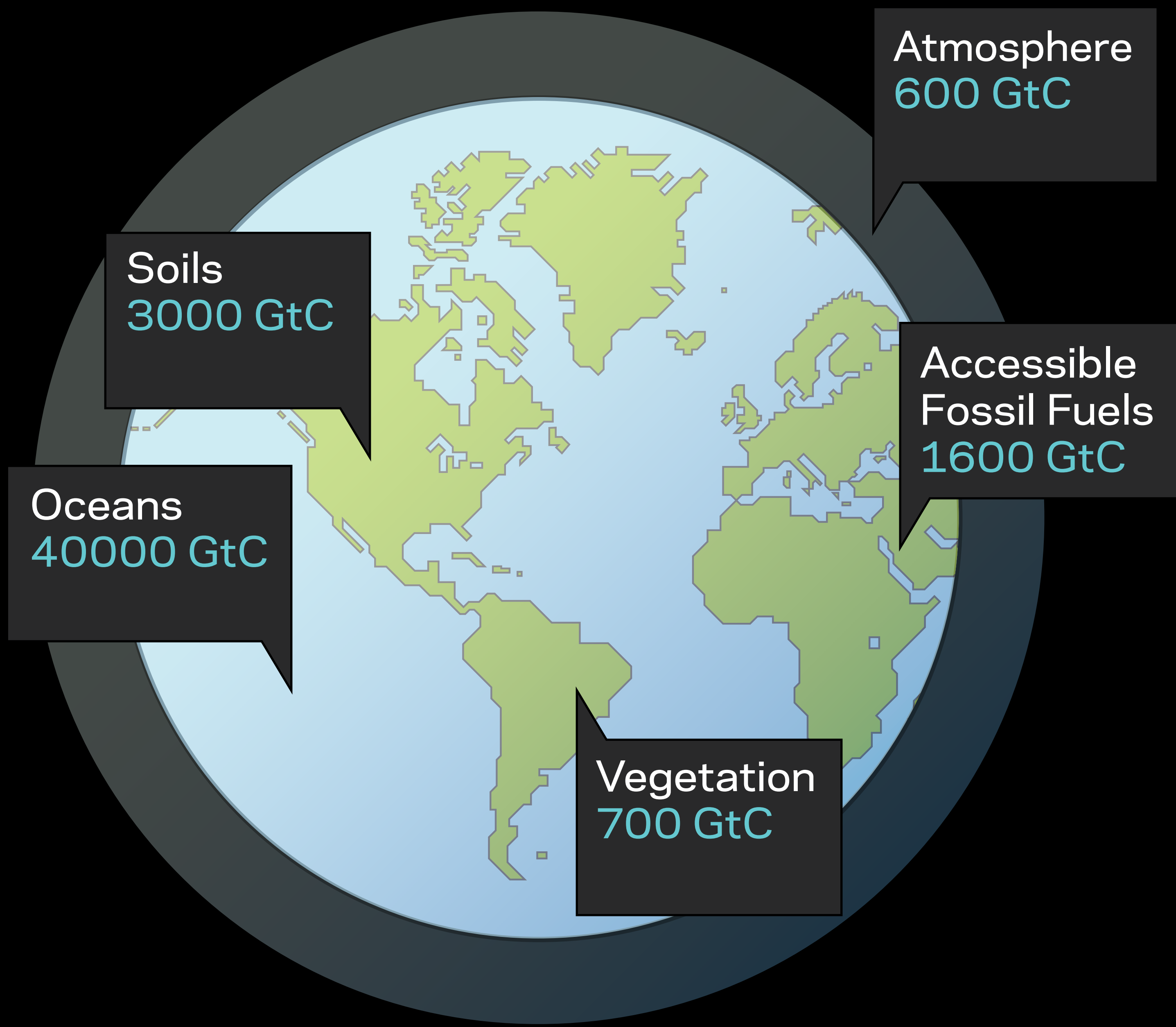

380
370
360
350
340
330
320
310
CO_2 Level (ppm)
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
Mauna Loa Direct Measurement
Hawaii
Ice Core 20 year Average
Law Dome Antarctica

Where is all the carbon?

There is a lot of carbon in the world.
Humans are mostly water, and then mostly carbon.
The carbon is stored in many places in the world's environment.
Carbon will seek to find a chemical equilibrium.
As we push more carbon into the atmosphere by burning fossil fuels, we change the equilibrium and the carbon concentrations in these various deposits changes.
A Giga Tonne of Carbon (1 GtC) is 1 billion tonnes.
At current rates the increase of CO_2 in the ocean results in increased acidity which is reducing the ocean productivity by lowering the growth of plankton and killing coral reefs.
Burning forests and deforestation release the carbon trapped in vegetation into the atmosphere. The Indonesian forest fires of recent times released as much as 0.7GtC to the atmosphere.
The thing that we try to understand when looking at this slide is the flows of CO_2 through the reservoirs where it is "stored".
It is comforting to note that the reservoirs are much larger than the flows, which gives us hope of slowing and even reversing this phenomena.

Resources
The Oceanic Sink for Anthropogenic CO2 http://www.pmel.noaa.gov/pubs/outstand/sabi2683/sabi2683.shtml
Socolow at princeton: http://www.princeton.edu/mae/people/faculty/socolow/

Where is all this carbon we talk about?

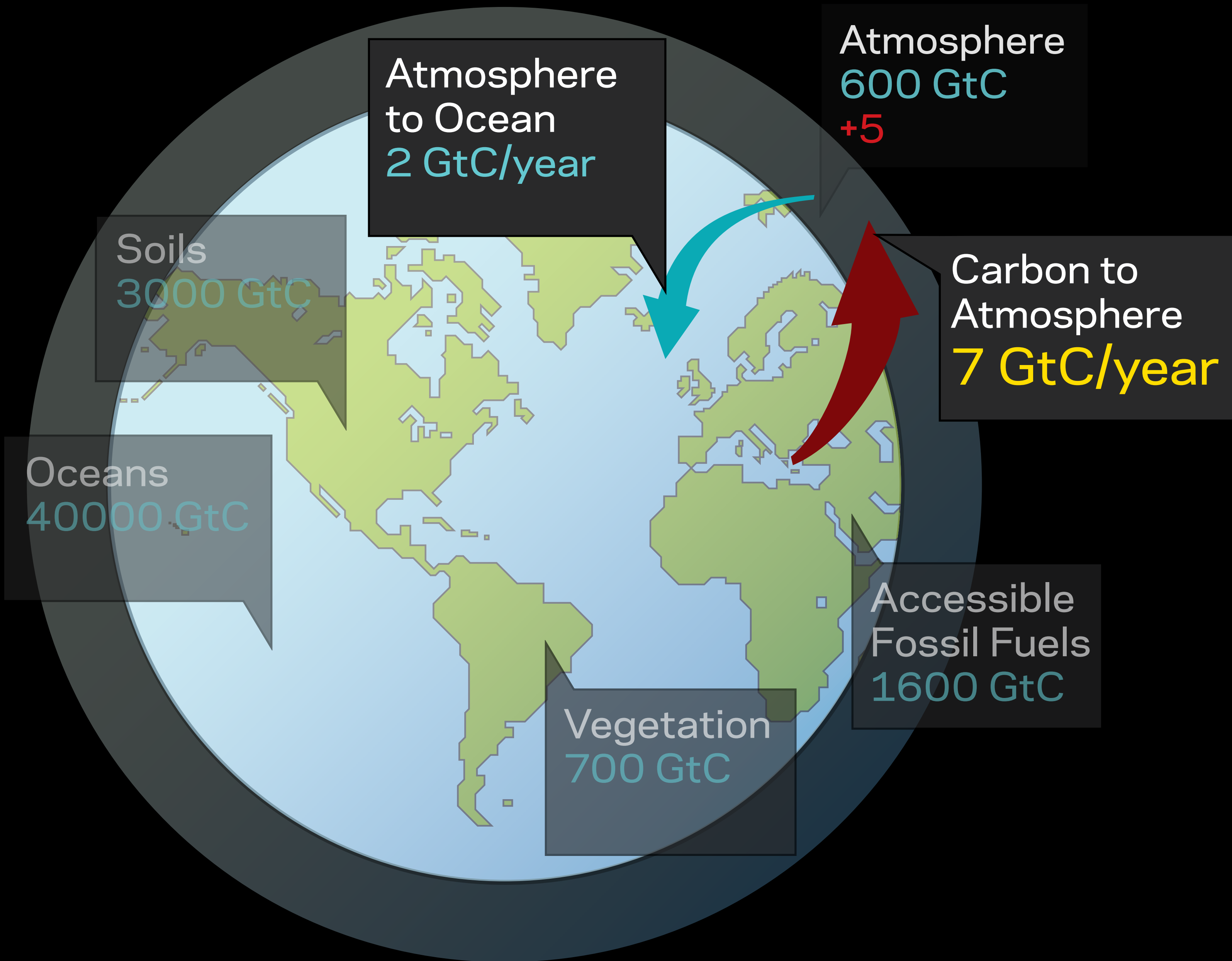


How is human activity changing the carbon balance?

Fossil fuels were carbonaceous things billions of years ago that over time (heat and pressure) became oil, gas, coal, and those things we generally know as fossil fuels.
We now burn those things at a rate much faster than the oceans and other natural systems can absorb them.
As a measure of the natural rate at which carbon is stored via photosynthesis, the current estimates is around 40 Gigawatts (GCEP, Stanford, Exergy Flows). That is the rough rate at which new oil and coal is being made - if you wait a few million years to harvest it.
The cartoon at right shows you a very simple form of the carbon picture. At the rate of 2 GTC/yr the acidity of the ocean actually increases. This implies even if we only add 2GTC to the atmosphere and consequently to the oceans we have another problem (ocean acidification) as well as the CO_2 problem and climate change problem to deal.
The result of trying to force the 7GtC into the atmosphere with only 2GtC coming back out, is a net increase of 5GtC into the atmosphere yearly, consequently the CO_2 concentration in the atmosphere increases.

Resources
Organic Carbon Distribution on earth:
http://oceanexplorer.noaa.gov/explorations/deepeast01/background/fire/media/carb_dist.html
Gas Hydrates:
http://oceanexplorer.noaa.gov/explorations/deepeast01/background/fire/fire.html
USGS Carbon Cycle:
http://geochange.er.usgs.gov/carbon/
Global carbon distribution:
http://www.eomonline.com/Common/currentissues/Aug02/sheffner.htm
Carbon Cycle Science:
http://www.carboncyclescience.gov/
North American carbon budget and implications for the global carbon cycle:
http://www.climatescience.gov/Library/sap/sap2-2/final-report/sap2-2-final-all.pdf

Out of equilibrium



The result of CO_2 change is climate change.

The extra CO_2 in the atmosphere creates something now widely known as "the greenhouse effect". Through mechanisms described in much more detail in the resources, heat is trapped within the blanket of earth's atmosphere and contributes to the heating of the whole planet. This is a complex phenomenon (for a great case study read about the atmosphere in the "winds of change"). This is why it will heat in some places and cool in others even when the overall, or average, trend is for global warming.

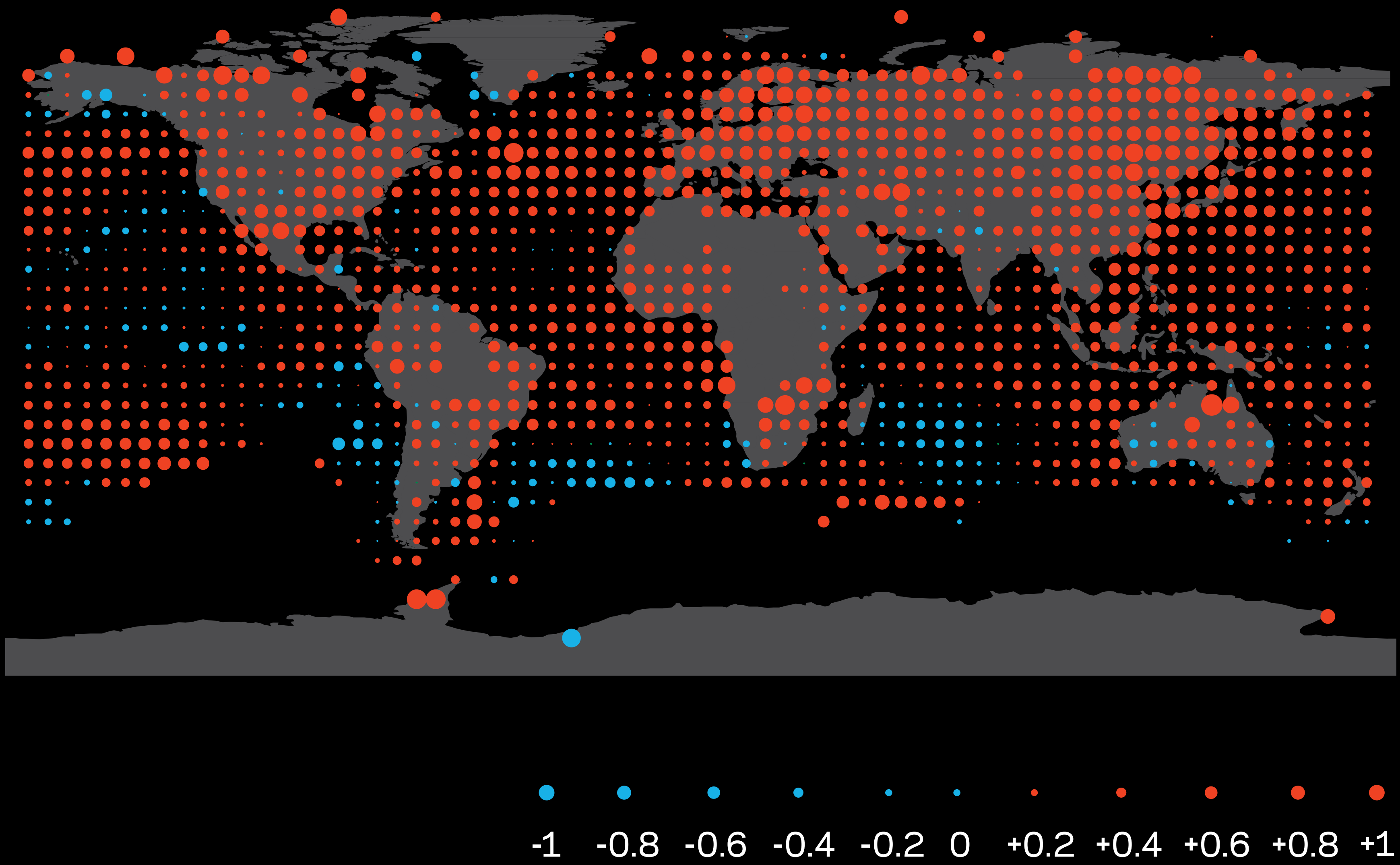
In the past 25 years (as you will have seen in Inconvenient Truth) the temperature has risen sharply, breaking all sorts of records.

Resources

The image at right comes from the British publication : "The Climate Change Challenge" Carbon Trust (URL).
Winds of Change.
http://worldviewofglobalwarming.org/

Temperature Changes around the world in the last quarter of the 20th century

Trends in °C per decade



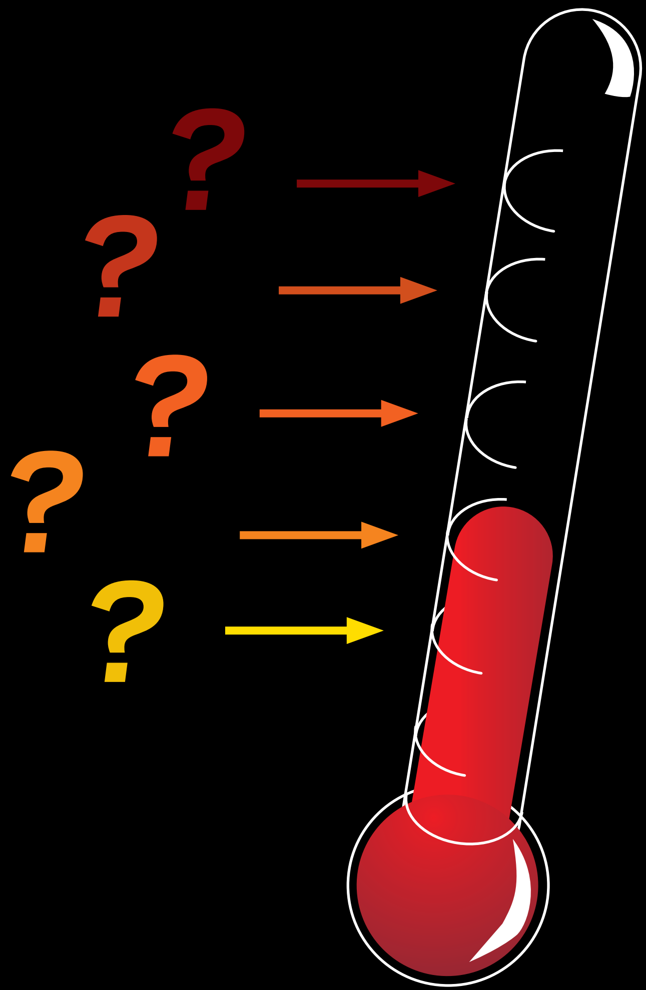
The great ethical question of our time is a choice.

At the end of the day, the climate change challenge comes down to the most difficult question ever faced by humanity. What temperature change, and what degree of environmental change, are we prepared to deal with?
We may not even have the social and political structures available to us with which to answer this question, and even if we do we may not have the collective will, and technical capacity to reach our target. It still helps us understand our situation however to think through the manifestations of this choice. That is what this document is about. Choices. It is about humanities collective choice, and the contributions of every single individuals' choices.

The reason this choice is so important, and belabored here, is that once the choice is made, we have reduced the problem from a complex sociological phenomenon into a technical specification which can be met through appropriate engineering. This is not to say the engineering is easy, but rather that once set, we have tools (science, engineering, large scale manufacturing, logistics, infrastructure management) to meet our goal. Delaying setting the target makes it more difficult to hit the target.

Resources
http://www.earthpolicy.org/Indicators/Temp/2008.htm
http://www.enn.com/press_releases/2317
http://www.washingtonpost.com/wp-dyn/content/article/2008/01/11/AR2008011103483.html?sub=AR
http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts.txt

What temperature do we choose?



Recent climate change, measured as temperature.

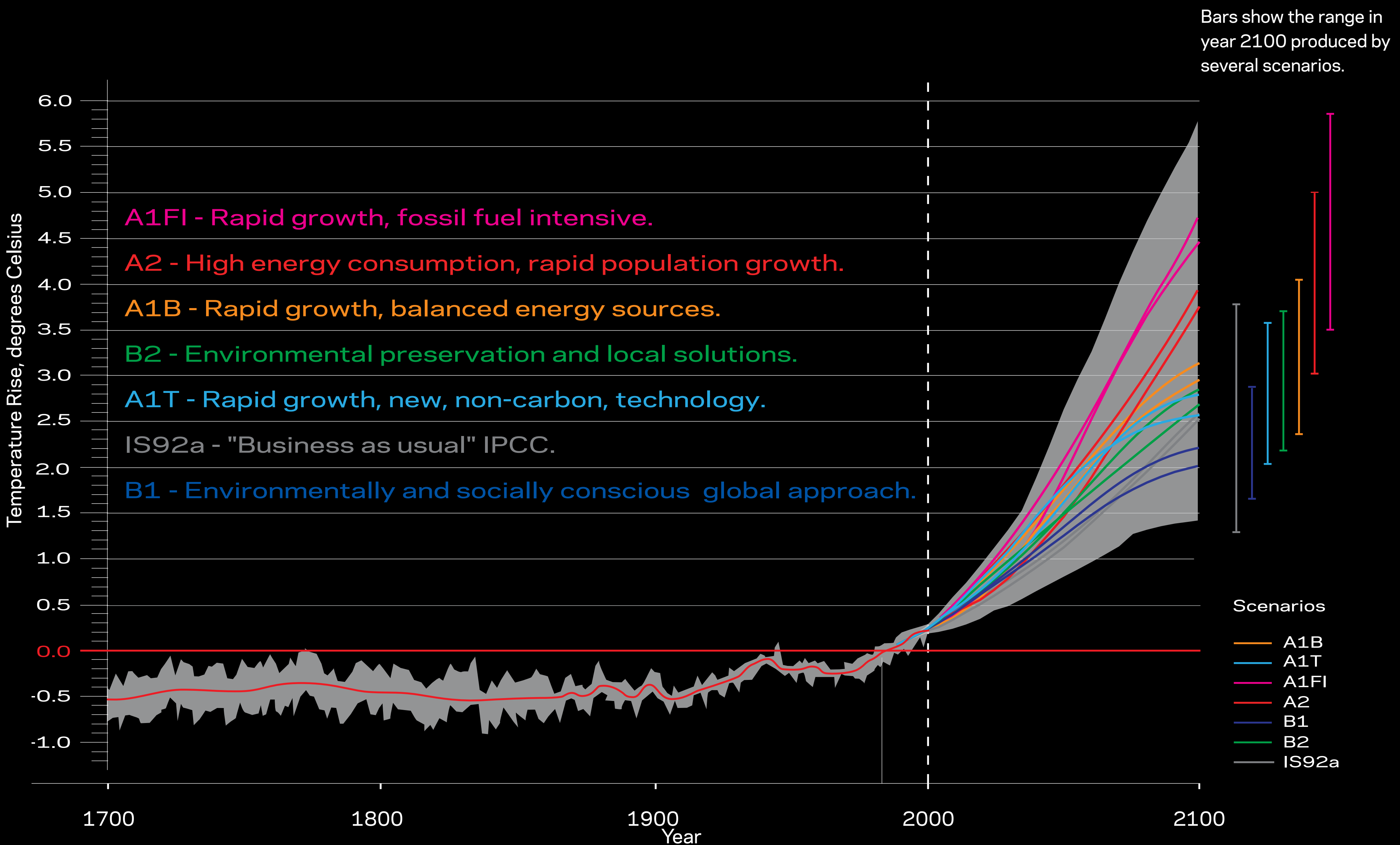
The graph at right (modified courtesy of Carbon Trust, UK) shows us how the temperature has changed in the last three hundred years.
The future portion of this chart (that which is ahead of us, not behind us) is obviously not measured, but rather predicted. Many groups of scientists try to “model” what the future will be by using measured knowledge from the past and under-standings of the physical phenomena of the world. Each of these groups works independently, yet also collaborates, and collectively they try to achieve the most accurate model pos-sible. Each groups models use different assumptions about the future behaviour of humanity, and that is why we see such vast differences in their calculations. What is perhaps the most imporant thing to understand after reading this chart is that even in the best case scenario of the groups modelling our future, we are still facing unprecedented and rapid climate change. Climate change that will happen in the lifetimes of the people reading this document.

“Consensus as strong as the one that has developed around this topic is rare in science.” Donald Kennedy, Editor-in-Chief, Science magazine.
“There’s a better scientific consensus on this than on any is-sue I know, except maybe Newton’s second law of dynamics.” James Baker, Administrator, NOAA.

Resources
Study of global warming consensus : Science, December 3, 2004 Vol. 306, Issue 5702,1686

Recent temperature changes

Models vs. Scenarios



The link between CO2 concentrations and our climate future.

Here we have overlayed the predictions of this group (ref) over the temperature graph. What everyone needs to understand about this very important graph is that this is the choice we have to make. Once we decide upon the temperature change that we deem acceptable it implies a target CO2 concentration. Even if we hit our target of CO2, there is uncertainty about what temperature the earth will eventually equilibrate at. This uncertainty would generally imply that we should be conervative. If faced with an uncertain stock market most people would invest in safe bonds or place their savings under the bed. The wise thing to do in our climate situation is probably similar. Invest in hitting the safest target possible. For the purposes of this argument we will choose 450ppm. If it were up to me I would choose 400ppm, or even 280ppm - the pre-industrial revolution CO2 concentration. I choose 450ppm because it is a very ambitious goal (much more ambitious than the 550ppm chosen by the Stern Report - for example) yet it still implies a high level of doom and gloom, and an unprecedented level of social change.

The choice... the likely consequences...
We try our best to predict the consequences of various CO2 concentrations, and this is perhaps the least predictable of all of the predictions in this talk.

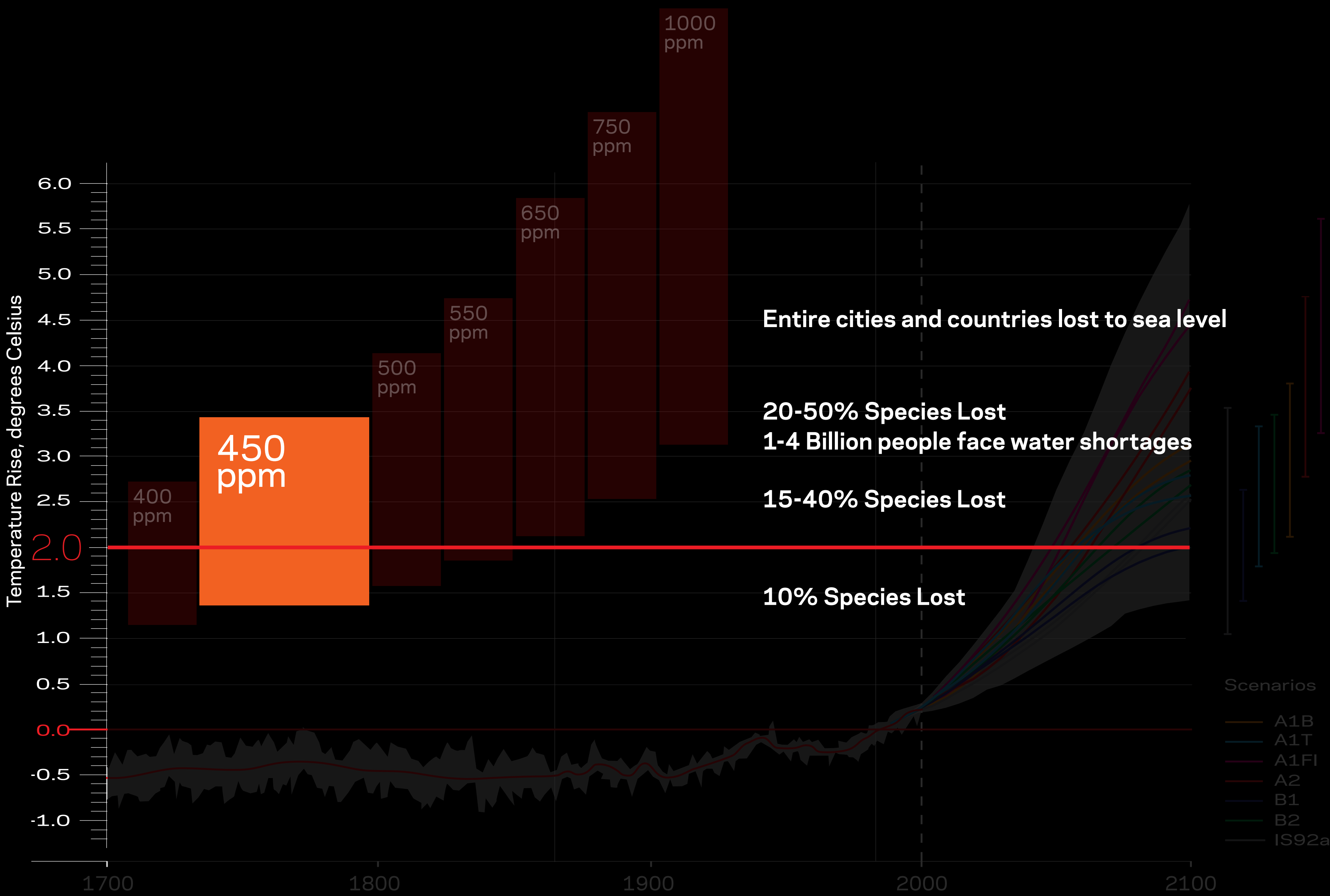
Reference greenpeace and WHO and WWF climate change predictions.

I have the distinct impression that most people who suggest a number here are not wanting to commit. If they commit too high and make a mistake people will criticise them greatly. If they commit too low it will make the immediate job harder and the economic consequeneces more volatile. Choosing lower would appear much more prudent than choosing higher in terms of risk of human life and environmental destruction.

Resources

This is the best paper I have been able to find for choosing this number:
http://www.princeton.edu/mae/people/faculty/socolow/socdoc/index.pdf
Thomas et al. 2004. Extinction risk from climate change. Nature 427:145-148
IPCC. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge
Scholze etal. 2006. A climate-change risk analysis for world ecosystems. PNAS 103(35): 13116-13120.
Hare, W. 2003. Assessment of Knowledge on Impacts of Climate Change. Potsdam Institute for Climate Impact Research. Potsdam, Germany 5 Hales et al. 2002.
Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. 6Graßl et al. 2003.
Climate Protection Strategies for the 21st Century: Kyoto and beyond. German Advisory Council on Global Change Special Report, Berlin.
WWF. 2004. Great Barrier Reef 2050. WWF-Australia

Choose your target



It’s a choice, with consequences. How hot do you want it?

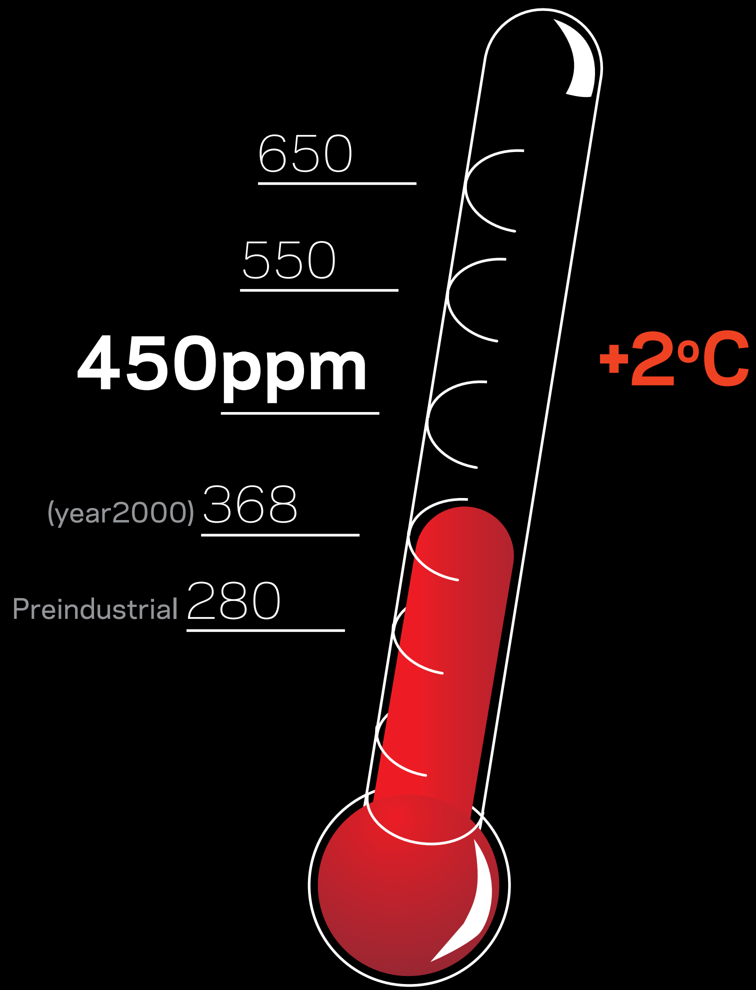
At the risk of over emphasizing the point, I return to the great question of our lifetime. What temperature rise do we allow? Just 1 degree? more? what temperature rise do we believe our children will cope with?

Recognise that the temperature choice as represented just reflects the global average. In fact it will mean higher variability over land, and lower variability over the sea. Temperatures will rise proportionally much more towards the poles, less around the equator.

Resources

Avoiding Dangerous Climate Change: A Scientific Symposium on Stabilisation of Greenhouse Gases was a 2005 international conference that redefined the link between atmospheric greenhouse gas concentration, and the 2 °C (3.6 °F) ceiling on global warming thought necessary to avoid the most serious effects of global warming. Previously this had generally been accepted as being 550 ppm. The conference concluded that, at the level of 550 ppm, it was likely that 2 °C would be exceeded, based on the projections of more recent climate models. Stabilising greenhouse gas concentrations at 450 ppm would only result in a 50% likelihood of limiting global warming to 2 °C, and that it would be necessary to achieve stabilisation below 400 ppm to give a relatively high certainty of not exceeding 2 °C. The conference also claimed that, if action to reduce emissions is delayed by 20 years, rates of emission reduction may need to be 3 to 7 times greater to meet the same temperature target.
http://www.stabilisation2005.com/outcomes.html

What temperature did I choose?



Exactly how much CO_2 can we emit? What does this mean in terms of our energy production?

From our choice of the climate change we are prepared to deal with we inferred the CO_2 concentration we can tolerate (and hence) we know that we can only emit roughly 2 billion tonnes of carbon (2GtC) into the atmosphere annualy. There are good arguments that this number should in fact be 1.4 GtC or even 0 GtC.

The amount of "allowable carbon" into the atmosphere is very difficult to calculate. It also depends upon how soon we act, and what time frame we wish things to stabilise on.

If you are doing the full calculations on allowable CO2 from fuel use, you should probably also consider emissions from deforestation and agricultural practices.

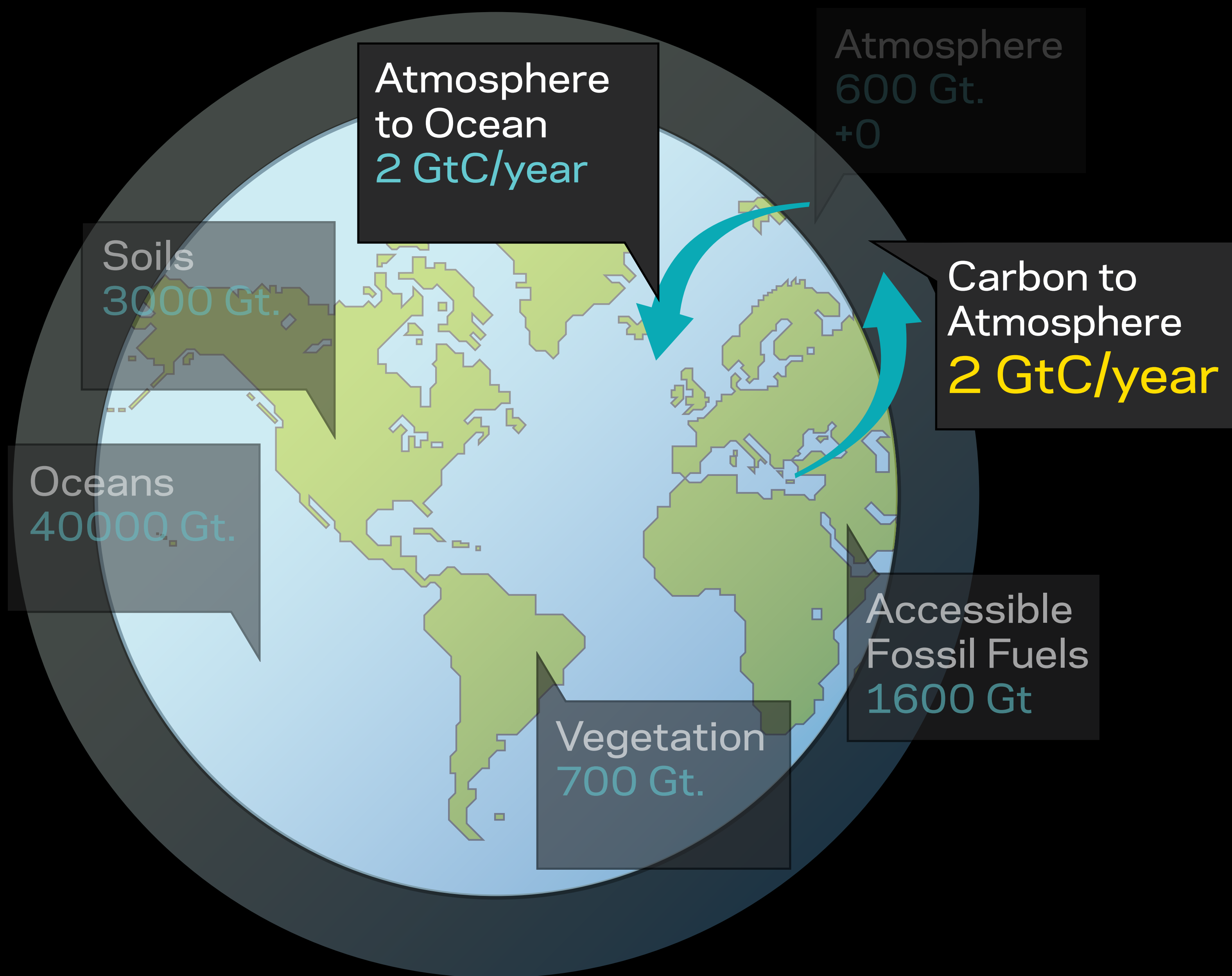
“Humanity already possesses the
fundamental scientific, technical,
and industrial know-how to solve
the carbon and climate problems
for the next half-century.”
Stephen Pacala and Robert Socolow
Science, August 13, 2004

I've seen good arguments that this number really needs to be 1.4GtC, and other good arguments that in the long term it has to be 0GtC. I would like to fill in a much better discussion around this number.

Resources

http://www.princeton.edu/mae/people/faculty/socolow/socdoc/index.pdf
http://www.columbia.edu/~jeh1/
http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html
http://www.eia.doe.gov/oiaf/1605/factors.html
Brazilian and other rainforest destruction emissions of greenhouse gases : http://www.osti.gov/bridge/purl.cover.jsp?purl=/10180014-HcIB3H/

What is implied by a 450ppm CO_2 target?



The choice. The consequences. When will you see the results?

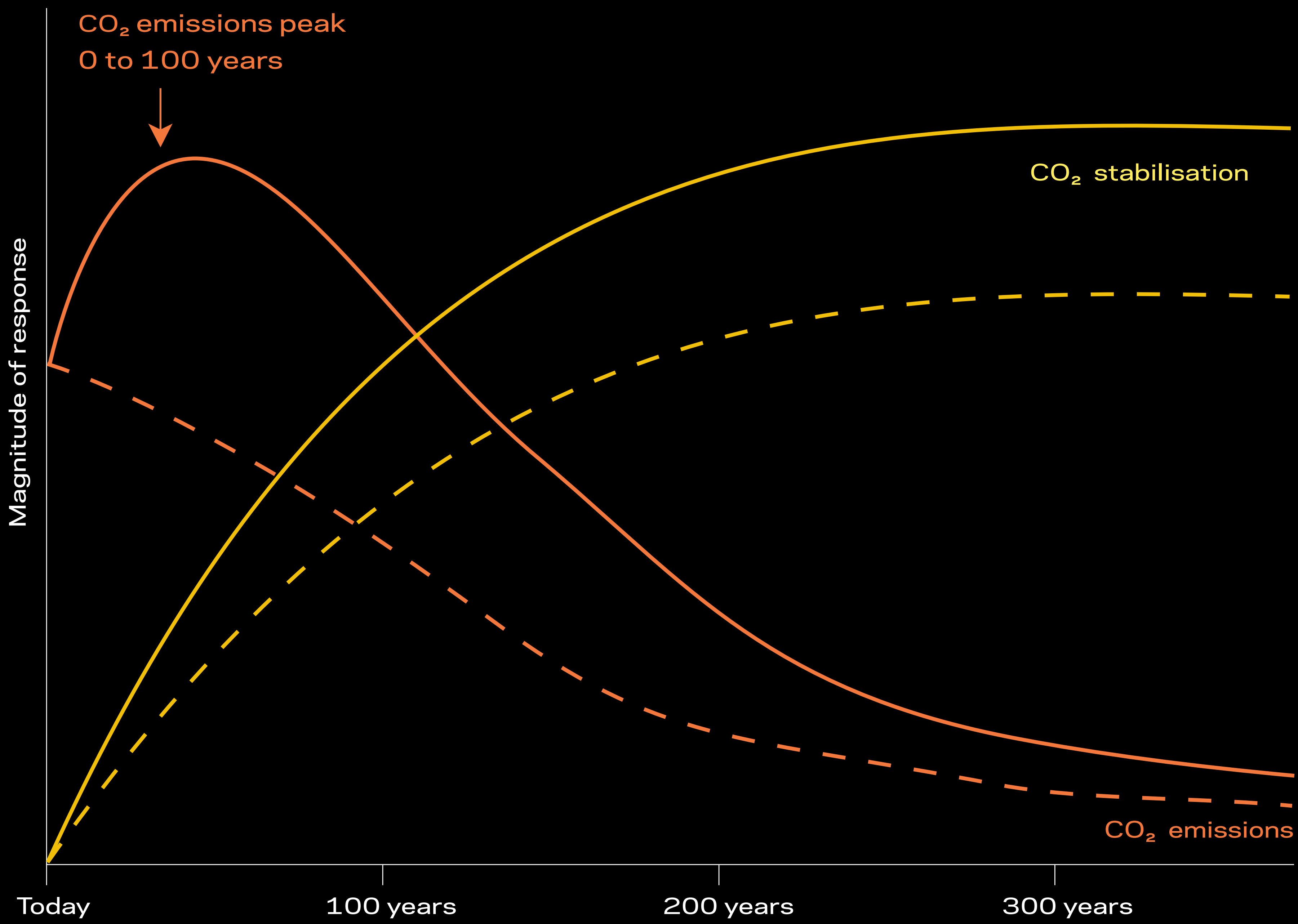
I think the phenomena shown in this graph is the most difficult to understand. The reality of climate change is that you have to act before you see the worst of it. If you wait until you can feel the temperature, it's already too late. This is because temperature increase and sea level rise happen much slower than CO_2 change. Even after we level off the atmospheric CO_2 change, the inertia in the rest of the environment will mean hundreds and thousands of years before things settle. This is why it is not accurate to say "we can still stop climate change". We are now working to stop "worse climate change" or "much worse than worse climate change".

Need better references and models here. This is a difficult and important concept to communicate.

Resources

http://www.bp.com/sectiongenericarticle.do?categoryId=9015928&contentId=7029022 BP's target.

The time is now



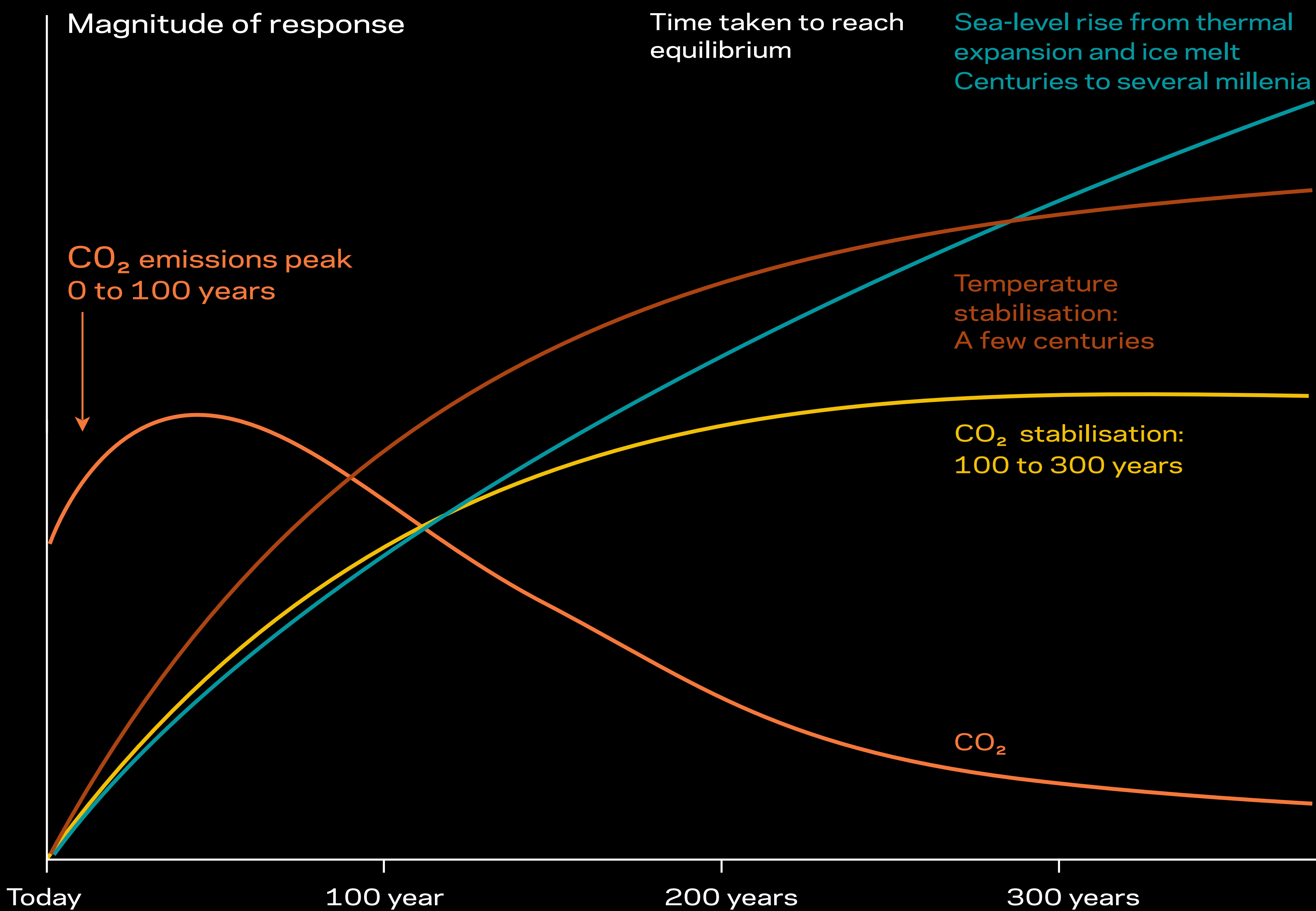
The choice. The consequences. When will you see the results?

Beyond the CO_2 stabilisation question that lags the current CO_2 concentration, the other phenomena we care about, temperature and sea level, also both lag by significant time periods. 100-300 years. It's hard enough to imagine doing things now that have an effect in 25 years, but pre-emptively doing the things that have an effect not on you, but your grandchildren? That is going to require new ways of thinking and relating.

Resources

http://www.bp.com/sectiongenericarticle.do?categoryId=9015928&contentId=7029022 BP's target.

Unfortunately results wont be seen on the timescale of necessary actions.



2 Billion Tonnes of Carbon per year is how much power?

I'm sure there will be lots of contention about this number. That's OK. I don't mind contention as long as it is part of the process that leads to a consensus.

I need to check how idealised these numbers are. Do they really account for efficiency losses?

This is a very important number to get right as it determines what we need to shoot for in terms of non-carbon producing energy technologies.

Again, we have to consider non-fuel based sources of CO_2 and other green-house gases. I'm sure that will suggest this number will be much much lower.

The amount of energy that can be generated from this amount of CO_2 depends on what kind of fossil fuel is burned.

Resources

http://bioenergy.ornl.gov/papers/misc/energy_conv.html
http://www.eia.doe.gov/oiaf/1605/factors.html

How much power from that much carbon?

$$2\ \text{GtC} \times 44/12 = 7.3\ \text{GtCO}_2$$

which gives:

2.5	TW	- if its all coal
4.4	TW	- if its all gas
3.2	TW	- if its all oil
**30*	*TW*	*- nuclear is not entirely CO_2 free...*

2° C (3.6° F) → 450 ppm → 2-3 TW from carbon fuels.

At the end of the day it's about energy

How did we put so much CO_2 into the atmosphere?

At the end of the day it's because of our desire for energy that is undeniably useful to humanity and the way we operate.

To understand the rest of this document you at least need some intuition for the differences between work, energy, and power.

Work is the exertion of a force over some distance. I perform work on an apple when i lift it from the ground to a table.

Energy is: the ability to do work. It's a measure of how much work you can do, whether it be moving apples, or heating your house.

Power is: the rate at which you consume energy or do work. Lifting the apple onto the table quickly requires more power than doing it slowing, but the same amount of work is performed.

Resources
http://en.wikipedia.org/wiki/Work_%28thermodynamics%29
http://en.wikipedia.org/wiki/Energy
http://en.wikipedia.org/wiki/Power_%28physics%29

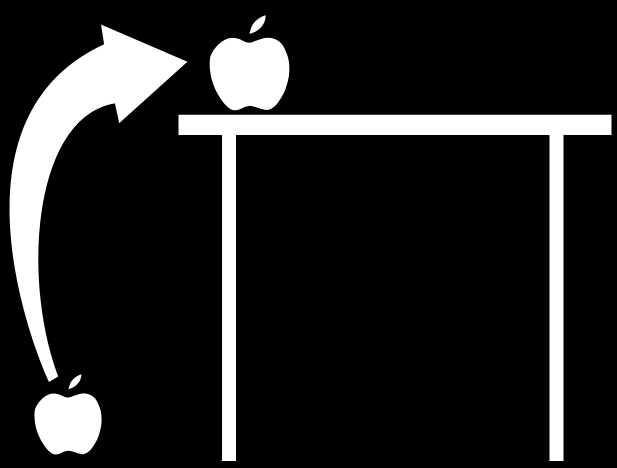
Energy & power basics

Energy is measured in Joules (J)

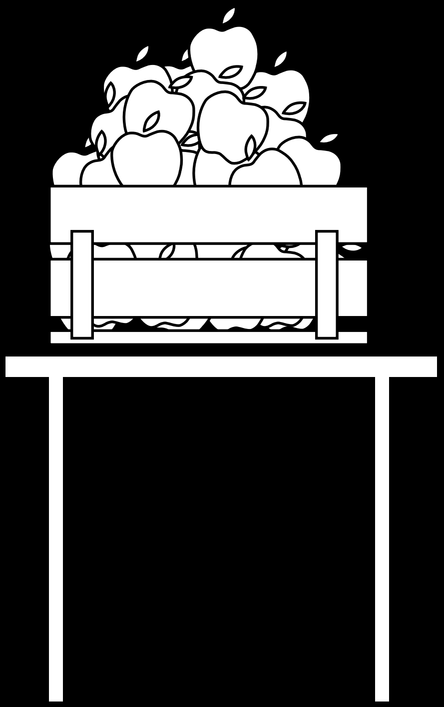
Power is measured in Watts (W).

1 Watt = 1 Joule / second

Lifting an apple from the ground to the table. ~ 1 Joule



40 apples per second from the ground to the table = 40 Watts.



Running your Apple laptop takes 40 Watts.

An intuition for the scales of power and energy

It is very difficult to have an intuition or understanding of all these different units and numbers. We all have a rough understanding of the amount of power in a light bulb. We know the size of a wind turbine. We understand the power of a car. Many people have stood at Hoover Dam, or Niagara Falls and been awed by it's power. Hopefully this table helps us put in perspective everything else said here.

These numbers are not exact. The Hoover dam for example is closer to 2GW. Some kettles are below 1kW, some above. Very large modern wind turbines can be 3MW with experimental installations now at 5MW.

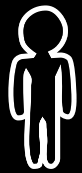
It's very hard to imagine a TW, because no single machine really uses this much power.

Resources

http://bioenergy.ornl.gov/papers/misc/energy_conv.html
http://physics.nist.gov/cuu/Constants/energy.html
http://www.convertit.com/Go/ConvertIt/Measurement/Converter.ASP
Google calculator (on-line) is a very useful tool for rapidly converting between units.

Power

100 W = You, sitting there, reading.

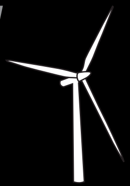


1000 W 1kW = Domestic kettle

1 kilowatt (kW) = 1000 W

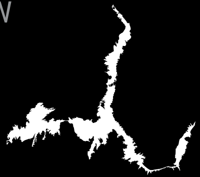
1000000 W 1MW = Diesel locomotive / wind turbine.

1 megawatt (MW) = 1000 kW



1000000000 W 1GW = Hoover dam

1 gigawatt (GW) = 1000 MW



1000000000000 W 1TW = World power consumption, 1890

1 terawatt (TW) = 1000 GW

US energy consumption, 1635-2005.

Here we have the amount of energy consumed in the united states since it's colonisation by europeans.
Overlayed on this graph are the key people who's theories, inventions, or discoveries, enabled us to harness new energy sources, or to use energy in new and different ways. The reason for putting their lifespan in the graph is to show you that these enormous increases in global energy consumption happened in the lifetimes of single people. These technologies played out in single lifetimes. That's why it should be possible to play out new forms of energy production in our lifetimes from different sources. This image gives me hope for a solution in my lifetime.

Resources

http://www.eia.doe.gov/aer/ep/ep_frame.html
http://www.eia.doe.gov/aer/append_e.html
isaac newton

Isaac Newton http://en.wikipedia.org/wiki/Isaac_newton

james watt http://en.wikipedia.org/wiki/James_Watt

carnot http://en.wikipedia.org/wiki/Nicolas_L%C3%A9onard_Sadi_Carnot

james joule http://en.wikipedia.org/wiki/James_Joule

thomas edison http://en.wikipedia.org/wiki/Thomas_edison

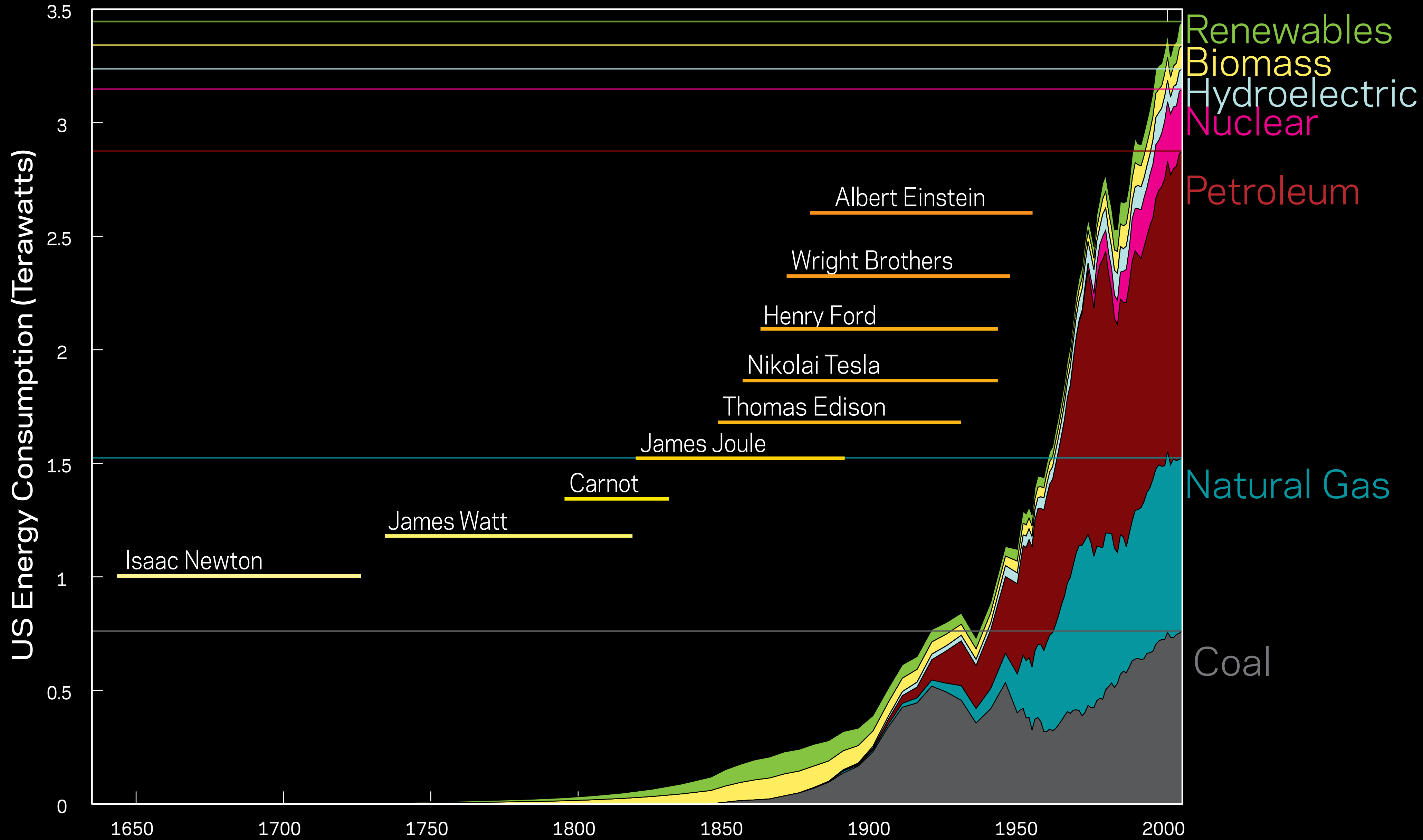
nikolai tesla http://en.wikipedia.org/wiki/Nikola_Tesla

henry ford http://en.wikipedia.org/wiki/Henry_ford

wright brothers http://en.wikipedia.org/wiki/Wright_brothers

albert einstein http://en.wikipedia.org/wiki/Albert_einstein

US energy consumption (TeraWatts)



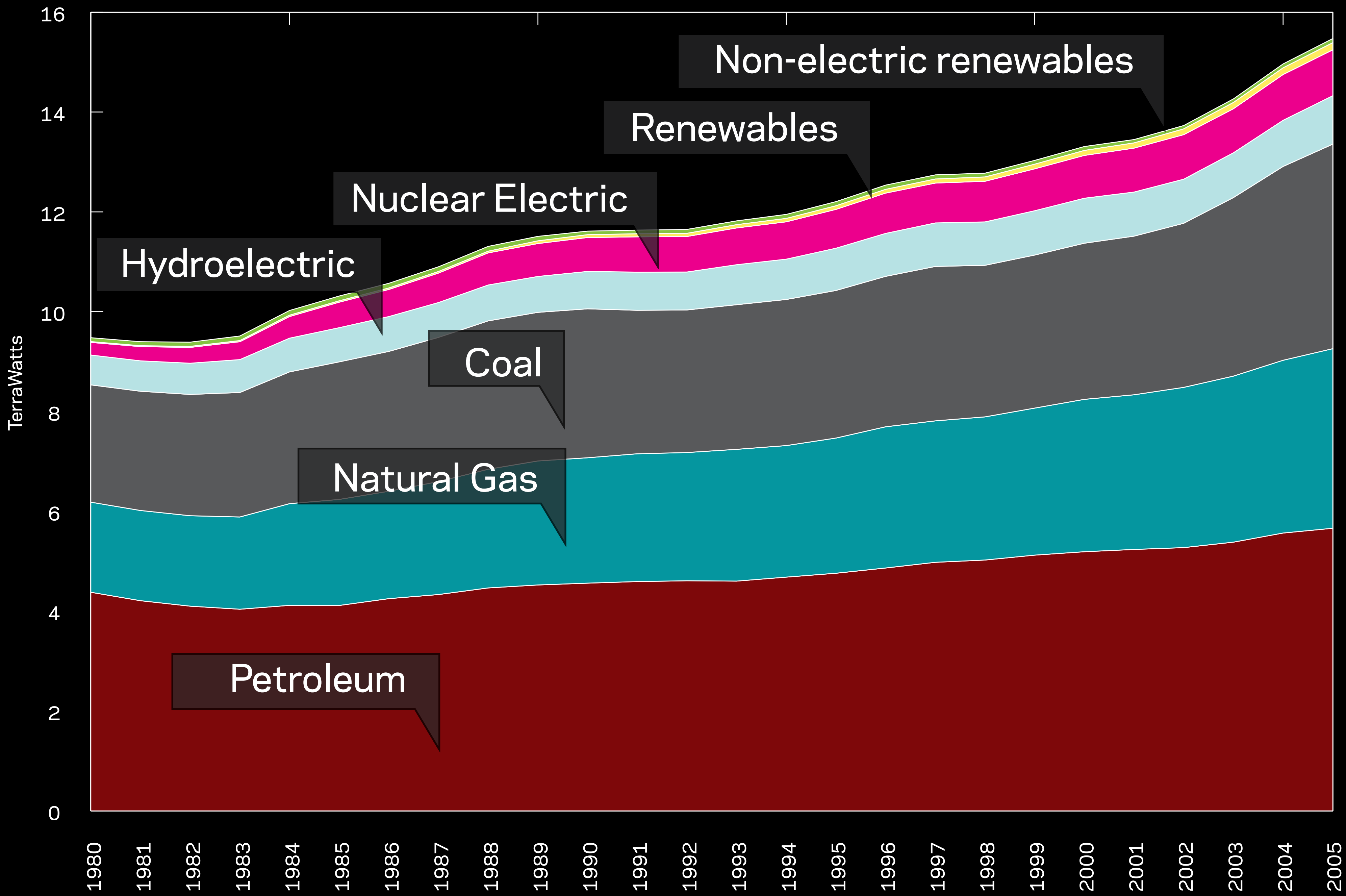
Global Energy Consumption, 1980-2005.

The most interesting piece of this graph is the increase of 6TW that occurred in the last 25 years.

I'm still looking for a global energy consumption graph that has a longer time series. It would be great to get this back to 1600, as with the US data.

Resources
http://www.eia.doe.gov/oiaf/ieo/world.html

Global energy consumption, 1980-2005 (TeraWatts)



Making it personal. Your own power consumption.

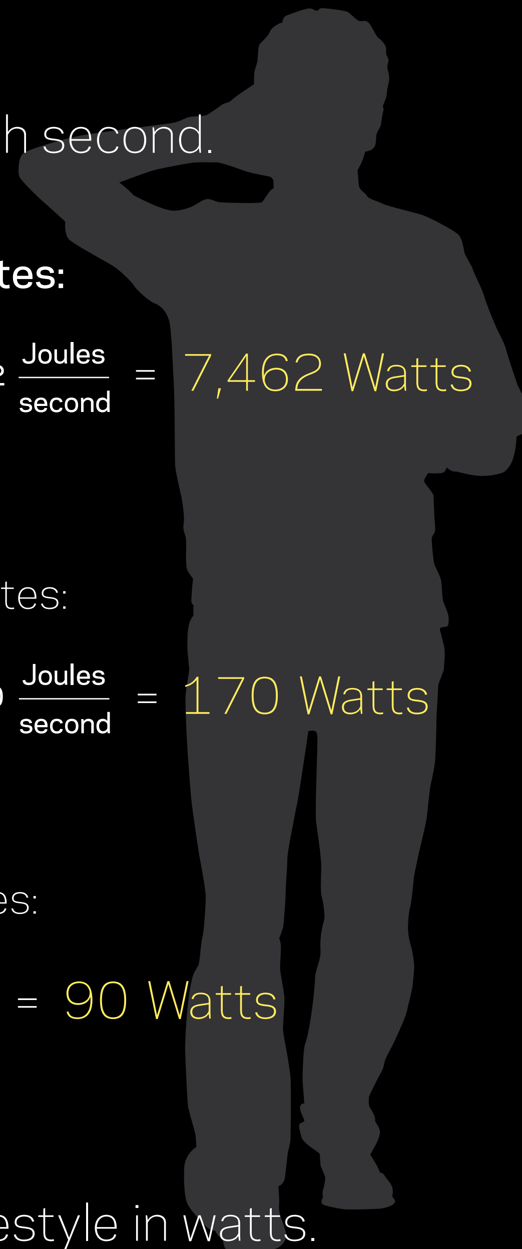
I chose Watts as a convenient unit to do all of my calculations in. Watts is a measure of power, which makes it independent of time. People often ask "Watts per what?". The correct answer would be "Watts per always". It's the average. If you are burning a 100 Watt lightbulb it is using 100 Watts whilever it is turned on.

I can conveniently use Watts now to add together the things I do that happen on markedly different timescales. The yearly things, the monthly things, the daily things.

Resources

The Power of me:
Calculating my energy consumption

Power, in Watts, is like an average.
The average amount of energy, in Joules, you use each second.



If you do something yearly (like fly 105,000 miles), it contributes:

$$\frac{168{,}207 \text{ kilometers}}{1 \text{ year}} \times \frac{1 \text{ year}}{31{,}536{,}000 \text{ seconds}} \times \frac{1.40 \text{ megajoules}}{1 \text{ kilometer}} = 7{,}462 \frac{\text{Joules}}{\text{second}} = 7{,}462 \text{ Watts}$$

If you do something monthly (like your electricity bill), it contributes:

$$\frac{122 \text{ kilowatt} \cdot \text{hours}}{1 \text{ month}} \times \frac{1 \text{ month}}{2{,}952{,}000 \text{ seconds}} \times \frac{3.6 \text{ megajoules}}{1 \text{ kilowatt} \cdot \text{hour}} = 170 \frac{\text{Joules}}{\text{second}} = 170 \text{ Watts}$$

If you do something daily (like drink 1 Energy drink), it contributes:

$$\frac{1 \text{ energy drink}}{1 \text{ day}} \times \frac{1 \text{ day}}{86{,}400 \text{ seconds}} \times \frac{7.84 \text{ megajoules}}{1 \text{ bottle}} = 90 \frac{\text{Joules}}{\text{second}} = 90 \text{ Watts}$$

So now you can add all these things.
Yearly things + Monthly things + Daily things = your lifestyle in watts.

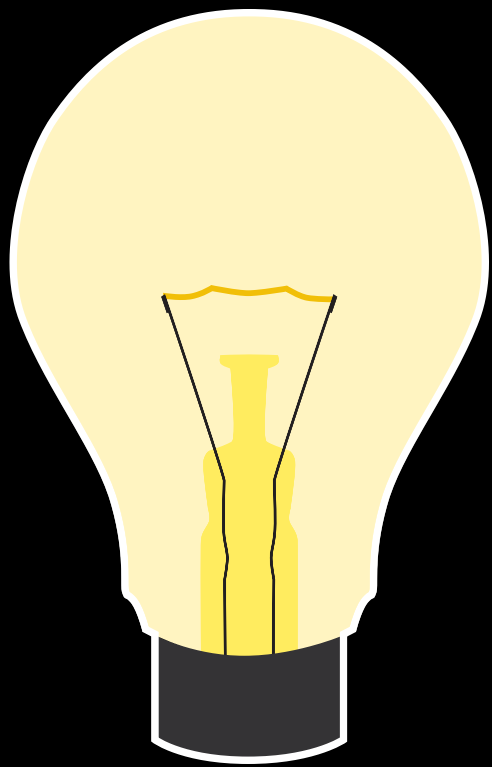
Life as a light bulb. Life bulbs?

Thinking of your life in lightbulbs might help you build an intuition for your power consumption.

remember: "Watts per always"

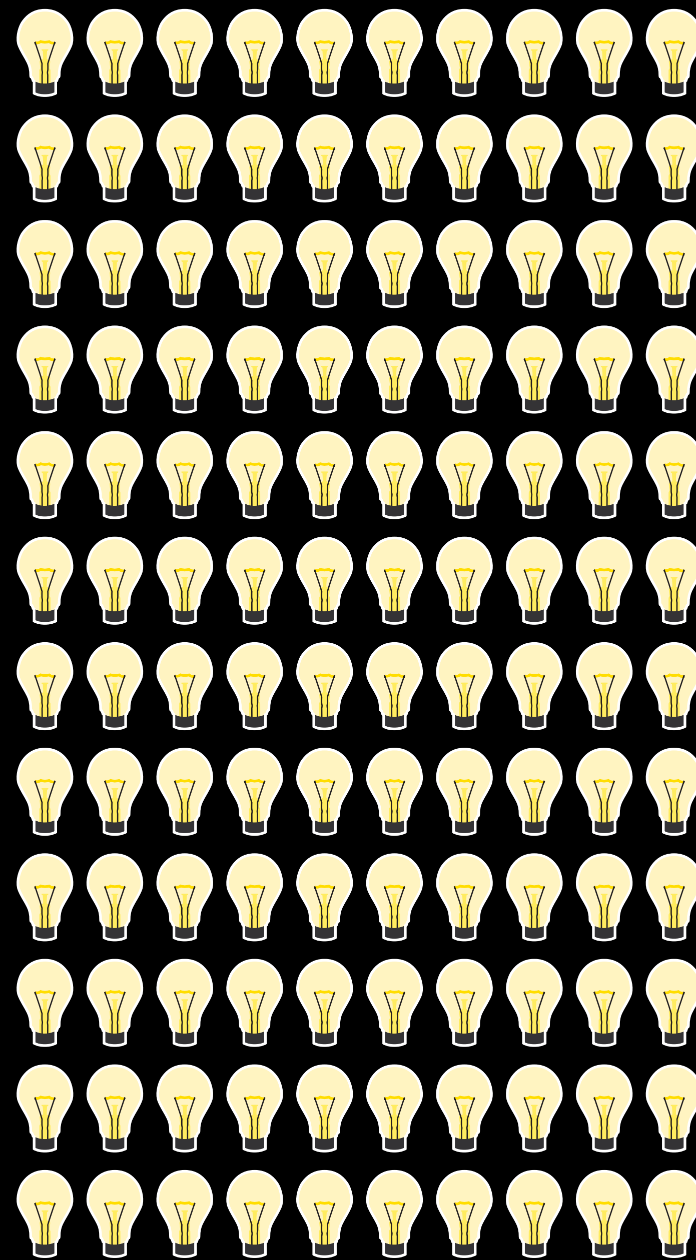
Resources

"Watts per always"



Think of your life in light bulbs....

A 12,000 Watt lifestyle is 120 x 100 watt light bulbs burning permanently.



My personal “energy footprint” for 2007.

People should be prepared to look at their own personal foot print. This helps in many ways.

If you know where you are using energy, you know how you can save energy.

If you know how much energy you use, you can understand the challenge facing all humanity.

Learning how dificult it is to calculate your own energy use, gives you a sense for how modern life annures you to the realities of your own energy consumption. The modern practice of filling a car with gasoline is a great example. When you insert the nozzle into the tank you don't even notice that it pours in a volume of gasoline that likely weighs as much as you do. It's much more of a magical process - insert money, wait a few minutes, and your car is ready to drive. Would we see the world differently if you actually saw that huge volume of liquid fuel being transferred every time you fill your tank?

These calculations are a mixture of first principles calculations, published data and estimetes. It is by no means completely comprehensive, and in fact not nearly as accurate as I would like. I hope to improve it in time. I hope that this document helps induce change in the availability of the information that would make this easier.

The accuracy of this data is probably only +/- 50%. In all cases I have tried to use the low estimate. In all likelihood my personal energy consumption is much higher.

I am an unusual person, so is everyone else. I fly more, I drive less. I consume less, I use more internet, your numbers are going to be different and I encourage you to calculate them. I was shocked to see my result. We all need a shock.

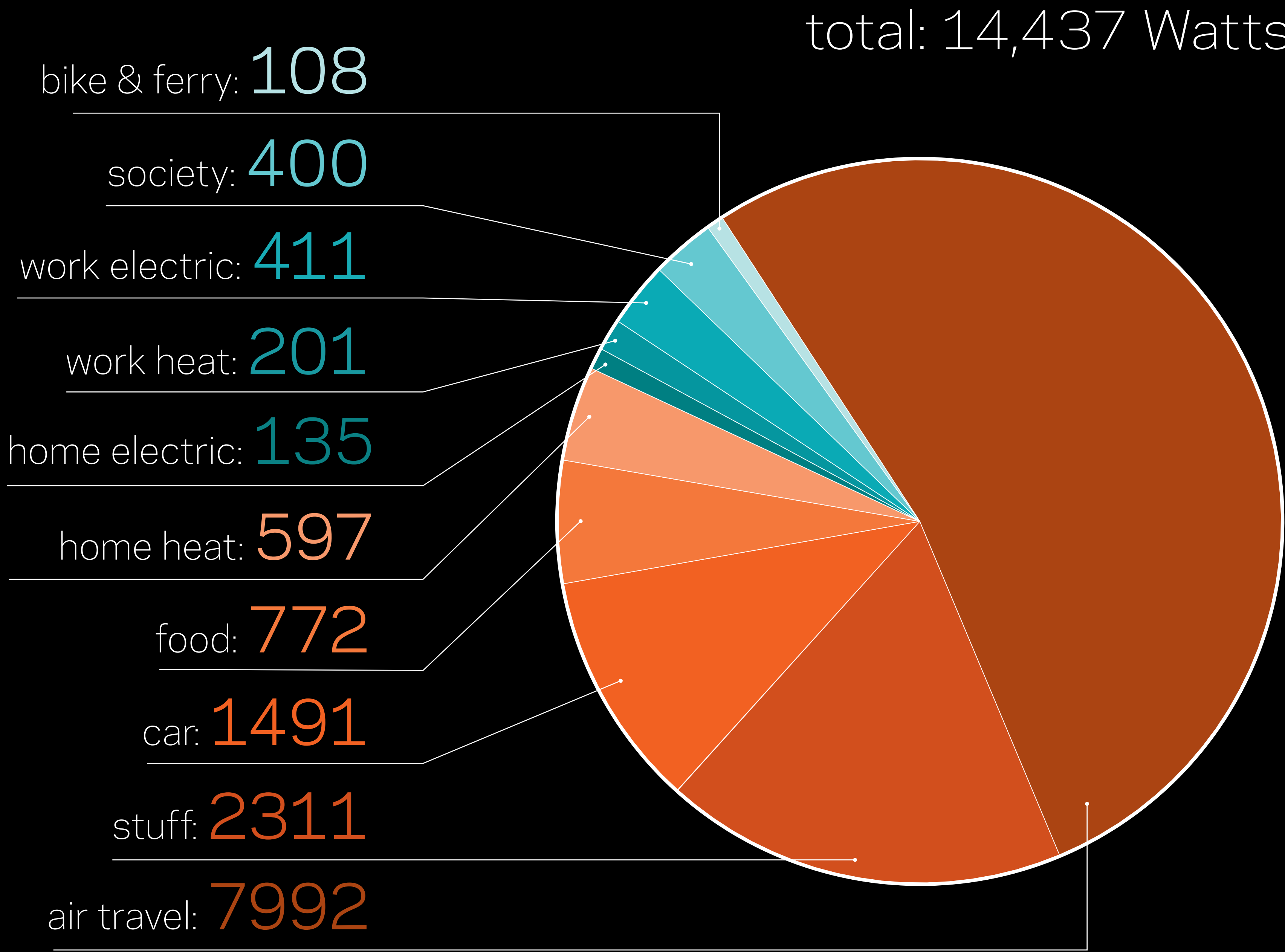
Resources

The two best books I've found on calculating your own footprint are both british.
"Living a low carbon life" - Chris Goodall, http://www.lowcarbonlife.net/
"Without hot air" - David J C MacKay , http://www.withouthotair.com/

LOCAL STEP 1

My Lifestyle

Saul Energy Use 2007



My flying 2007 - The biggest piece.

Modern aviation is wonderful. It has literally changed the world in many good ways. If everyone flew as much as I do, it would change it in bad ways.

I used a value of 1.4MJ / km flown to arrive at my number. I've seen numbers that are 1.1MJ/km. Both of these numbers assume fully loaded air craft, 747's or 737's. I know that only a small proportion of my flights are on full aircraft.

I've read articles that claim it is really 2-3 times this value if you take into account energy for the infrastructure of flying - airports etc.

So while I do know the number of miles I flew quite accurately, and I have a reasonable estimate of energy per km, I am fairly confident that overall my energy for flying is a low estimate.

It should be required for airlines to publish the MJ / passenger mile values for their airlines, and that airlines compete to outperform each-other on this measure.

Date	Itinerary	Mileage
2/9/2008	SFO-LHR	5,350
2/14/2008	LHR-SFO	5,350
3/1/2008	SFO-ATL	2,130
3/2/2008	ATL-SFO	2,130
4/21/2008	SFO-ATL-CPH	6,720
4/30/2008	HEL-AMS-ATL-SFO	7,465
5/11/2008	OAK-OGG-HON-OAK	7,340
6/9/2008	SFO-BOS	2,700
6/13/2008	BOS-SFO	2,700
7/30/2008	OAK-DC	2,400
8/1/2008	DC-OAK	2,400
8/22/2008	OAK-ORD-MON-QUE	2,721
8/27/2008	QUE-DTW-SFO	2,740
9/24/2008	SFO-JFK	2,580
9/28/2008	JFK-SFO	2,580
10/10/2008	OAK-BUR	325
10/10/2008	BUR-OAK	325
10/27/2008	SFO-BOS	2,700
10/28/2008	BOS-ORD	863
10/30/2008	ORD-SFO	1,840
11/2/2008	SFO-JFK	2,580
11/10/2008	JFK-SFO	2,580
11/30/2008	SJC-SJO	3,010
12/3/2008	SJO-SJC	3,010
12/7/2008	SJC-VIJ	3,680
12/12/2008	VIJ-SJC	3,680
12/22/2008	SFO-SYD-SFO	14,840
--	SFO-DR	4000
--	DR-SFO	4000
--	SFO-HON	3600
--	HON-SFO	3600
	Total miles	**111,939**
	kilometers	**180,148**
assuming :	**1.4MJ/km**	
2007 Flying:	**252,207,701,222**	**Joules**
Divide by seconds in a year : 31,557,600		
	WATTS for 2007 flying	**7,992**

Resources

http://www.salon.com/tech/col/smith/2008/02/22/askthepilot265/index1.html

Flight

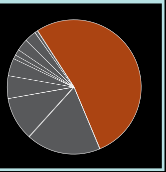
Saul Griffith in 2007: 112,000 Miles

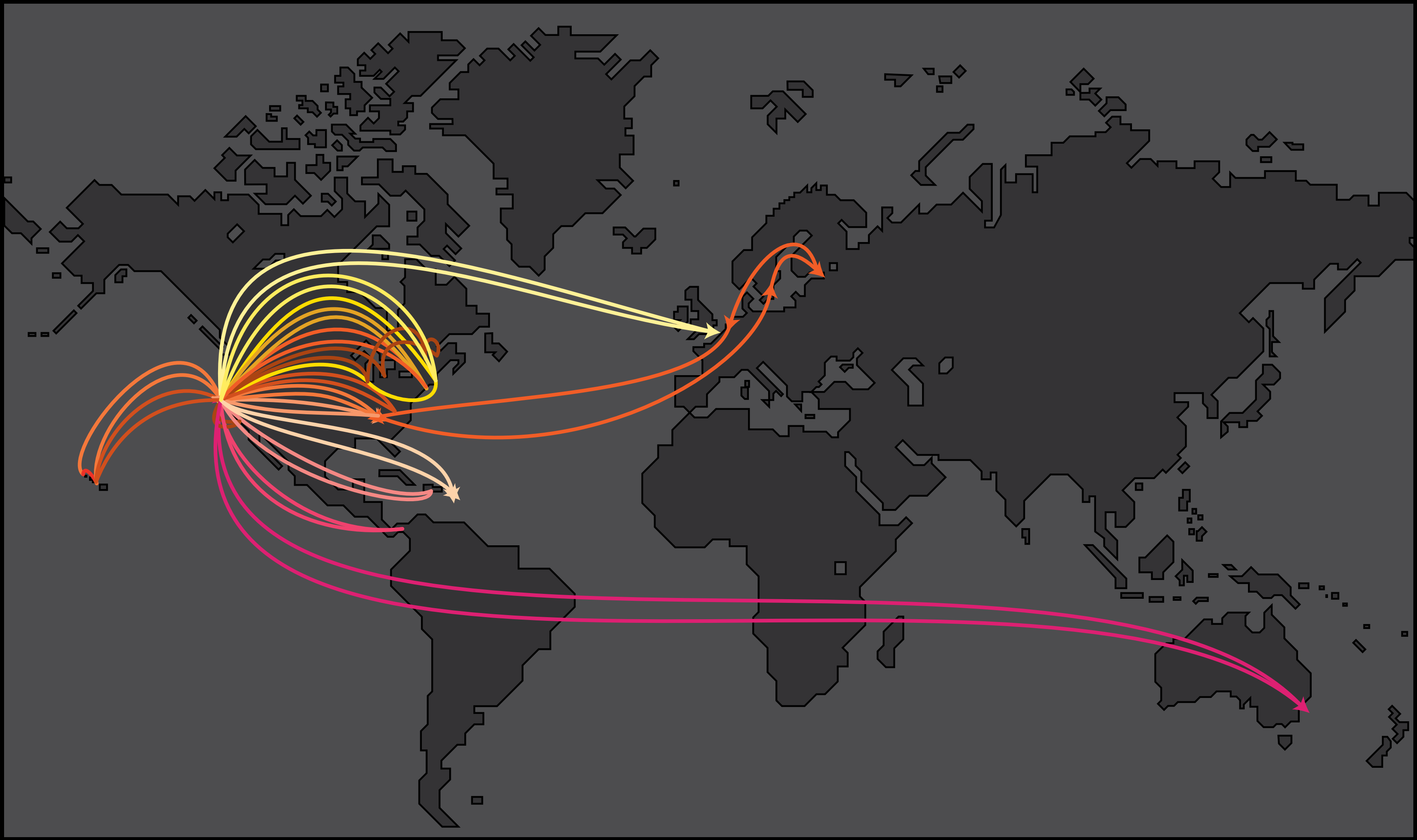
7,992 Watts equivalent. 18.500 kg CO_2

LOCAL STEP 1

My Lifestyle

Air Travel





Driving.

Like my flying, i can honestly tell you that my estimate for my number of miles driven is true, because each vehicle has an odometer, and I have recorded my miles in each. Here is my actual driving miles and cars for 2007:
Honda: 4500 miles.
Dune Buggy. 1000 miles.
Toyota Tacoma: 1200 miles.
Toyota Hilux: 700 miles.
Dodge Sprinter.600 miles.
Taxis and rentals. 2000 miles.

It was the equivalent (10000 miles) of:
Driving from San Fracnisco - Seattle - Chicago - Atlanta - New York, in a HYBRID HONDA. Taking a Taxi rom NYC to BOSTON. Rental car (average 4 door sedan) BOSTON to KEY WEST. Dodge Sprinter (medium sized efficient van) from Key West to Jacksonville (Diesel)). Jacksonville to Tucson in a "truck" or "suv" - toyota tacoma and toyota hilux. Finally I drove my vintage VW dune buggy from Tucson to San Diego, to San Francisco to return home.

I always think of the Citroen 2CV when I think about fuel economy. It has been called the best example of minimalism ever applied to the design of a car.

"Pierre-Jules Boulanger's early 1930s design brief – said by some to be astonishingly radical for the time – was for a low-priced, rugged "umbrella on four wheels" that would enable two peasants to drive 100 kg (220 lb) of farm goods to market at 60 km/h (37 mph), in clogs and across muddy unpaved roads if necessary. France at that time had a very large rural population, who had not yet adopted the automobile, due to its cost. The car would use no more than 3 litres of gasoline to travel 100 km. Most famously, it would be able to drive across a ploughed field without breaking the eggs it was carrying. Boulanger later also had the roof raised to allow him to drive while wearing a hat."

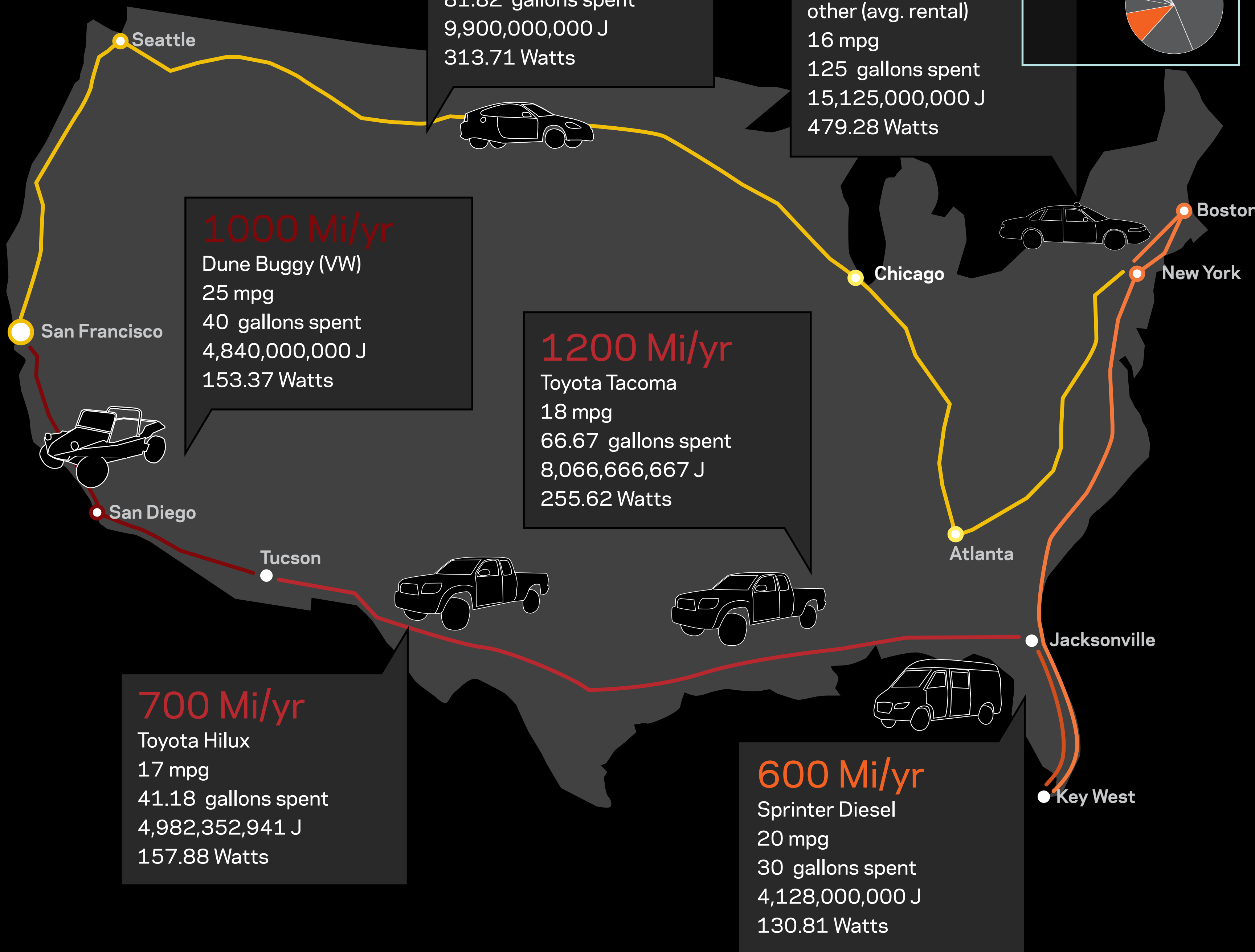
3 liters per 100km is 78 MPG. With 1930's technology !

It's interesting to reflect here, that although the majority of my power budget was spent flying, flying is in fact extremely efficient in terms of energy per passenger mile travelled. The Honda Insight which i drive which by all measures is an extremely efficient automobile, is not quite as fuel efficient as travelling the same number of miles by jet.

Resources
http://www.fueleconomy.gov/
http://www.epa.gov/fueleconomy/
http://en.wikipedia.org/wiki/Citro%C3%ABn_2CV

Driving
10,000 Miles
1,491 Watts

LOCAL STEP 1
My Lifestyle
Car



Home Energy Consumption

I was surprised at how much energy I was using in my home. As regards the electricity, I was surprised that it was so low. As for the heat, I was very surprised that it was so high. My house is in San Franciscowhere year round it is quite mild, some would say chilly in the winter. I don't think the house is terribly well designed for heat use which helps me to understand the gas bill. The heat is gas heated and is blown throughout the house. Most of the windows are double glazed, but not all. The main floor of the house is a concrete slab which is always cold.

A Kill-A-Watt power consumption meter was very helpful in looking at the individual contributors in my house:

In terms of electricity, the main consumer is likely the refrigerator (139 Watts when operating).
Computer: 60W running, 25W sleeping.
Wireless phones 3 x 1 Watt.
Electric Toothbrush 1 Watt (it's always charging!).
Laptops when in use: 21 W (IBM) 35 W (Apple)
Cell phone chargers: 0.5 W

The rest of the power is mostly in lights.

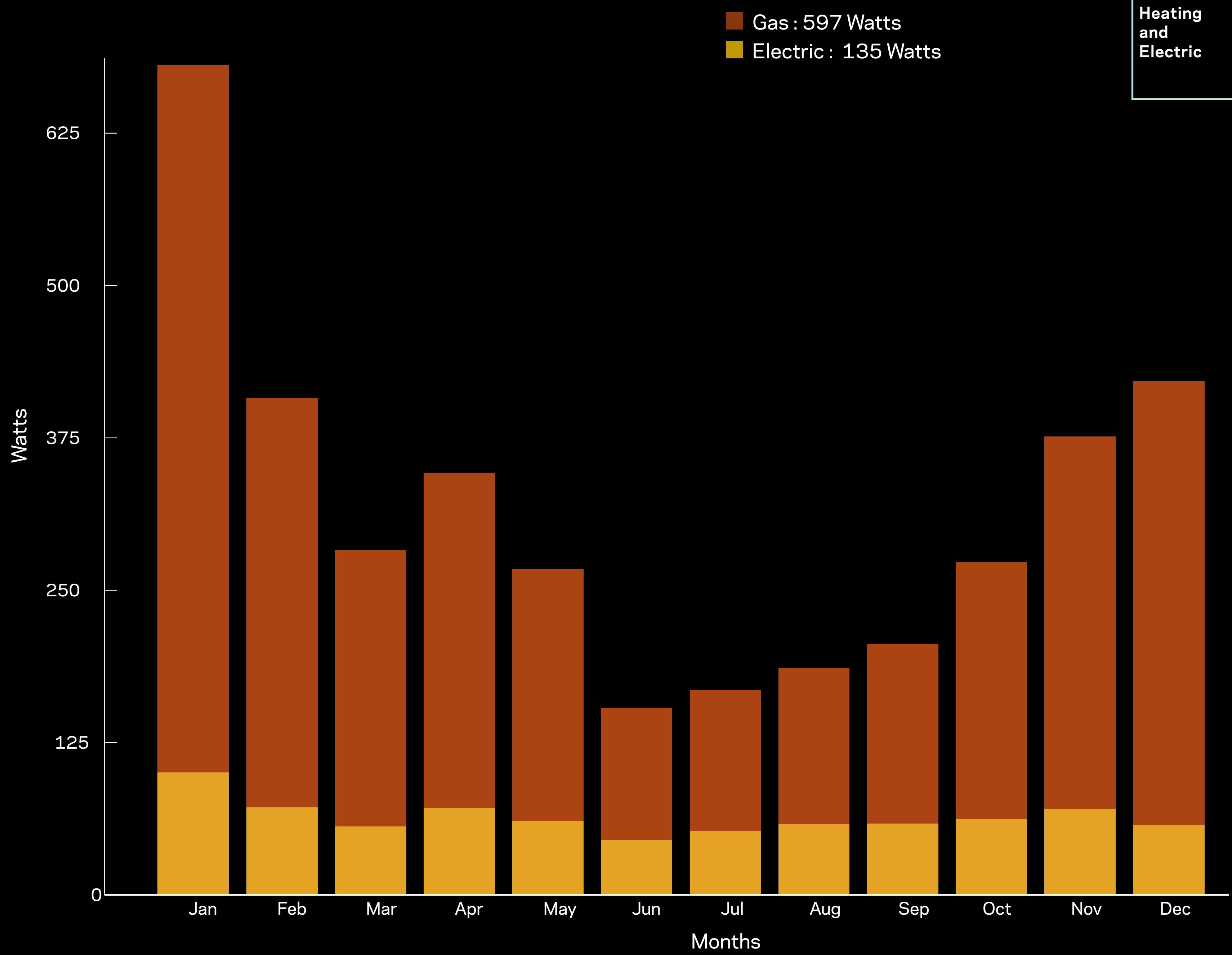
I don't own a television, though we do use a projector occasionally for movies, and we do have a 20 Watt stereo, but it doesn't use that much power at the volumes we run it at. The washer and dryer are gas. The washing machine is electric. The stove is gas, but has an electric clock and display.

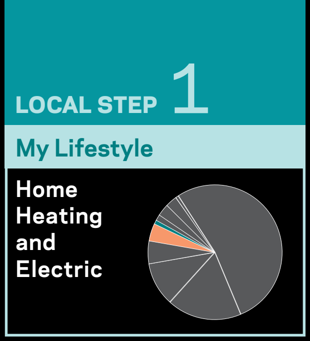
Range	Days	Therm	W(gas)	Kwh	W(electric)
12/8/06 - 1/8/07	32	58	2,213	323	420.57
1/9/07 - 2/7/07	30	57	2,320	290	402.78
2/8/07 - 3/9/07	30	33	1,343	207	287.50
3/10/07 - 4/9/07	31	23	906	167	224.46
4/10/2007 - 5/9/07	30	27	1,099	206	286.11
5/10/07 - 6/9/07	31	21	827	180	241.94
6/10/07 - 7/10/07	31	11	433	134	180.11
7/11/07 - 8/8/07	29	11	463	146	209.77
8/9/07 - 9/8/07	31	13	512	173	232.53
9/9/07 - 10/8/07	29	14	589	164	235.63
10/9/07 - 11/6/07	29	20	842	174	250.00
11/7/07 - 12/7/07	31	31	1,221	211	283.60
Totals	**364**	**319**	**1,070**	**2375**	**271.86**

My 2007 PG&E utility bills, totals which i have divided by two to share with my fiancee.

Resources
http://www.pge.com/myhome/myaccount/explanationofbill/
http://www.amazon.com/exec/obidos/search-handle-url/index=blended&field-keywords=kill%20watt&results-process=default&dispatch=search/ref=pd_sl_aw_tops-1_blended_9407002_1&results-process=default

Domestic energy consumption
2 person stand alone house, 2br, Mission District, SF.





Power Consumption at work...

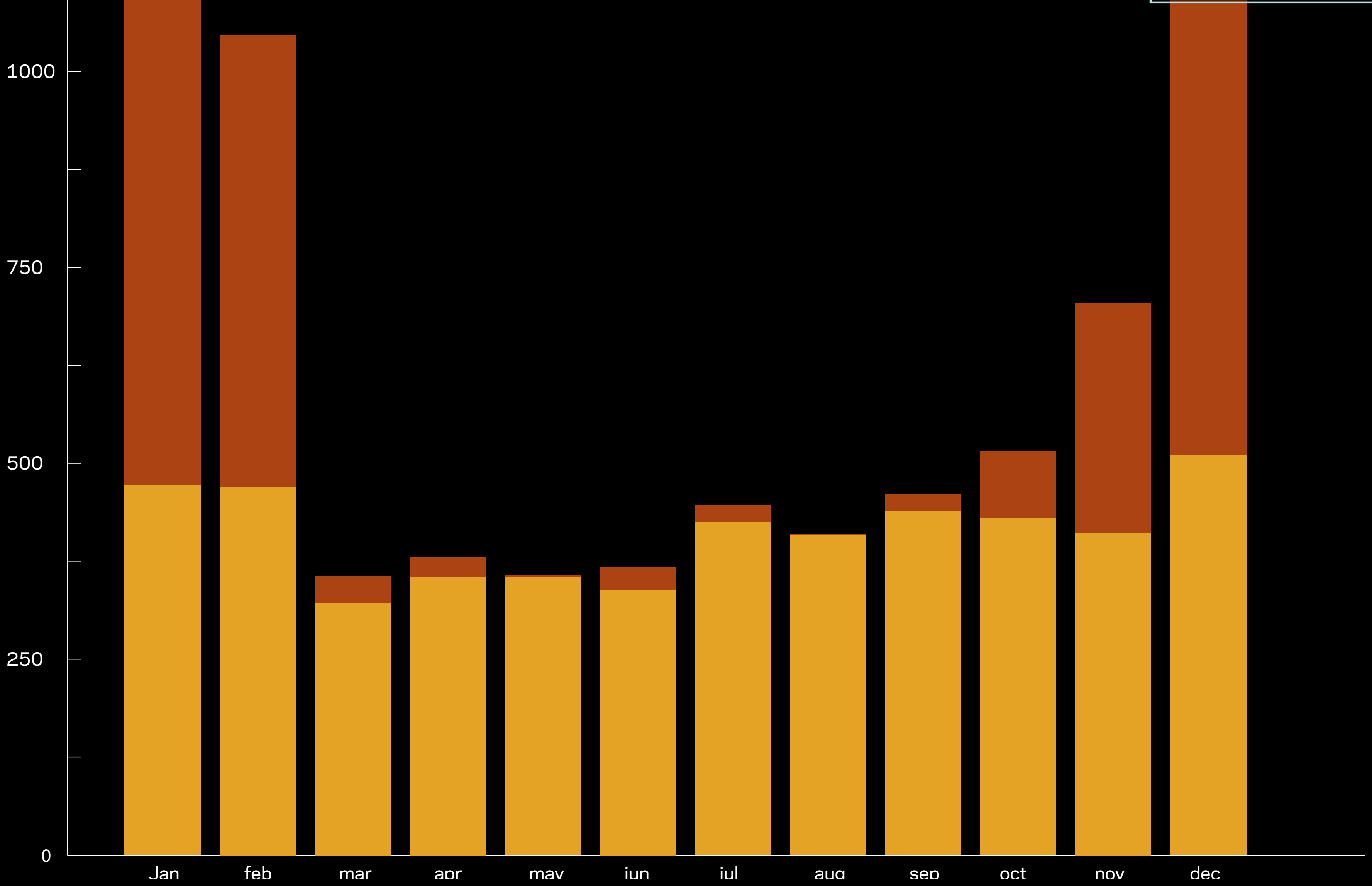
This slide brings up a very interesting point... where do you draw the lines in figuring out your own energy consumption? Does work energy go against you or the product of that work? Hard.... The best accounting and economics minds of our time should be focussed on this question...

My workspace is in Alameda, California, and houses 4 companies. One is a wind energy company, one works on human charged power devices, one works on optical instruments, and the fourth is an internet start-up.

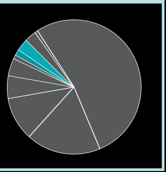
I was surprised at the very high level of electricity consumption. Everyone in the building uses a lot of computers, I am sure that is a large component.

Resources

Work Power Consumption...
18,400² Foot Office, 40 People sharing



LOCAL STEP 1
My Lifestyle



Consumerism.

Every purchasing decision you make has consequences...
Without doubt this is the least accurate section of my calculatinos. Whether by design, gross neglect, or indifference, we have allowed ourselves to reach a point where as consumers we cannot account for the energy of production of the products we consume.
This list is by no means necessary, and many are based on wild estimates.
For example, I have guessed at the embodied energy of my Honda insight and amortised it's energy over a 10 year lifetime. I ignored the other cars that I use, own, or co-own.
For the New York Times I really only calculated the embodied energy of the newsprint per the average weekly weight of the three papers I recieve (friday, saturday, sunday). I'd like to calculate energy of getting NYT online instead, but I don't really like reading the paper in bed off a laptop.
The internet consumption figure is very hard to nail down with estimates between 0.5 and 5% of total energy in the US. I think I use more than the average amount of internet.. Should I accept more than 1 / 300 000 000^{th}? I don't have great confidence in this number, but I'm confident it is a low estimate.
For waste disposal I used the average American's trash disposal rate and the number of miles I guess it travels to the dump in an average dump truck. I'm pretty sure this number is low too.
I calculated a specific case for a bottled drink, and assumed I drank one of those each day (I didn't add the bottle to the food calculation elsewhere, if you are wondering).

The real point here is that a significant amount of my energy consumption (or power use) is in the things or stuff that I buy and use. What I have at right is almost certainly a gross under-estimate of the real energy requirements. I'd love to be able to calculate this more effectively, but the tools are not available, and the data from the companies that produce the goods are non-existent. I would hope that will change with public pressure.

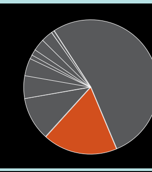
Resources
http://www.greenbiz.com/news/columns_third.cfm?NewsID=30152
http://www.victoria.ac.nz/cbpr/documents/pdfs/ee-coefficients.pdf

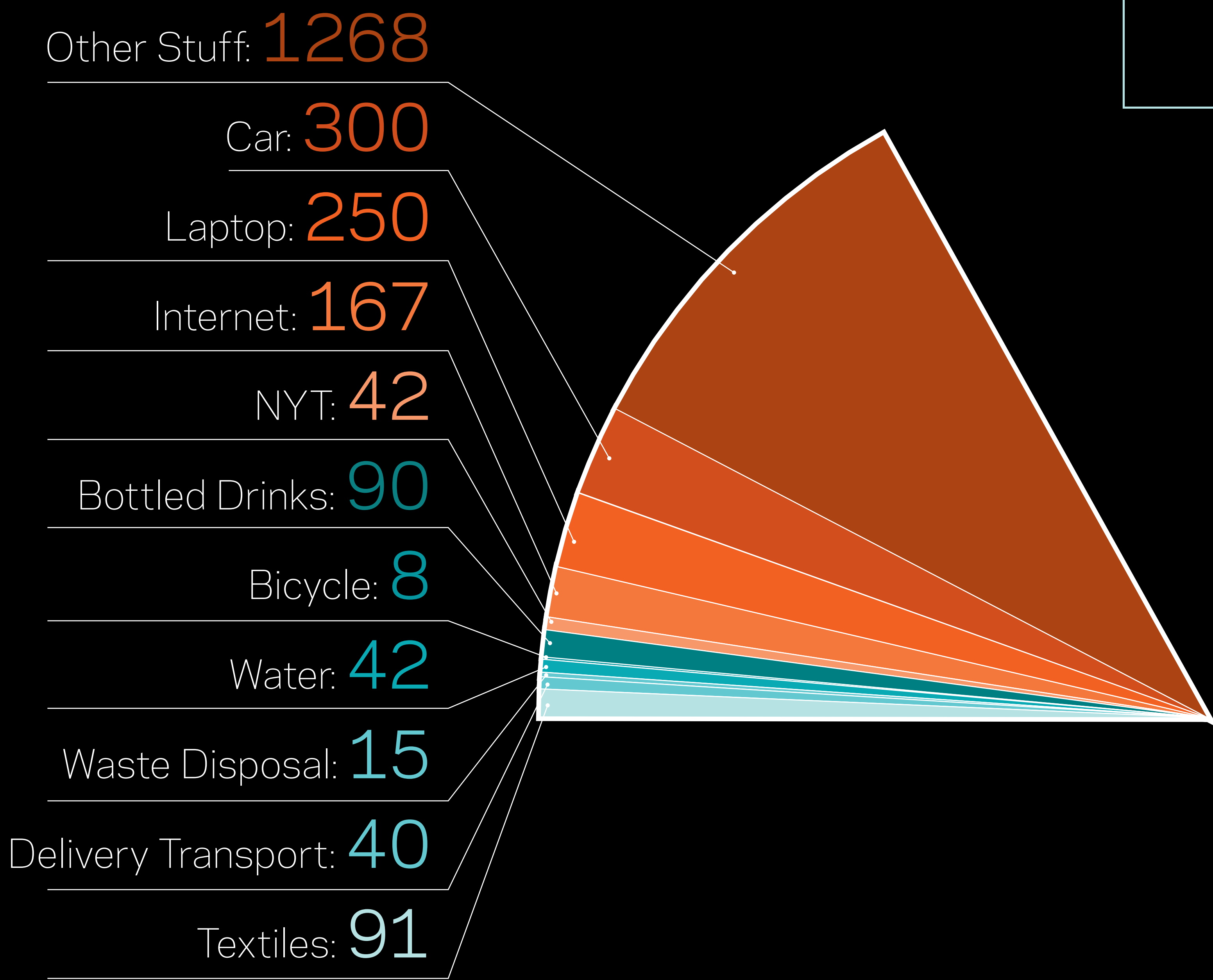
Saul's Materialism Expanded 2,311 Watts

LOCAL STEP 1

My Lifestyle

Stuff





Eating.

This component is almost certainly going to be the most contentious...
If the consumerism numbers were wildly innacurate, these numbers are only slightly better. The wine number comes from a study by someone with the alias "Dr.Vino" who actually did quite a good comparative study of the energy cost of Napa vs. Bordeaux wines for american consumption. Much of the meat numbers comes from assumptions used by David MacKay in "Without Hot Air". I assumed 50gms each of chicken, pork, and beef, each day.
The farming and fertilizer numbers are my 1 / 300 000 000th share of the amount of energy used for these things in the US as a whole.
My transportation estimate is based on 200 miles average distance for all of the foods I eat.
I haven't factored in any refrigeration.

Again, I have low confidence in this number being correct. I'm not sure how I could calculate it more accurately unless I was given a lot more information from food producers. I think this is an important area of research, and the positive note is that more and more people are seemingly investigating this.

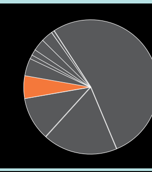
Resources
Omnivore's Dilemna, Michael Pollan, http://www.michaelpollan.com/omnivore.php
http://drvino.com/
http://en.wikipedia.org/wiki/Nicolas_Cl%C3%A9ment

My 2007 diet.

LOCAL STEP 1

My Lifestyle

Food



772 Watts

Milk Cheese: 30 W

Wine: 76 W

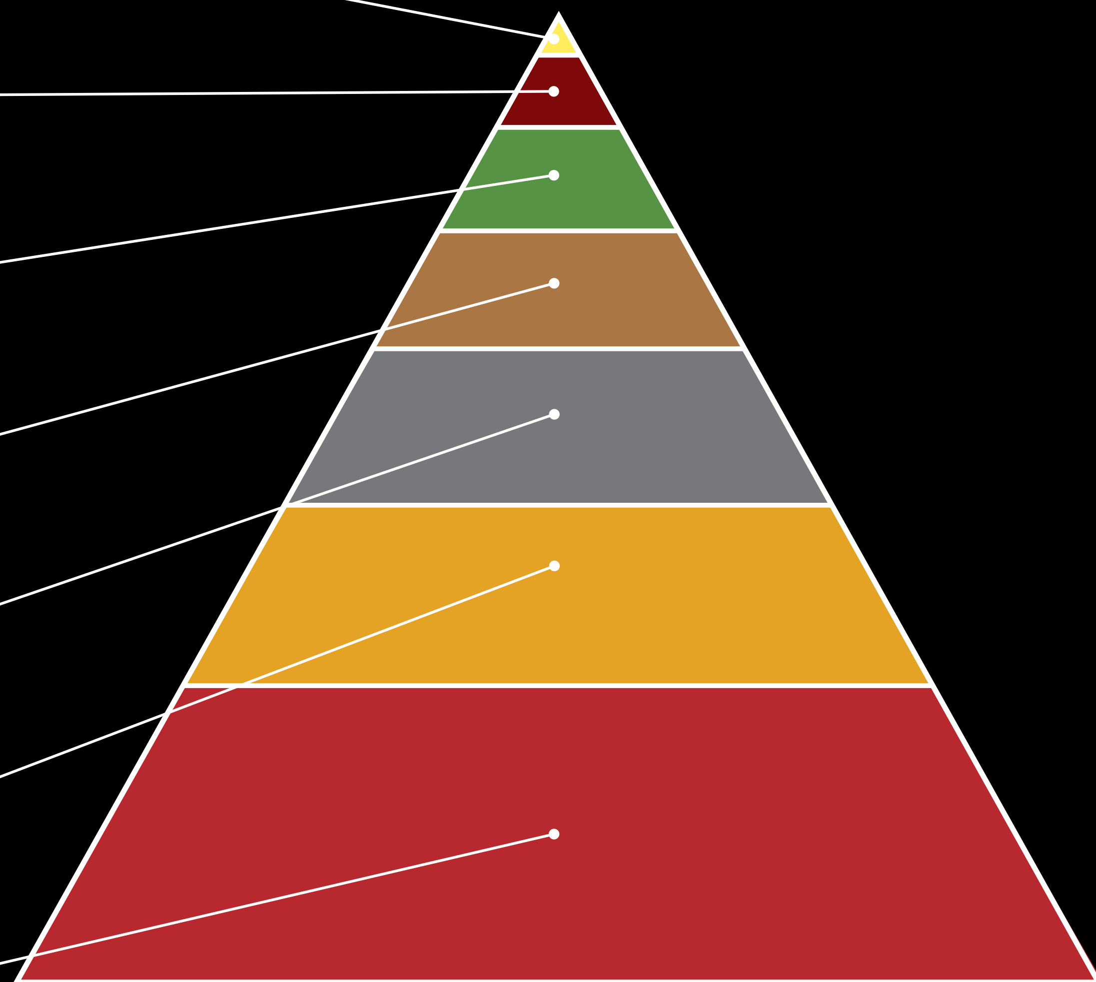
Vegetables: 100

Farming: 100 W

Transportation: 120 W

Fertilizer: 125 W

Meat & Fish: 221 W



You have to include your share of the social fabric...

Fortunately the US government publishes it's energy use by department, I can thus determine my share by dividing by the number of US citizens.

Amusingly this gives me a figure for the US military at an accuracy higher than I can get for the energy consumption of my laptop's construction, or for the delivery of food to my table. And people think the US military is secretive !. They might be, and this number may also be a low estimate, but the most interesting thing to bring up here is that due to freedom of information acts, we can have access to the US government data, whereas for corporations, we cannot. I'd posit a reasonable argument for the same principals of freedom of information (at least regarding energy consumption) for all corporations.

The US nuclear arsenal is not listed (as far as I can tell) in the govt. data, so I have had to guess this value based upon a guess of their budget. I don't know whether it is high or low, but I do know that rightly as a resident of the USA, some portion of the power consumed for keeping the silos warm, should be on my bill.

NASA only gets 1.1W. I think I'd like them to get more. They build and operate a lot of the satellites that give us the crucial data that helps us understand the climate change problem!

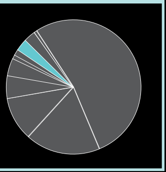
Resources

http://www.eia.doe.gov/emeu/aer/txt/ptb0113.html - US govt energy consumption by department.
http://www.census.gov/population/www/ - US population clock.

LOCAL STEP 1

My Lifestyle

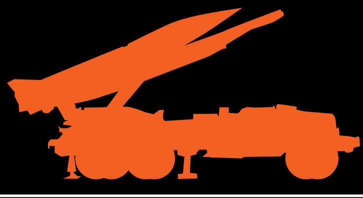
Society



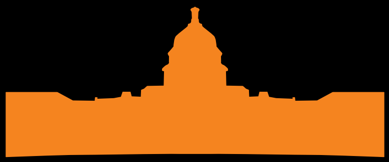
Society

US Military: 94 W

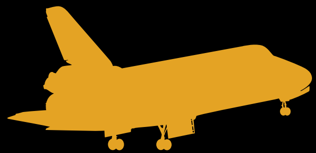
US Nuclear protection: 50 W



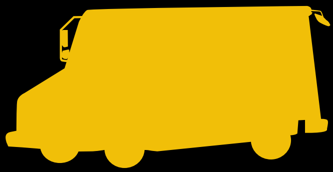
US Government: 18 W



NASA: 1.1 W



USPS: 5 W



Other: 232 W

“Carbon Calculators” - ethical calculators and the hardest ....

Everyone tells you about their “carbon footprint”....

I used the same information I had for my personal calculation as an input to 13 different on-line “carbon calculators” The results were not encouraging. The variance was higher than the accuracy. If these are the tools the general public has to understand their energy consumption, then we simply need better tools. I'm fairly confident that my estimate was at least a factor of two low (as described in previous pages) so my 14000 odd watts, is very likely at least 25000. Are these online calculators similarly innaccurate? I am sure they are. Very few asked me any questions about consumption and the things I buy. At best they all calculate the easy things - your air travel, your car travel, your utility bills. They nearly all stop there.

More by luck I suspect than by genius, the average of all 13 calculators ended up at 11,400Watts, which is the US average.

Is carbon even the right metric to be measuring in?

Resources

http://www.cheatneutral.com/
http://michaelbluejay.com/electricity/
this is how one of the calculators works : http://www.climatecrisis.net/takeaction/carboncalculator/howitwascalculated.html

Footprint calculators?

11333	www.climatecare.org (34 T CO_2)
7800	www.carbonneutral.com (23.4 T CO_2)
16800	www.earthday.net (8.4 planets)
6248	www.safeclimate.net (18.7 T CO_2)
11300	www.bp.com (34 T CO_2)
12040	www.travelmatters.org (36.1 T CO_2)
8783	www.climatecrisis.net (26.4 T CO_2)
12000	www.conservation.org (36 T CO_2)
10167	www.carbonfootprint.com (30.5 T CO_2)
2887	www.epa.gov (8.7 T CO_2)
8067	green.msn.com (24.2 T CO_2)
17433	www.earthlab.com (52.3 T CO_2)
23600	www.treeswaterpeople.org (70.8 T CO_2)
11420	average - which is remarkably close to US average?
14437	My calculation
25000	My estimate

A nobel prize in economics for energy auditing?

This may look like a flippant one line slide. I'm actually quite serious. I think that the issue of energy, power, carbon, carbon dioxide, foot print, etc. calculating is extremely complex, extremely difficult, and extremely important. This is where the best minds of philosophy and economics should meet and help define structures by which this accounting becomes easier for everyone.

Throughout this document, there is room for criticising whether I have accounted for the same things twice. This is a boundary problem. Should I really include my work energy consumption on my personal budget? Should I count the packaging of my foods under food or under stuff? Should employees or shareholders take the carbon of a company?

We need a better framework here, this is a contribution that would be tremendous if economists were to take this on as their greatest challenge.

Resources

http://nobelprize.org/
http://nobelprize.org/nobel_prizes/economics/laureates/
http://en.wikipedia.org/wiki/Nobel_Prize_in_Economics

Nobel Prize in economics for energy auditing?

Each Individual can make an enormous difference.

Great change cannot happen without everyone.

The point of the next few slides is to put in perspective the numbers of people involved.

Don't be intimidated be the challenge. Remember that the behaviour of humanity is the sum of all of our actions. Changing your own actions is the first step.

Resources

Me

LOCAL STEP 3
My Share

It’s not just you though...

When preparing this talk, my fiancee and I had quite heated arguments. The lifestyle changes I was contemplating as a thought experiment she didn't completely agree with. She wanted her say in the way we would change our lives together, and didn't and still doesn't agree with all the conclusions I drew from gathering this material.

If it is difficult to find agreement with those nearest and dearest to you, imagine how difficult global change will be. I certainly made more progress as I started to discuss the positive changes that would occur if we embarked on some set of lifestyle changes. That certainly worked better than saying "starting next week we can only visit your parents once every 3 months!".

Resources

Me and my ladyfriend

This is a thousand people.

You can imagine a thousand people. It's probably the size of your high school, or of the largest gathering you have ever been to except for sporting events.

Resources

1000 people

LOCAL STEP 3

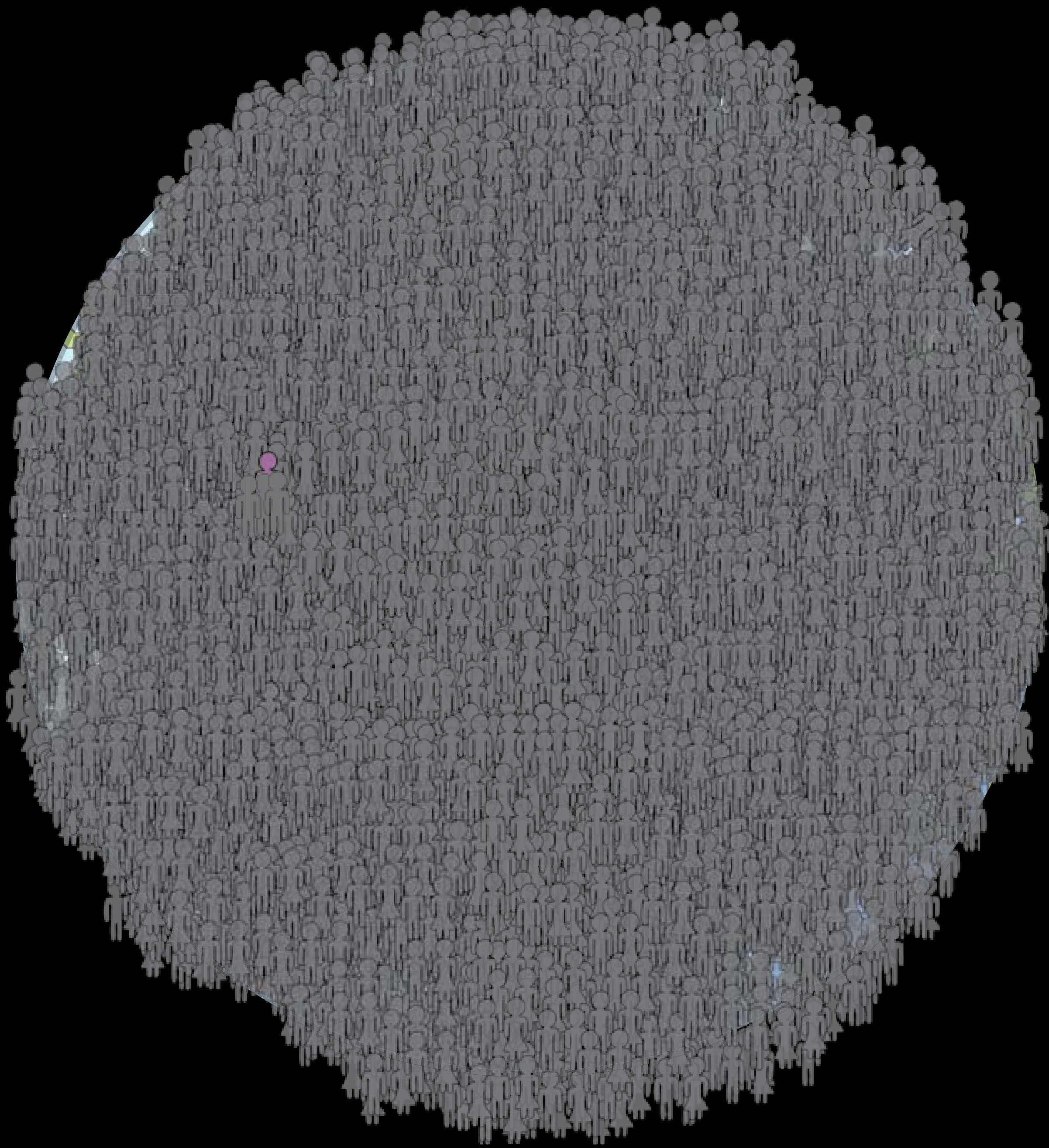
My Share

This is a million people.

You have probably never seen 1 million people in the same place at the same time. It is a lot of people. It is most likely the rough magnitude of people in the city you live in....

Resources

1 000 000 People



This is a billion people.

Nobody has ever seen a billion people in one place at the same time. It is more than you can imagine.

There is one interesting thing about thinking about 1 billion people, or even 6.65 billion people.

A coal fired power plant is typically a gigawatt or multiple gigawatts. That's a billion or a few billion watts.

Right now a new coal fired power plant is installed roughly every week somewhere in the world.

Every time 1 billion people use 1 extra watt, that's a gigawatt power plant that needs to be installed somewhere.

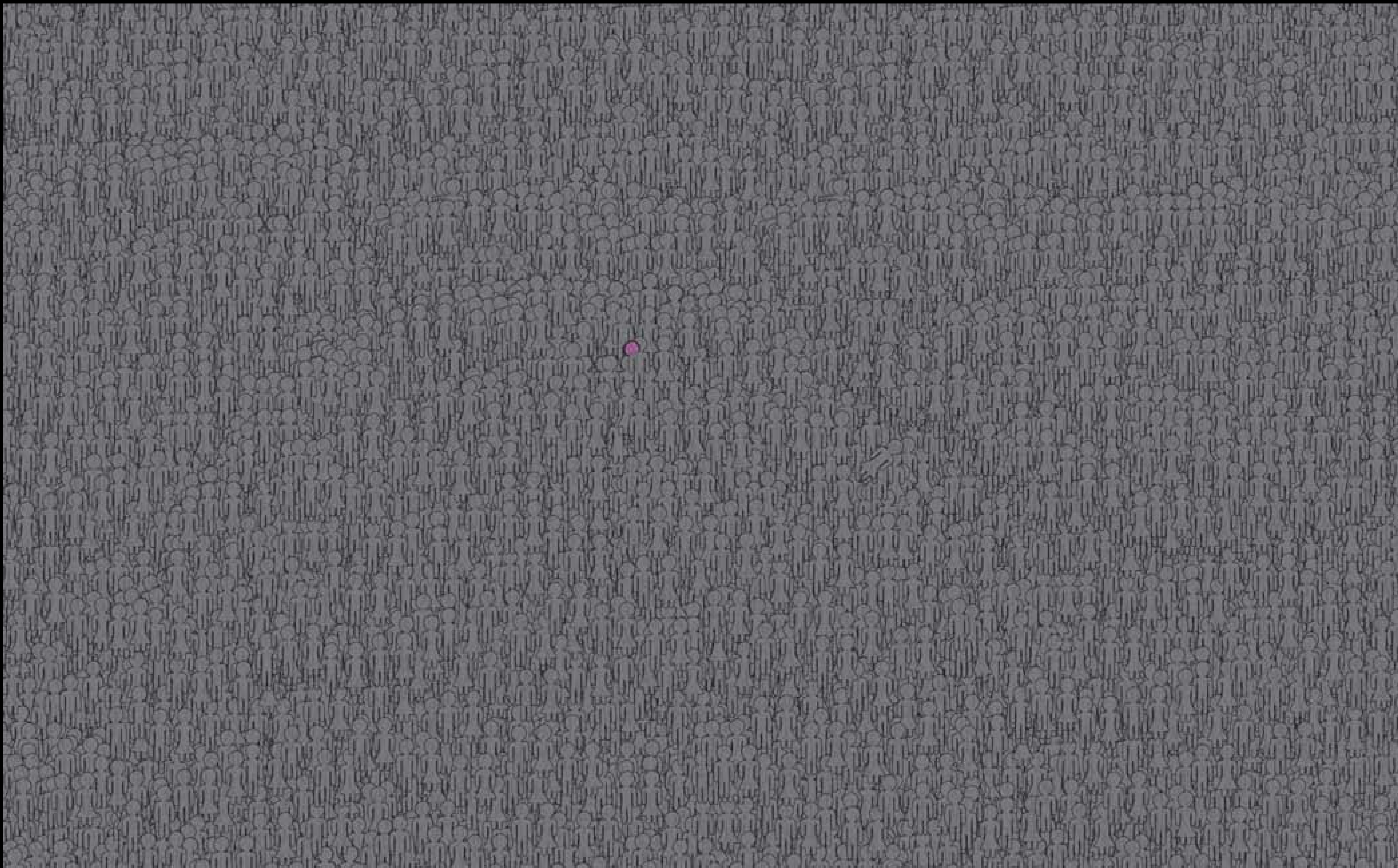
Conversely, every time 1 billion people reduce their power consumption by 1 watt, that's a gigawatt power plant we can turn off.

Turning a 25 watt light bulb off for 1 hour more each day is the equivalent of reducing 1 watt from your lifestyle.

There is the overwhelming assumption based on simple mathematical models of existing population rates that the population will rise steadily to something like 9Billion in 2050. I find it very difficult to believe the extremely simplistic geometric progressions of these models. I suspect it is much more likely that the growth rates will be slower.

Resources
http://www.prb.org/

1 000 000 000 People



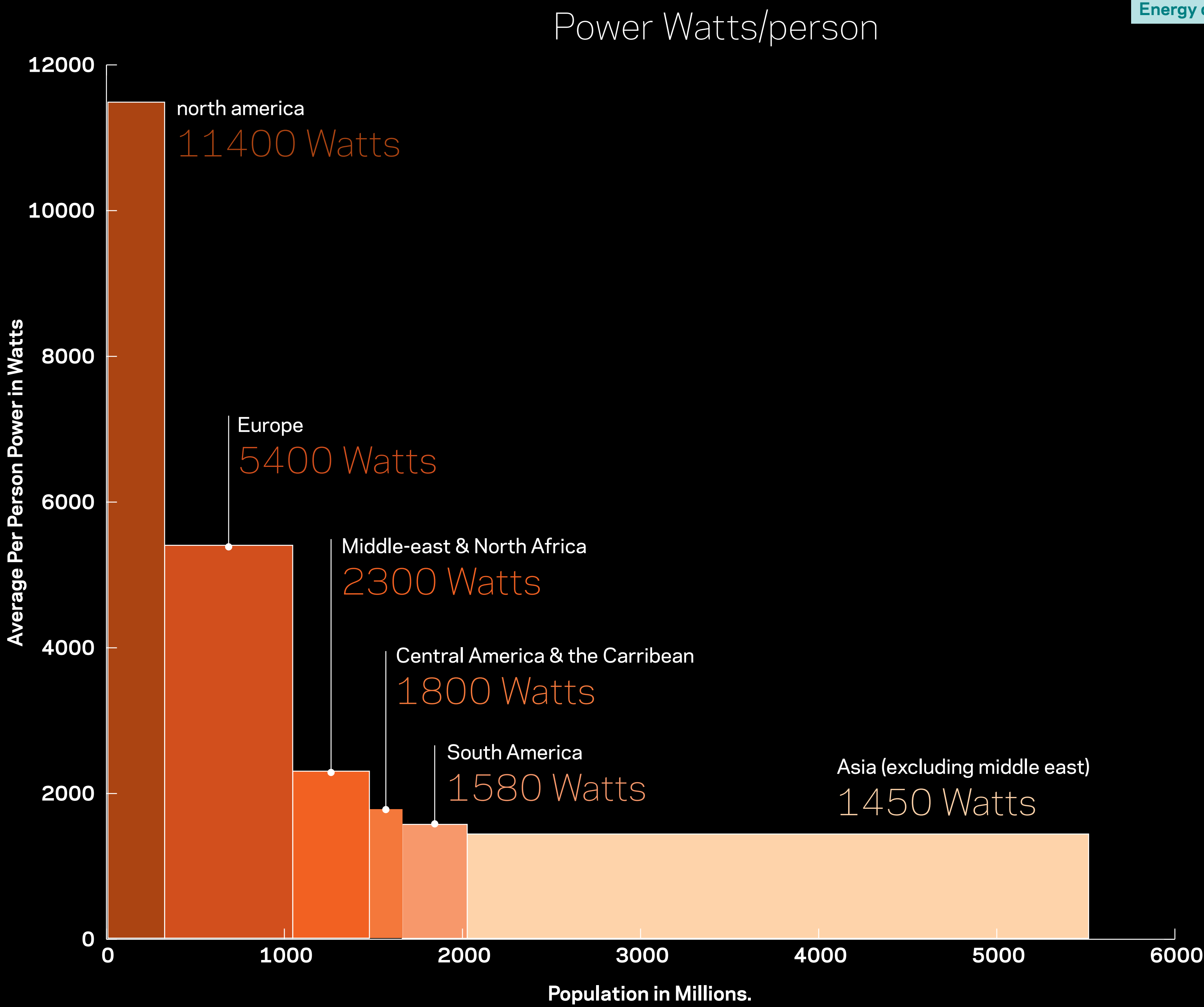
The demographics are important.

Now you've seen one person's in depth tally, you understand how easy it is for your personal consumption to add up. From published data we can look at how different countries compare on a per capita basis. This gives us perspective on where the power is consumed and by whom.

Resources

http://en.wikipedia.org/wiki/World_energy_resources_and_consumption
http://atlas.aaas.org/index.php?part=2&sec=natres&sub=energy
http://www.worldmapper.org/
http://www.eia.doe.gov/oiaf/ieo/world.html
http://earthtrends.wri.org/searchable_db/index.php?theme=6&variable_ID=351&action=select_countries

Energy Use by Region



6.65 Billion people and the division of our energy resources.

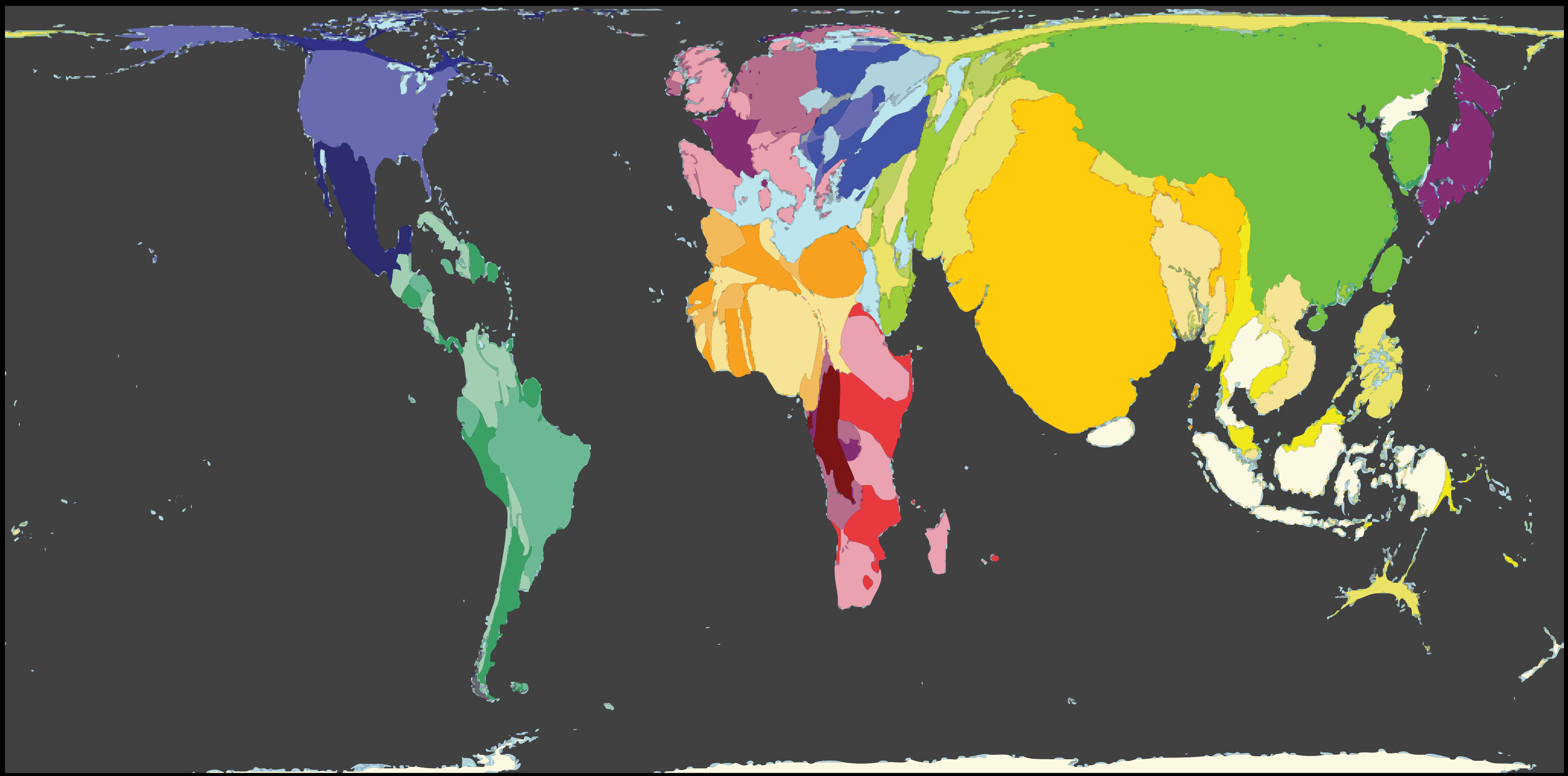
To put my personal energy consumption in perspective, I thought it would be useful to see how it would be impacted if I took an equal share of today's world energy consumption. With 6.65 billion people and 15 terawatts, it turns out that my equal share should be 2255 Watts. That's quite a lot less than my 14000 Watts, and not even 1/10th of my more realistic estimate of 25000 Watts.
What changes will I have to make to hit a 2255 Watt target? The next slides put it in perspective.

There is a hidden assumption in these slides and this talk that humanity's power consumption will remain at 15TW and that the population will remain at 6.65 Billion. Obviously neither of these things is true. These numbers were really used just to inform the thought experiment. If the population rises significantly that makes the challenge that much greater. Similarly if our power consumption rises significantly that makes the power generation challenge with non-carbon technologies that much greater.

Resources

Wikipedia and World Population http://en.wikipedia.org/wiki/World_population
CIA's The World Factbook https://www.cia.gov/library/publications/the-world-factbook/print/xx.html
World POPClock Projection, U.S. Census Bureau http://www.census.gov/ipc/www/popclockworld.html
United Nations report: The World at Six Billion http://www.un.org/esa/population/publications/sixbillion/sixbillion.htm

6 650 000 000 People



$$\frac{15\ 000\ 000\ 000\ 000 \text{ Watts}}{6\ 650\ 000\ 000 \text{ People}} = 2\ 255 \text{ Watts per person.}$$

My new life. Shooting for 2255W

Lots of people in the world already do it, and it is reasonable to consider that we might give everyone a roughly equal share, that is, live a lifestyle equivalent to 2255 Watts.

I wanted to know what changes I'd have to make to my life in order to be able to say "I live a 2255 W lifestyle".

As my base caclulations I used the same data I used for my 2007 calculations. I removed those things I can do without, I lowered those things that were consuming too much energy. Throughout the process I really tried to keep for myself a lifestyle that I would enjoy, and that perhaps would even be better than the lifestyle I enjoy today. Privation is not the goal of this exercise, it is to raise my own awareness of my energy use, and my awareness of what my energy use should look like in the future if I am to be a good citizen of the world.

It turned out that I found it very difficult to get to 2255W. The easiest way will obviously be to further decrease my air travel. I didn't do it here however, because given my work-life, no-one could imagine me completely stopping flying.

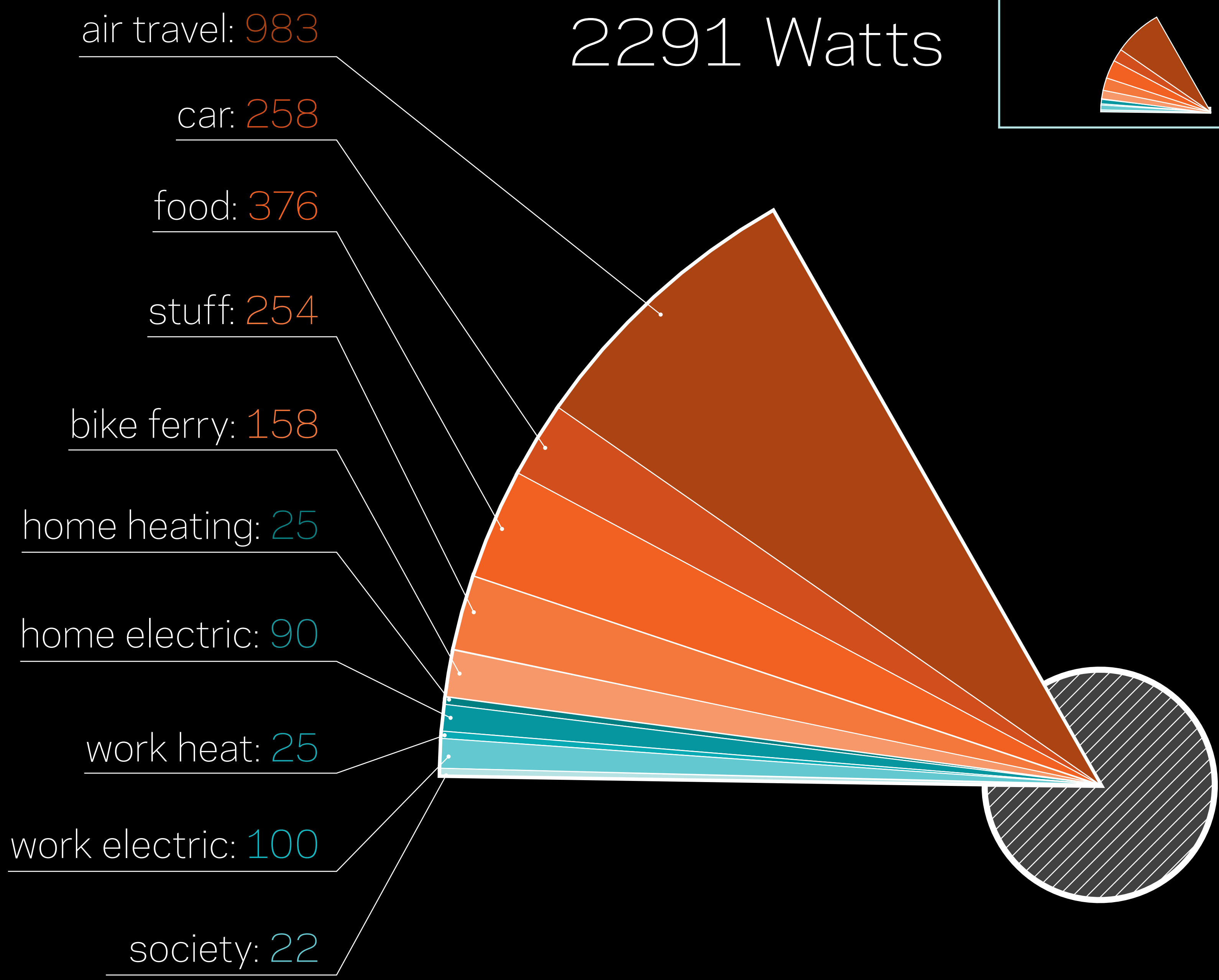
It certainly looks like tele-conferencing and tele-commuting are the most important technological developments for me to adopt. If it could be substituted for all business related travel I would be in much better collective shape. I'm quite certain that if I only get 2255W that I'd prefer to use the majority on my family, my hobbies, my sports, and my recreations and lifestyle.

Resources

Incidentally 2000 Watts is a number that an inspired group of people are already using as their target goal : http://en.wikipedia.org/wiki/2000-watt_society

My New Life


LOCAL STEP 4
My New Life


2291 Watts
air travel: 983
car: 258
food: 376
stuff: 254
bike ferry: 158
home heating: 25
home electric: 90
work heat: 25
work electric: 100
society: 22

My new flight paths.

My 2007 measured flight data was quite obviously unsustainable. I did a lot of work and was very productive on all of those trips, and some trips were even fantastic holidays, but I can't keep that up. In my new 2000W life I am now allowed to fly:

Once every year from San Francisco to the east coast (probably either New York or Boston).

Once every three years I can fly from San Francisco to Sydney, Australia, to visit with my family; my parents, my sister and brother in law, and her neice and nephew. If my family alots a similar flight travel priority I can probably spend time with my closest family once every year (with my sister visiting once every three years and my parents once every three years, not overlapping).

Once every 4 years I can fly to Europe. I do business in Europe, but I also enjoy vacationing in Europe, so it is quite obvious that I will now have to combine those two things. More careful planning would mean the trip would probably be much longer and I would travel within Europe by train and bicycle to see friends and business colleagues.

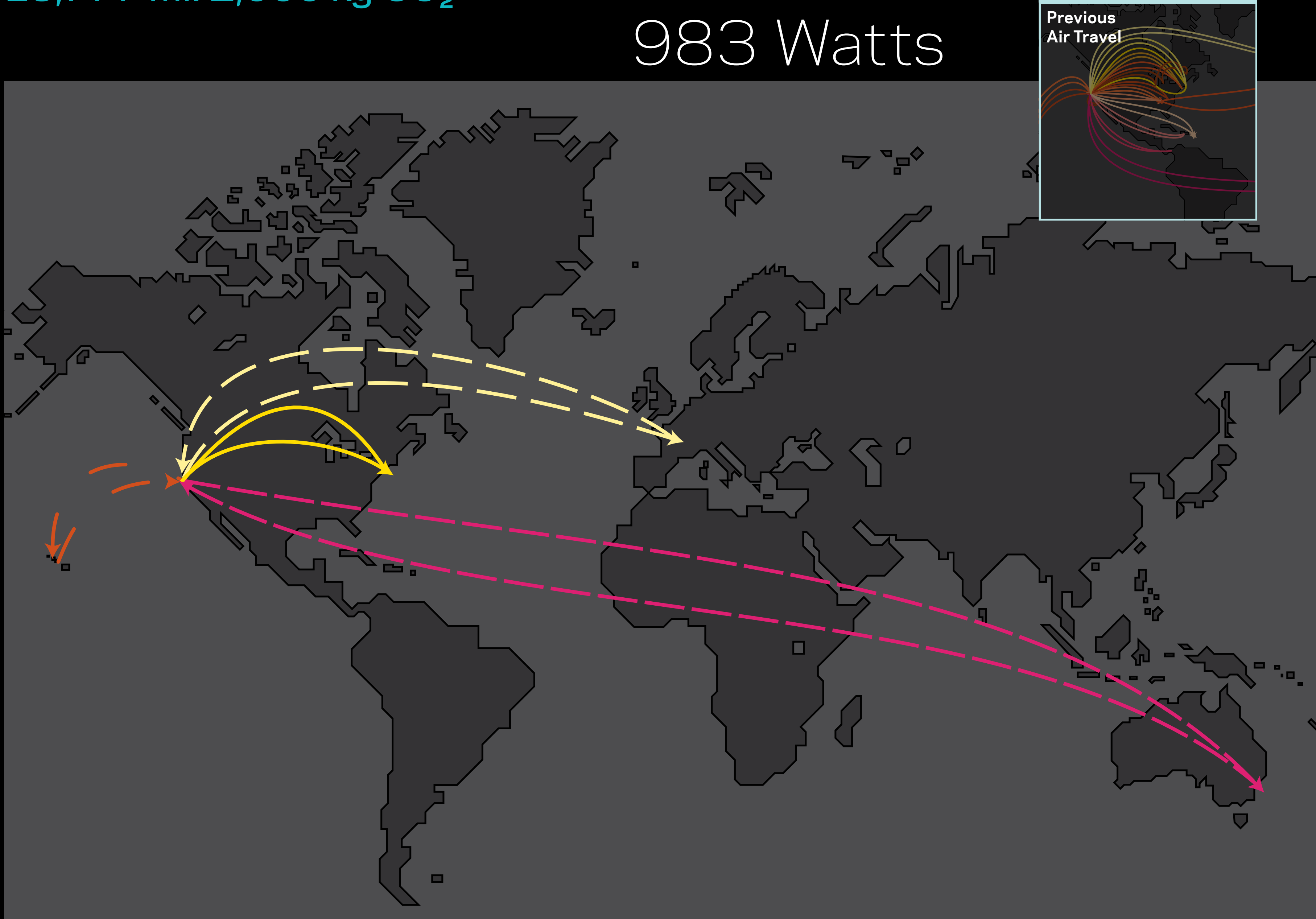
I have also included one return trip to Hawaii every 10 years for a holiday. This distinctive treat will be cherished all the more because I know that it is rare, and that it should be rare, and I can understand that the places I will visit on holidays will only be there if we protect the environment. Perhaps our holiday destinations will be more beautiful because we use visit them more sparingly and collectively protect them from climate change.

Resources

Sed imperdiet arcu id lacus. Suspendisse quis orci. Morbi sem ipsum, sagittis rutrum, fermentum vitae, commodo non, magna.
Donec augue. Vestibulum est felis, auctor lobortis, vestibulum in, tempus eget, eros. Fusce pretium ante id ante. Ut pretium cursus pede. Nam congue dolor a erat. Duis tellus diam, pulvinar ac, faucibus at, consectetuer egestas, diam. Fusce mauris elit, cursus sed, mollis ut, varius in, turpis. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Etiam pede augue, porta volutpat, vehicula vel, laoreet ut, elit. Mauris at lacus. Etiam lacus lectus, sodales vitae, convallis dignissim, imperdiet sed, eros. Proin id leo. Praesent ut orci. Nunc volutpat tellus et orci.

Saul Griffith. 2010:
13,777 Mi. 2,000 kg CO_2

983 Watts



LOCAL STEP 4

My New Life

My new driving habits.

As with the big changes in my flying habits, the other biggest impact on my life in a 2255 Watt lifestyle will be the changes in how I drive, where I drive, and with whom I drive.

You will remember in 2007 I drove the equivalent of a complete circumferential lap of the United States with a few side trips as well. In my 2010 future I will most likely not leave the Bay Area of San Francisco in my car.

I get to drive my fiancee's Honda Insight to work, from San Francisco to Alameda, twice per month. Most of those trips I will carpool with a passenger. I will probably choose the 24 wettest and coldest days of the year to drive and enjoy cycling and public transport for the rest of the year. I'm lucky enough that I can also work from home (tele-commute) on days where it is too wet to ride, and I do not have scheduled meetings.

From work in Alameda I will get to drive once per month in the company van to Mountain View or to Palo Alto. This trip will be with at least one other person and generally will be to go to talk to investors or partnering companies.

For family and recreation I get to use a few of my car trips.

Once every two months I can drive with my fiancee (by then she will be my wife) to Sebastopol, where her parents live. We will use her very efficient hybrid.

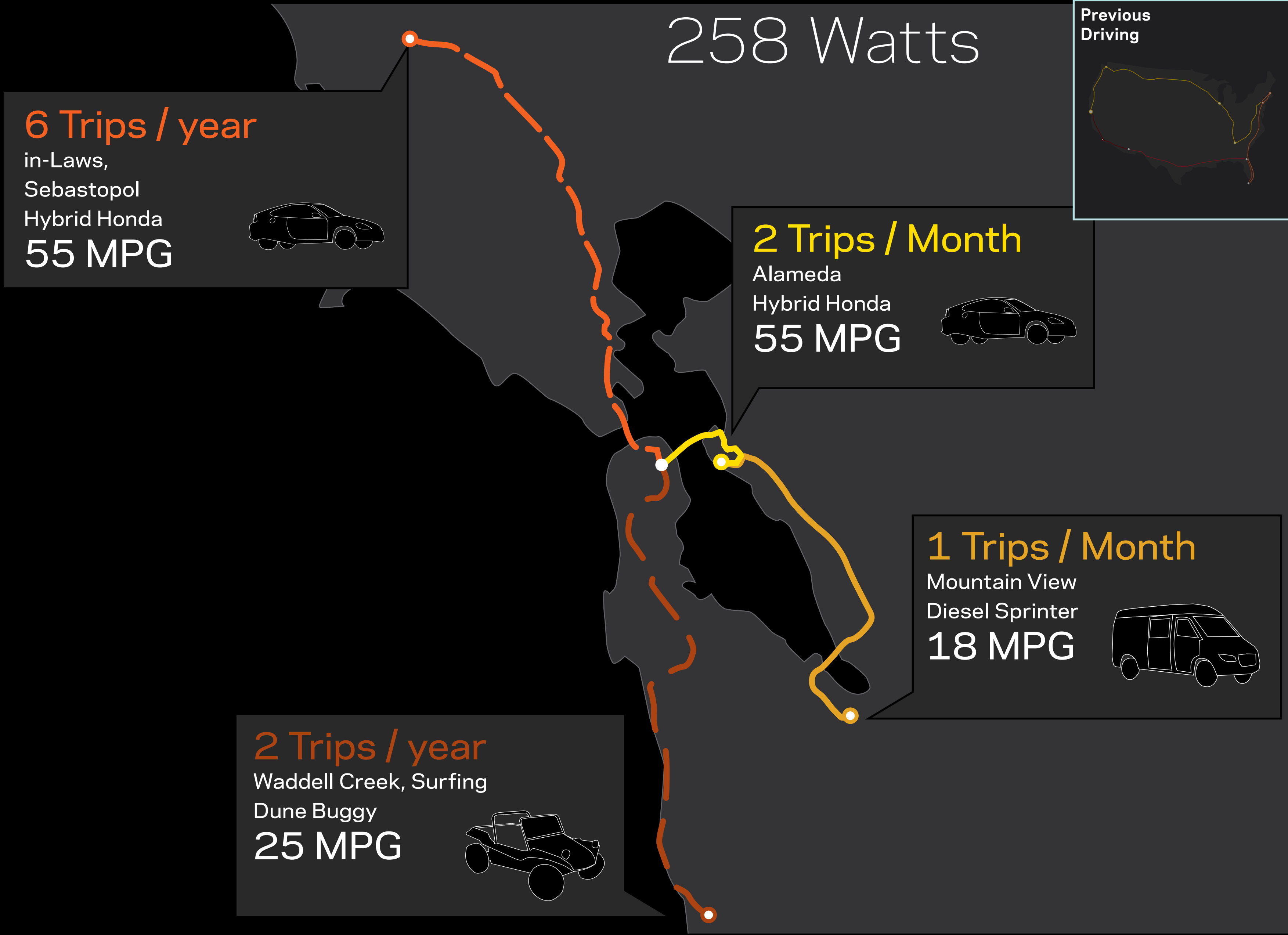
I still get to enjoy my vintage volkswagen beetle / dune buggy in the purest californian style. Twice per year I can load it up with surfboards and kites and drive to Waddell Creek, near Santa Cruz, to go surfing with one friend who will share the impact of this recreational trip. I probably will have to drive conservatively because (unfortunately) the Dune Buggy gets terrible mileage (closer to 12mpg) if I am driving it fast and aggressively (but boy is that fun!).

Resources
http://www.fueleconomy.gov/feg/findacar.htm

Saul's new driving habits

LOCAL STEP 4

My New Life



Food for thought.

Another big change in my life will be my eating habits. In all honesty though, they will probably be for the better, both in health and quality.

In 2007 it was fairly obvious that the most significant contributor to my food energy budget was my meat eating. By becoming “a 6/7ths vegetarian” I can cut out most of my meat energy use. It does consequently increase my vegetable budget, but not out-rageously.

Of all of my friends, those that I think are the healthiest, and have the best fitness, they are generally mostly vegetarian, but not exclusively. They eat more salads and vegetables and fruits than I do, and less meat. It will probably be good for me to adopt their diet. I’m currently 216lbs or 98 kg, and I really should be 185lbs and 84kg.

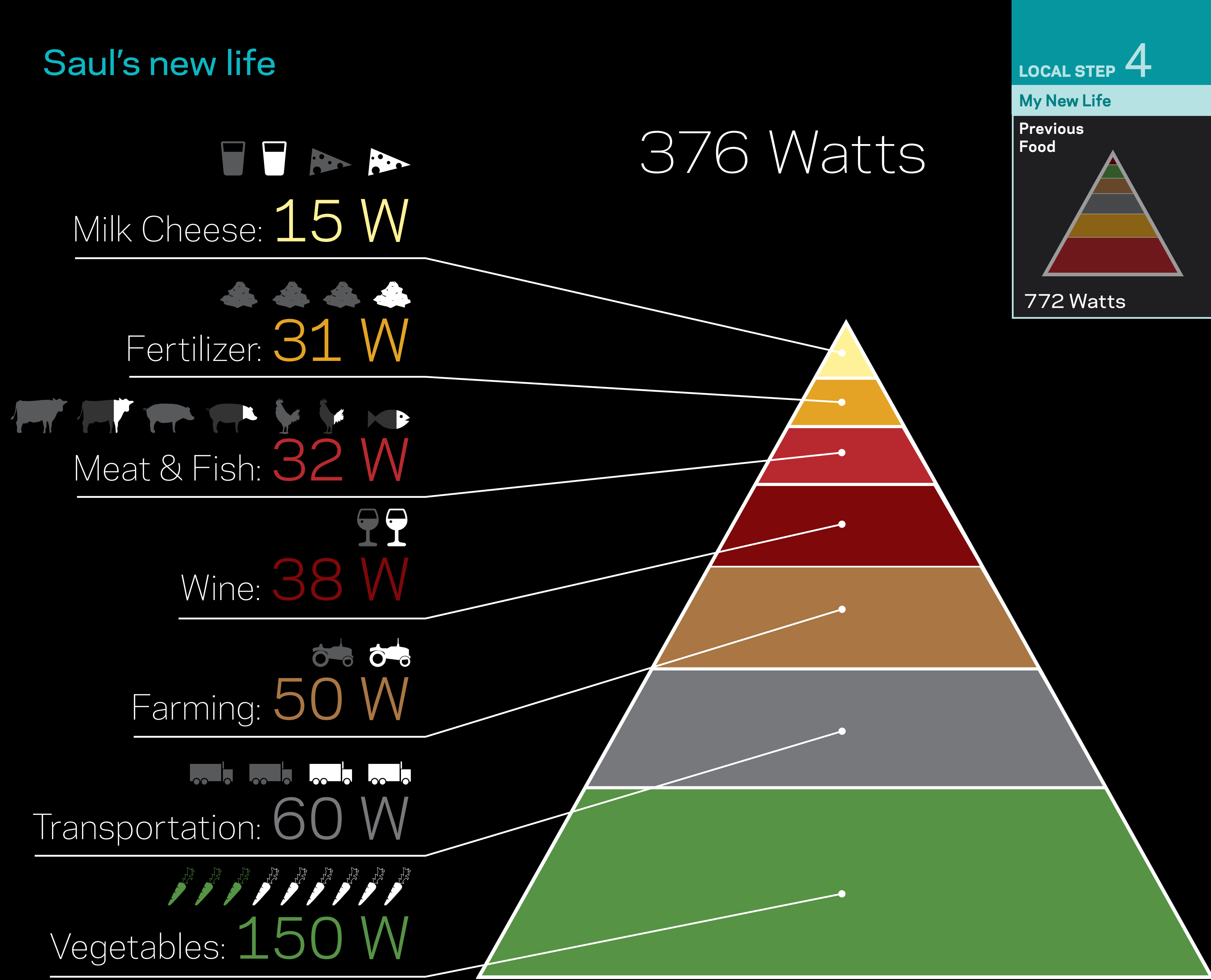
To further decrease my energy budget for food I have to reduce drastically the miles that the food travels. Eating local really does make sense. Hopefully I’ll be eating fresher more seasonal food too. This actually excites me.

I also have to decrease the fertilizer budget which will probably happen if I eat “organic” food. I’m not sure how to calculate the relevant energy benefits of local organic vs. industrial agriculture, but optimistically I’m hoping that it really helps. Anecdotally I've heard recently that it doesn't help. That wouldn't be terribly surprising - large scale manufacturing typically has energy advantages. Once again a need for better data and better analysis.

I have to decrease my milk and cheese consumption by 50%. It was 450gms in 2007. I love cheese, and I love milk. A lot of the milk I drink now is in Mocha’s and Lattes and Cappuccinos. I actually like straight espresso more, so many fewer mocha’s and cheese for special occasions, not a daily staple in 2010!. You’ll note that I didn’t include coffee in either of my food calculations. It was too hard. Coffee is very energy intensive, so once again, my estimates are probably on the low side.

Wine ! I get to drink only one glass a day in 2010. That’s probably a health improvement, but wow, i do like wine.

Resources
Omnivore’s Dilemma.



Saul's new life
376 Watts
Milk Cheese: 15 W
Fertilizer: 31 W
Meat & Fish: 32 W
Wine: 38 W
Farming: 50 W
Transportation: 60 W
Vegetables: 150 W
LOCAL STEP 4
My New Life
Previous Food
772 Watts

Things. Stuff. Junk. Objects. Consumer products.

Where to start?

As my previous estimates of consumer items was already in-naccurate I didn't think it worthwhile to labor over projections of my future use of stuff, and my future consumption habits. In short though, the simplest fix is that I will have to buy fewer things, and make them last much longer.

I can actually imagine that this will mean an improvement in my quality of life. To only by extremely high quality items and to make them last my lifetime, if not the lifetime of my children as well. For furniture and bicycles and kitchen implements I can imagine this is possible, and I already attempt to do it. http://www.saulgriffith.com/Make/make10.pdf

This will be much more difficult for my electronics devices. I might own my dining table for 50 years and my children for another 50, but can I imagine a cell phone lasting 10 years? let alone 3? What about laptops?

There is no "away".

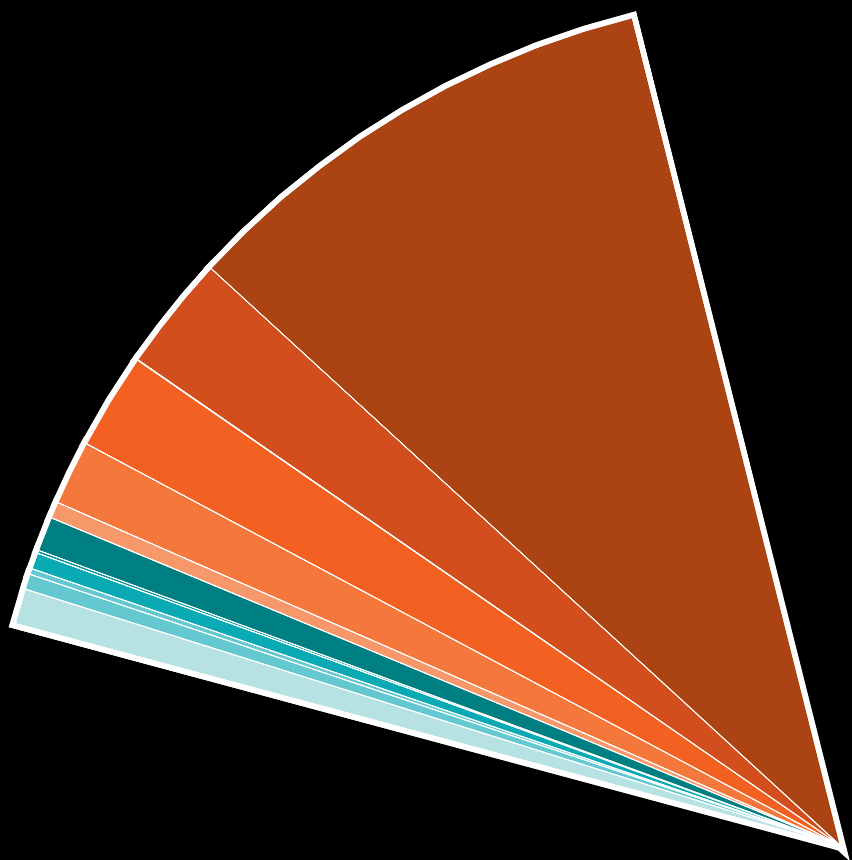
Resources

http://globalclimatechange.wordpress.com/there-is-no-away/
http://www.answers.com/topic/barry-commoner (originator of "there is no away")
http://www.saulgriffith.com/Make/make10.pdf

Saul's stuff, old life vs. new life

1/10th as much stuff lasting 10 times as long.

Old stuff: 2311 W



New stuff: 254 W

Why can't we all speak the same language?

Energy and power are not particularly intuitive concepts for people to grasp. For some reason, you can say "this needs a horsepower" and people can understand it, but when you say "this needs 750 Watts" they ask "Watts per what?". A lot of people are comfortable with kWh per day, because that's the units they pay their energy bills in. Oil companies like using units of Barrels of Oil Equivalent or MBOE. That's not intuitive to many others. Therms and BTU's (British Thermal Units) aren't exactly intuitive either.

This table is a little whimsical, but it will give a sense of the many different ways different people think about power and energy. We chose Watts for this document largely because it is based on the SI system and is well established as a standard.

We will certainly be better served by getting broad agreement on a standard so that people are generally able to compare things and understand things. I am personally like Watts and would vote for that, but I really don't mind as long as we find units for the energy conversation that are the most understandable for the most people. If that is horsepower I'm more than happy to talk in horsepower.

Note that I changed my current use estimate in previous slides to the number here. I didn't reclaculate this tabe, so there is a small discrepancy, but the result is the same.

Resources

http://bioenergy.ornl.gov/papers/misc/energy_conv.html

Google's online calculator is an excellent resource. It will automatically convert between many of these units. Try for example entering "2255 Watts in kilowatt hours per day" and see what you get.

Why are people confused?

My new life:	Measured by:	My old life:
2255 Watts	Engineers	14437 Watts
2255 Joules/second	Physicists	13390 Joules/second
194 MJ / day	"the French"	1.15 GJ / day
54 kW-hr/day	Electricity people	321 kW-hr/day
184 kilo BTU / day	Air conditioning people	1 million BTU / day
46 kilo(kilo)Calories / day	Weight Watchers	276 kiloCalories
143 Million foot-lbs per day	My VW mechanic	853 Million foot-lbs per day
184 pico-quadrillion BTU's/ day	DOE	1 nano-quadrillion BTU's/ day
1.5 gallons of gas / day	Your gas station	8.7 gallons of gas / day
4.3 kg of oil equivalent / day	Exxon	25 kg of oil equivalent / day
3 Horsepower	My grandfather	18 Horsepower
5.4 Tonnes of CO_2 per year	Environmentalists	32.1 Tonnes of CO_2 per year
0.76 (NEW WORLD) Tonnes of CO_2 per year	World Planners	I DON'T GET THIS MANY
2.2 billion carbon atoms per nanosecond	Chemists	14 billion carbon atoms per nanosecond

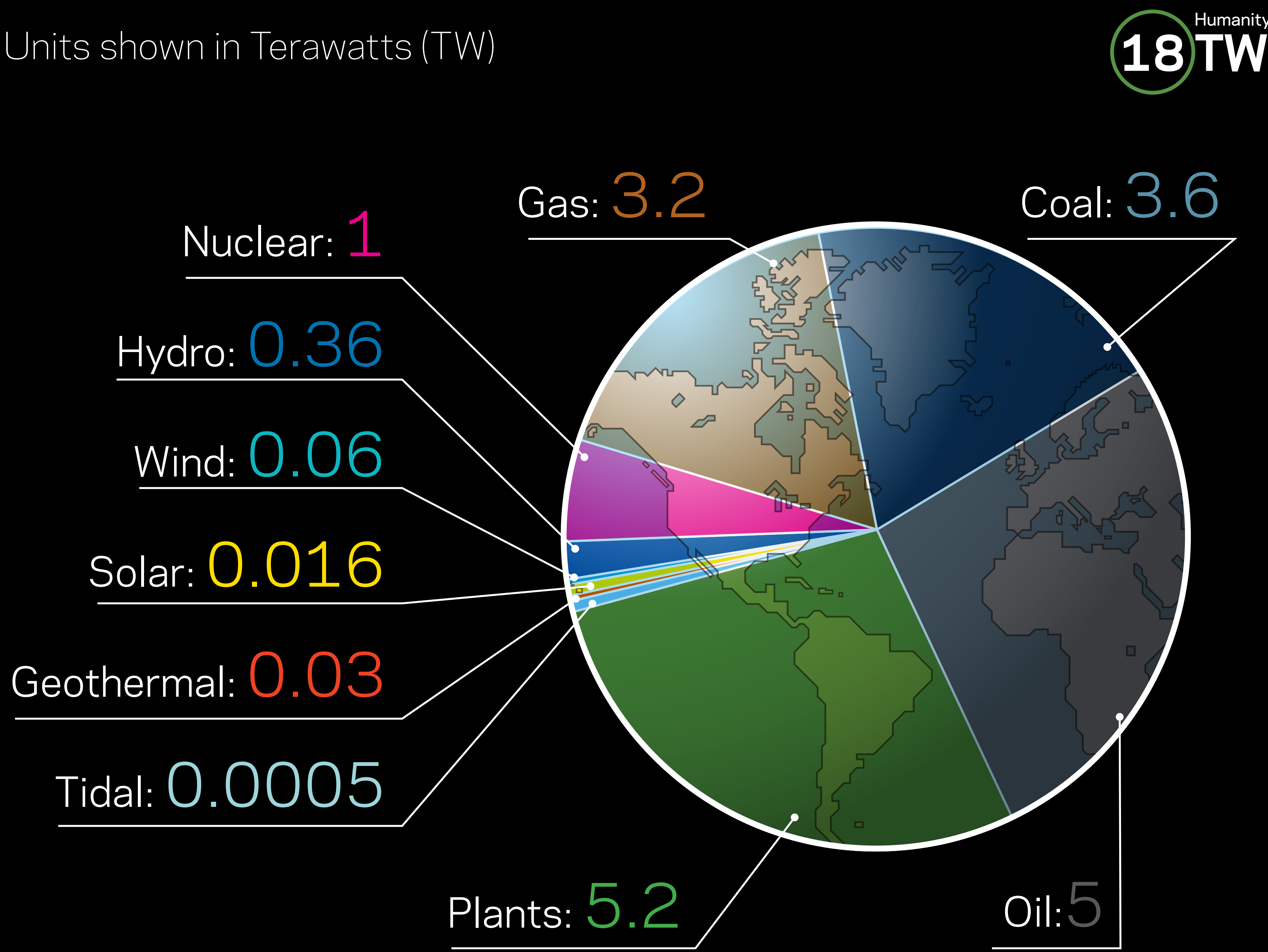
How we currently produce our energy.

These numbers are taken from the GCEP data. These do not differ significantly from other data sources, except that they include more of the energy attributable to plant mass, which we consume in the form of food, biofuels, and agricultural products.

Resources
GCEP study. http://gcep.stanford.edu/   this paper in particular : http://gcep.stanford.edu/research/exergycharts.html
http://www-esd.lbl.gov/SECUREarth/presentations/Energy_Brochure.pdf   http://www.exxonmobil.com/Corporate/Files/Corporate/tomorrows_energy.pdf
http://www.bp.com/genericsection.do?categoryId=6905&contentId=7030746
EIA : http://www.iea.org/Textbase/npsum/WEO2007SUM.pdf

Energy production

Units shown in Terawatts (TW)



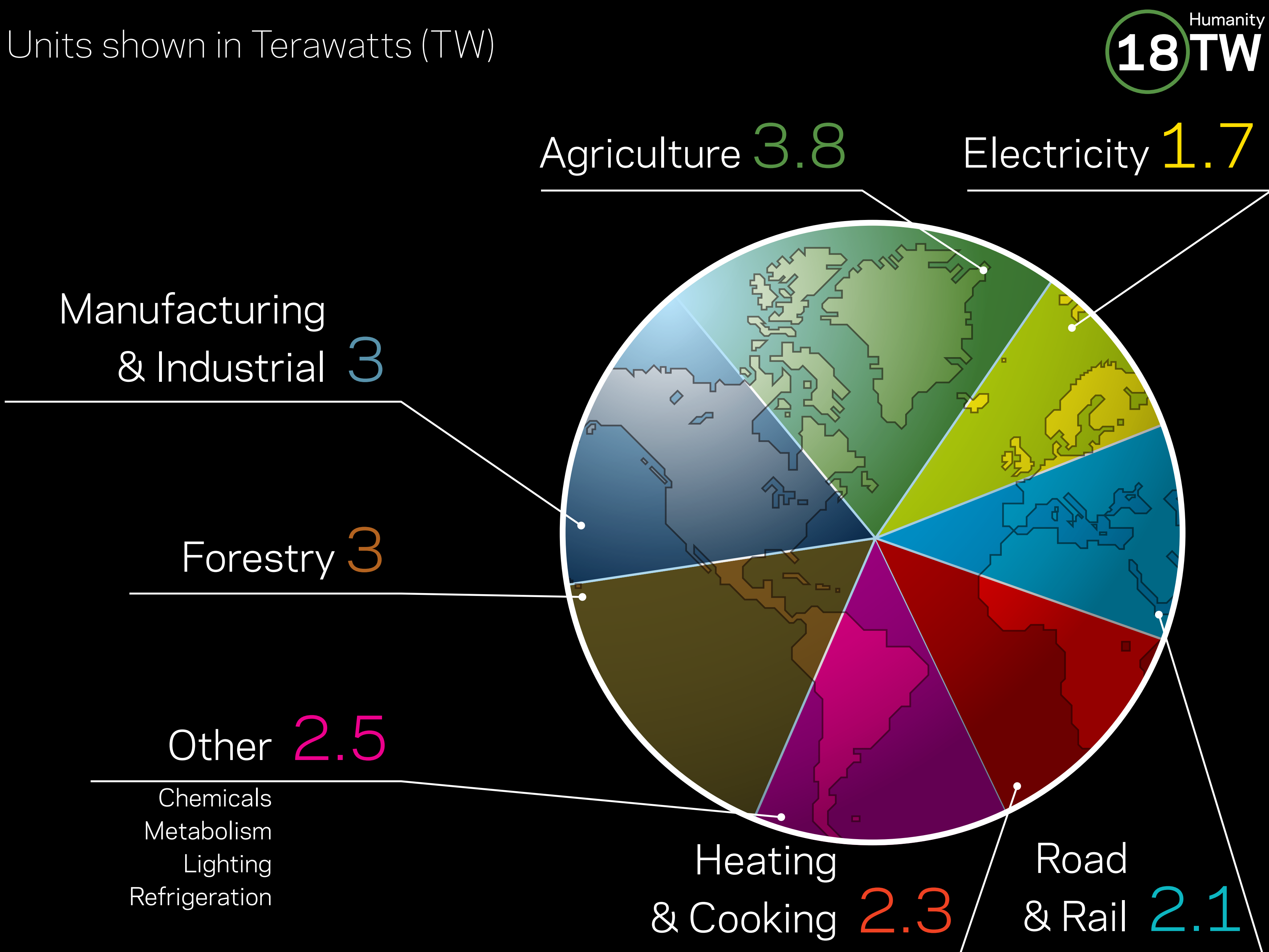
How we use our energy resources today.

I need to look at how they drew up these categories and what really is happening in each one...

Resources
GCEP

Global Exergy Consumption

Units shown in Terawatts (TW)



So far science knows of only 4 sources of energy

It is hard to predict what future scientists will discover and learn, but for now we need to do our planning with the resources that we know exist. All of the energy we have available to us as humans is derived from the 4 sources at right.

Fossil fuels are Solar - or more specifically old solar that was stored in the form of hydrocarbons produced over long periods of time by decomposing carbon life-forms.
Wind is solar.
Wave is solar.
Tidal power is gravity.
Fission and fusion are nuclear.
Heat was produced by solar, nuclear or gravitational forces and is now stored in places like the center of the earth (geothermal).

The inevitable question is going to be how do we create the energy we would like from these known resources?

Resources
http://en.wikipedia.org/wiki/Solar_energy
http://en.wikipedia.org/wiki/Gravity
http://en.wikipedia.org/wiki/Nuclear_power
http://en.wikipedia.org/wiki/Heat

Known Sources of Energy

GLOBAL STEP 5
Clean Energy Sources
15 TW

Solar 162 000 TW

Gravity 3.7 TW

Heat 32 TW

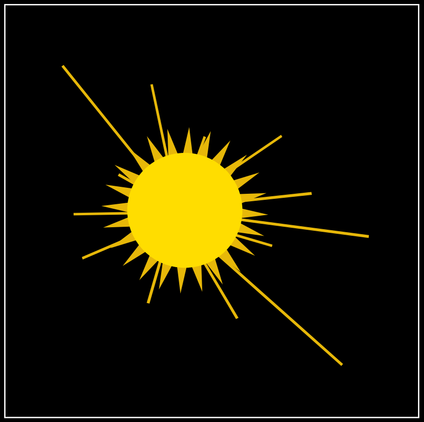
Nuclear 1^{10} ZJ

How much solar energy is there?

Resources

As a sanity check the above calculation was performed to understand other people's estimates of solar energy. The numbers above are in good agreement with the established figures. You can see more at GCEP.

162,000 TW Solar



Nuclear fusion radiated to earth.

Renewable

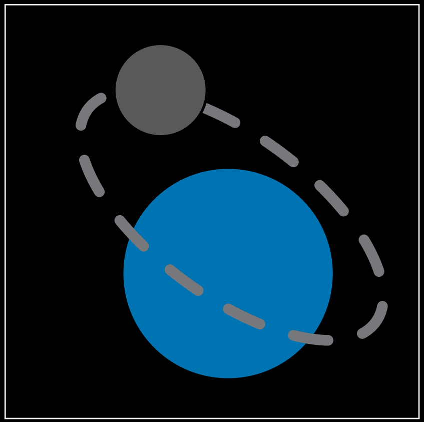
Until sun burns out (~5bn years)

Gravity.

It would be good to understand the differences between established opinion and the napkin calculaton.

Resources
wiki tidal...

3.7 TW Gravity



Movement of celestial bodies creates tides.

Ocean tides : 3.5 TW

Solid earth tides : 0.2 TW

Renewable

Heat

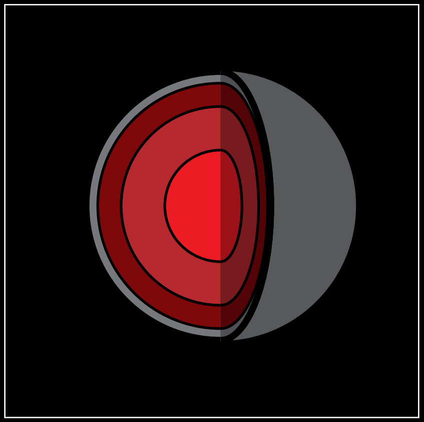
I've seen and heard the other estimates to be between 30 and 40 TW at constant flux, though it may be extracted faster non-sustainably.

Resources

MIT Geothermal study. http://web.mit.edu/newsoffice/2007/geothermal.html

32 TW

Heat 'geothermal'



Nuclear materials decaying in earth core

+

Original heat from gravitational collapse of early earth

+

Tidal forces.

Renewable

Nuclear Energy - Fission & Fusion

Nuclear power....

A secular person might say, "When god buried the dinosaurs for us so that we could dig them up later and burn them, she also buried some uranium". (In fact this was Jim McBride in one of his whimsical moments).

There are two familiar ways of extracting nuclear energy, the first is fission, the technology used to build atomic weapons as well as the technology that runs existing nuclear power plants. Fission is the separation of a parent element or isotope into new isotopes with a dramatic release of energy in the process.

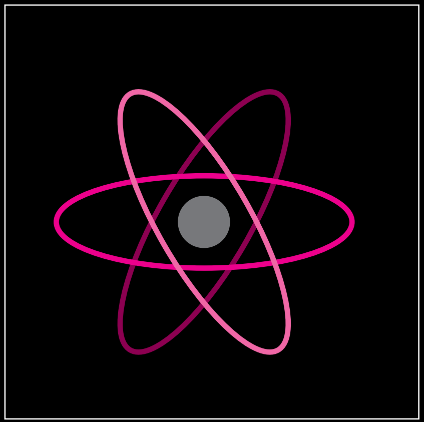
Fusion is the joining of two elements into a new element, and while it works perfectly (the sun is an existing example of a conveniently located fusion reactor) it is unclear that we will be able to contain a sustained fusion reaction for power production here on earth. There is a very good argument to invest a lot more research effort into fusion instead of less, which is the current trend.

There are two dominant designs for existing nuclear reactors, "once through" and "breeder". Breeder reactors use the nuclear material much more efficiently, but we do not use them very much now, largely for political reasons. If we do not use breeder reactors it looks like we will reach "peak nuclear" analagous to "peak oil" this century. Like any resource it needs to be used wisely. If we use breeder reactor technology we likely can get 1000 or more years of humanity's current energy production.

Resources
http://www.iaea.org/
http://en.wikipedia.org/wiki/Nuclear_power

1^{10} ZJ

Nuclear



Earthbound fissionable and fusionable materials.
Leftover from formation of universe.

Non-renewable

Uranium = 10^3 years

Thorium = 10^2 years

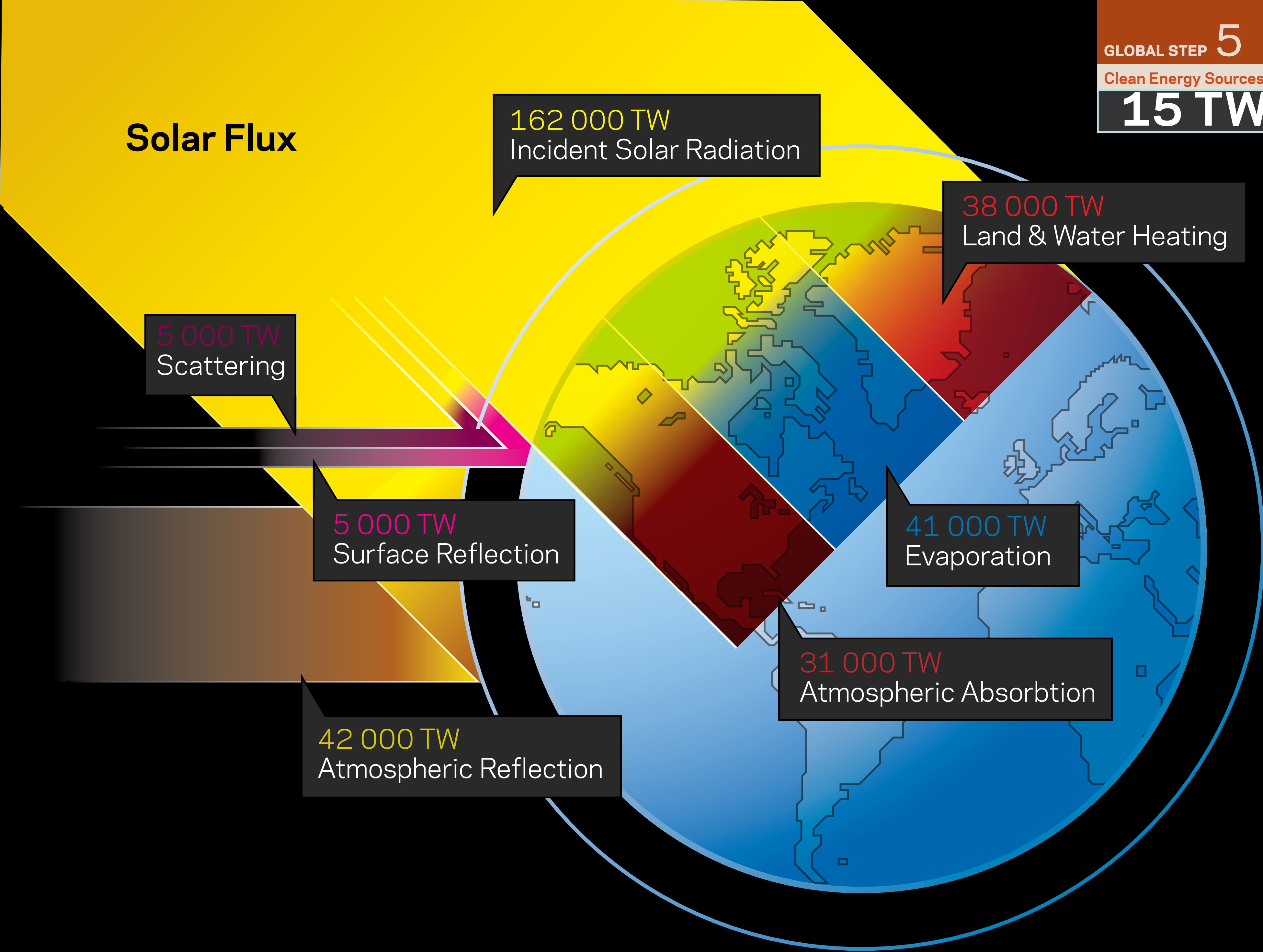
Deuterium = 10^{10} years

Lithium = 10^4 years

Where does all the solar energy go?

Scientists can estimate in some detail where all of the earth's solar energy goes....

Resources


Solar Flux
162 000 TW
Incident Solar Radiation
5 000 TW
Scattering
38 000 TW
Land & Water Heating
5 000 TW
Surface Reflection
41 000 TW
Evaporation
31 000 TW
Atmospheric Absorbtion
42 000 TW
Atmospheric Reflection

If we need to create “non-carbon emitting energy” where can it come from?

You will understand by now that we need to make a lot of energy from non-carbon emitting sources. This graphic shows you what you have to choose from.

Taking energy from any of these sources will have it’s own impact on the climate and environment.

Extracting all wave energy would flatten the oceans, which would affect ocean oxygenation, fish, surfers, beaches and natural erosion processes....

Extracting all tidal energy would reduce the tidal ranges in mangroves and swamps and tidal flats and other highly sensitive ecosystems. Strong consideration to be given to how much of each type.

Extracting hydroelectric power already has many negative consequences in carbon emissions from sunken forests, water table movements, etc...

Wind - extracting very large amounts of wind energy could slow down the natural flows of our ecosystem, and potentially even have a very small net heating effect. Just how much wind power there is, and what the safe extractable level is is not well understood. I haven't met anyone who doesn't think it could safely provide 20TW if that were something humanity chose to do.

Solar - a solar cell by design is not a very good reflector of light. It wants to convert all light into electricity, not bounce them back into space. For this reason if we cover significant areas of the earth with solar cells we will be reflecting less sunlight out into space which might have a small heating effect. It is well established that this would be barely noticeable against other heating functions.

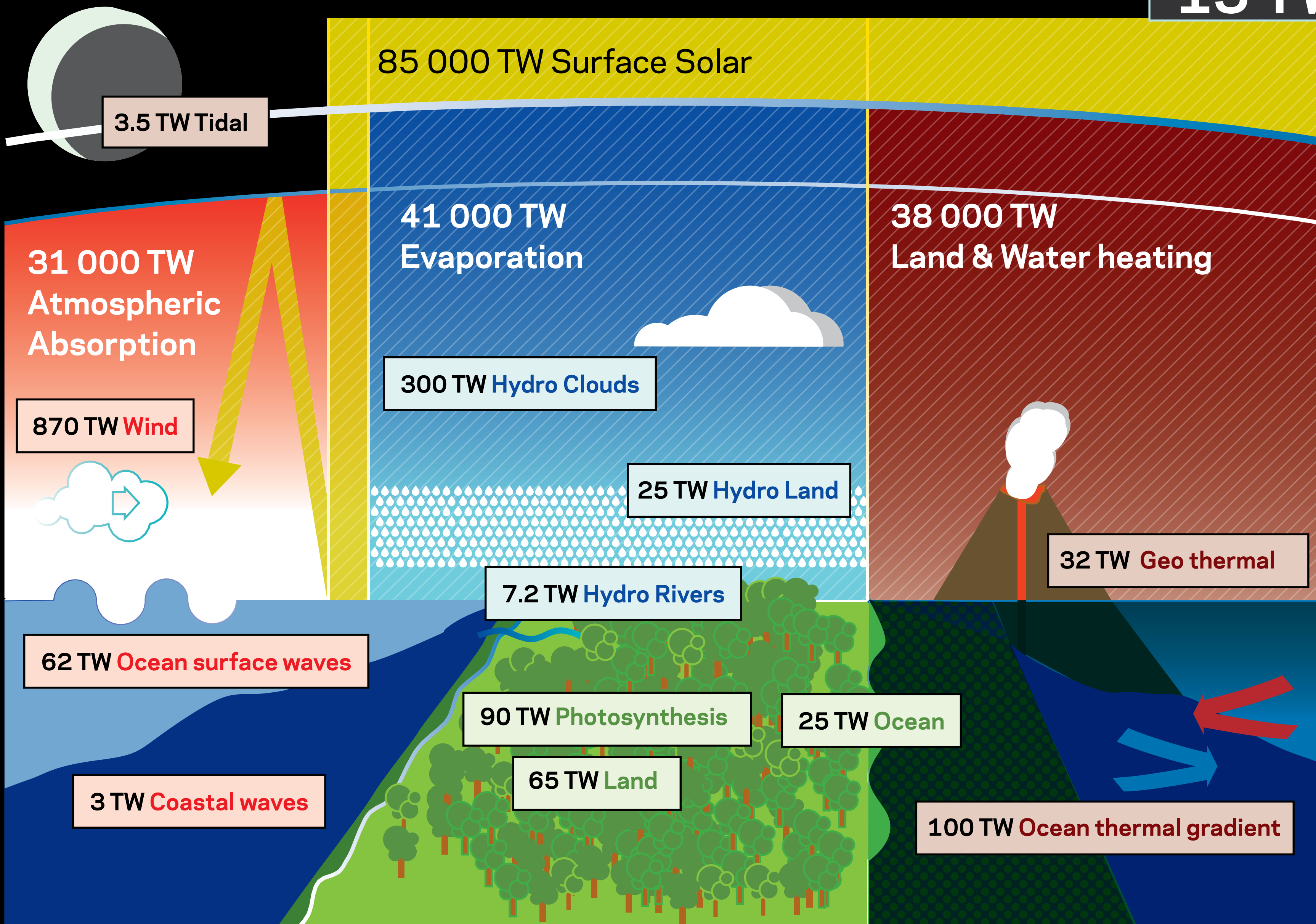
As a rule of thumb, and reasonably intutive to follow, we should probably take the most energy from the largest sources, and smaller amounts from others. Solar is king by that measure, and we should indeed have a huge effort in harnessing solar. Wind is also a very large resource that by harnessing we will be very safe. Sources such as tidal and wave power should be looked at very carefully before extracting very large amounts.

Resources

GCEP Exergy Resources study. Also in Energy. Journal.

Sources of renewable energy.

GLOBAL STEP 5
Clean Energy Sources
15 TW



Renewable energy and power density.

Power density is the amount of power that can be extracted by a machine (solar cell, wind turbine, etc) that interferes with 1 square meter of a renewable resource.

The reality is that renewable energy sources are very diffuse, or low power density, which means that installations of renewable power are more city sized, country sized even.

Perhaps insert here comparison of power density of solar to a typical gas station...

Resources

Power density is measured in W / m²

Renewable energy sources are a surface area problem...

Must cover large surface areas cost effectively and choose carefully where those surfaces are.

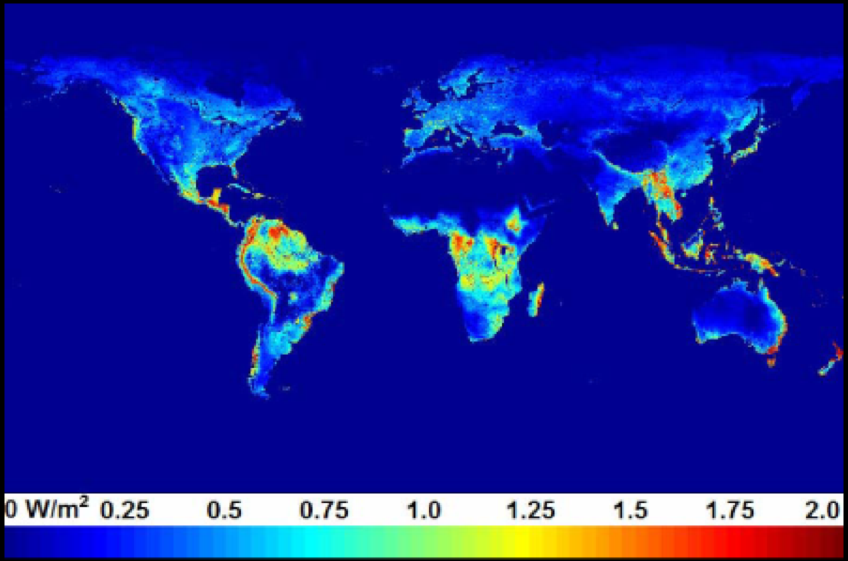
Power density.

These images are maps of the power density of various renewable energies mapped over the world. Obviously solar energy (and photosynthesis) is concentrated around the central, equatorial, band. Wind energy is concetrated above and below the equator at the mid-lattitudes for reasons you can find elsewhere.

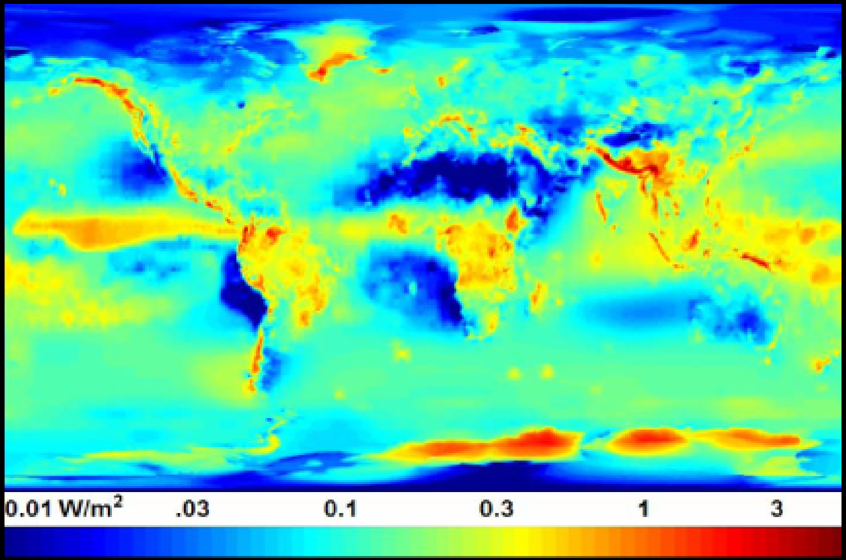
Resources
GCEP. NASA. NOAA.

Renewable Power Density Maps

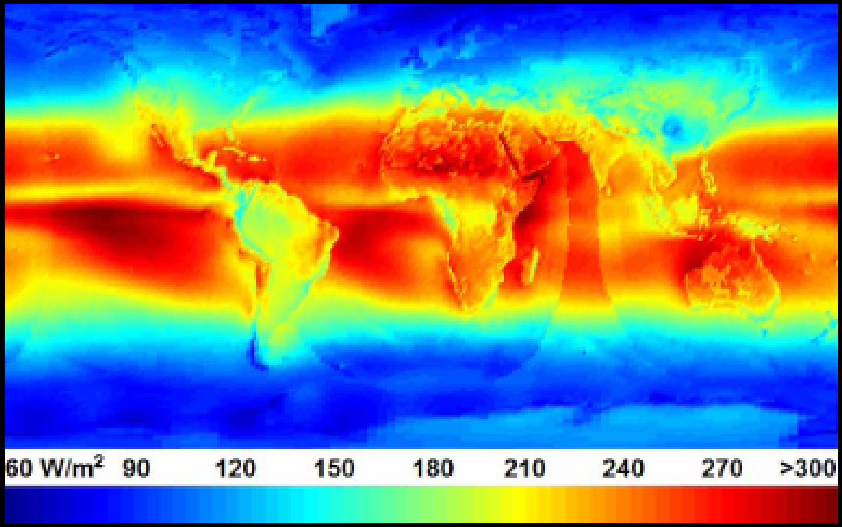
Photosynthesis



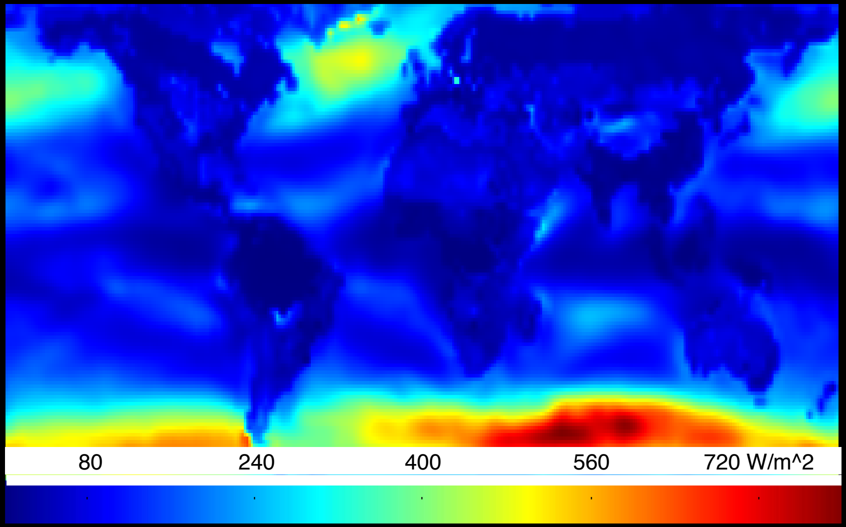
Precipitation (ultimately hydro electic)



Solar Radiation



Wind - 50m



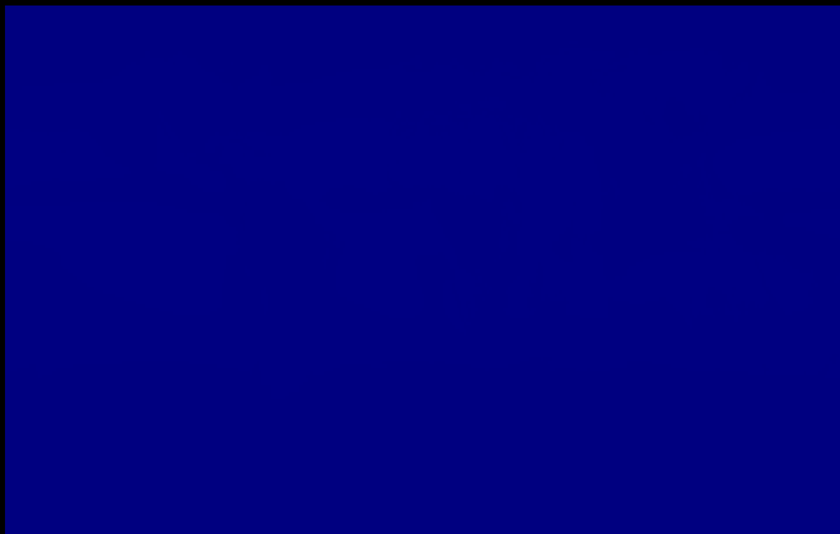
Comparative power densities.

If we remap the previous page's power density maps with the same scale, we can compare the relative power densities of these resources. Note that this is wind at 30m. It would be good to have this graph at 300m and 3000m as well for wind. If we acknowledge that what needs to be done is carefully planning the entire global energy system to protect the global climate system, then we should invest a lot more work in understanding where all of the energy sources are, their power densities, and their locations relative to population centers, fragile ecosystems, and other things pertinent to making the right choices for how we produce our power, cleanly.

Resources

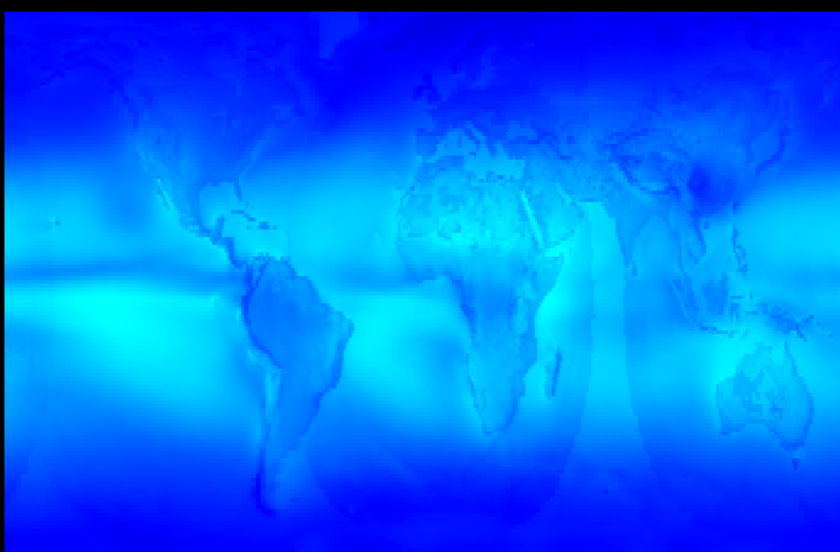
Renewable Power Density Maps (compared to wind)

Photosynthesis

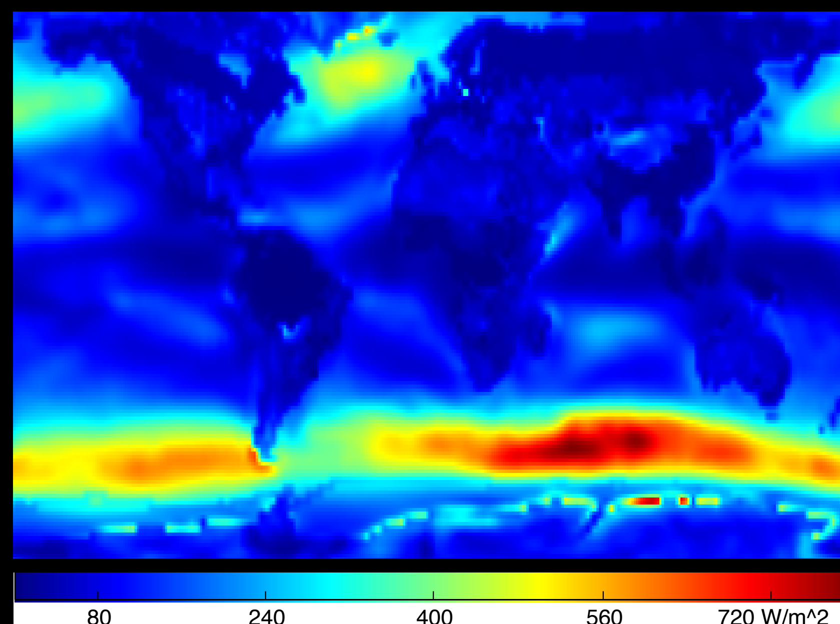


Precipitation (ultimately hydro electic)

Solar Radiation



Wind - 50m



Power density of “non-carbon” technologies.

Ideal power densities are shown. None of these are fully extractable.

Solar (efficiency, PV or thermal)
Wind (betz limit)
etc...

Wind is more variable, especially as you go higher.

It is very difficult to map wave energy onto this. (need to figure out a way).

These numbers aren't to prove the superiority of any resource over any other, but to put into perspective the large surface areas required for producing significant amounts of power from any of them.

Resources

Power density of the “renewables”.

GLOBAL STEP 5
Clean Energy Sources
15 TW

High Altitude wind—Jet Stream	1500 – 500 000	W / m²
Wind	200 – 1000	W / m²
Solar	90 – 300	W / m²
Tidal	0.5 – > 2	W / m²
Ocean Thermal Gradient	0.1 – 0.6	W / m²
Photosynthesis	0.25 – 2	W / m²
Precipitation	0.03 – 3	W / m²
Geothermal	0.05 – 0.25	W / m²

What is the engineering challenge?

Humans love challenges. With accepting and solving challenges we find our sense of purpose and can feel successful as contributors to the human enterprise.
Engineers in particular love challenges. Somehow, magically, they are bred to believe that they can do anything if only they are given enough resources. To some extent this is ture. In the case of our energy challenge, I have no fear that we have enough engineers with enough motivation and smarts to meet the challenge. All they need is to be given the resources.
They will need support from every facet of society, political, media, economic, educational, etc, but with that support what we need to do is well within the realm of possibility. People have compared this challenge to the Manhattan Project or the Appollo moon-shot. I think it is far more analagous to the retooling of manufacturing capacity worldwide for WWII. America alone redirected all of it's industrial capacity to win that war. Hitler's germany became a factory for his war machine. The Japanese empire spectacularly used their resources to wage war. What we need to do now is redirect many of our resources in a similar manner, except now we all fight together, side by side, in a fight against the challenge of our own lifestyles destroying our capacity for a good future.

15TW = current consumption, 2255W average personal consumption.
2TW = "carbon emitting energy" (this number maybe should be as high as 4TW)
1TW already from Nuclear.
0.5TW already from "renewables"

15 - 2 - 1 - 0.5 = 11.5 TW to go. How might we do that?

You can divide the pie many ways, but just for the sake of argument let's guess at one reasonable way to produce this amount of energy. It could be different, it probably should be different for reasons that I don't understand, but in order to get a sense of scale of the work we have to do, let's use these numbers:

2TW PhotoVoltaics.
2TW Solar thermal.
2TW wind.
3TW nuclear.
2TW geothermal.
0.5TW wave, tidal, biofuels.
(11.5TW)

Resources

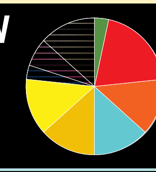
2033 Energy Mix

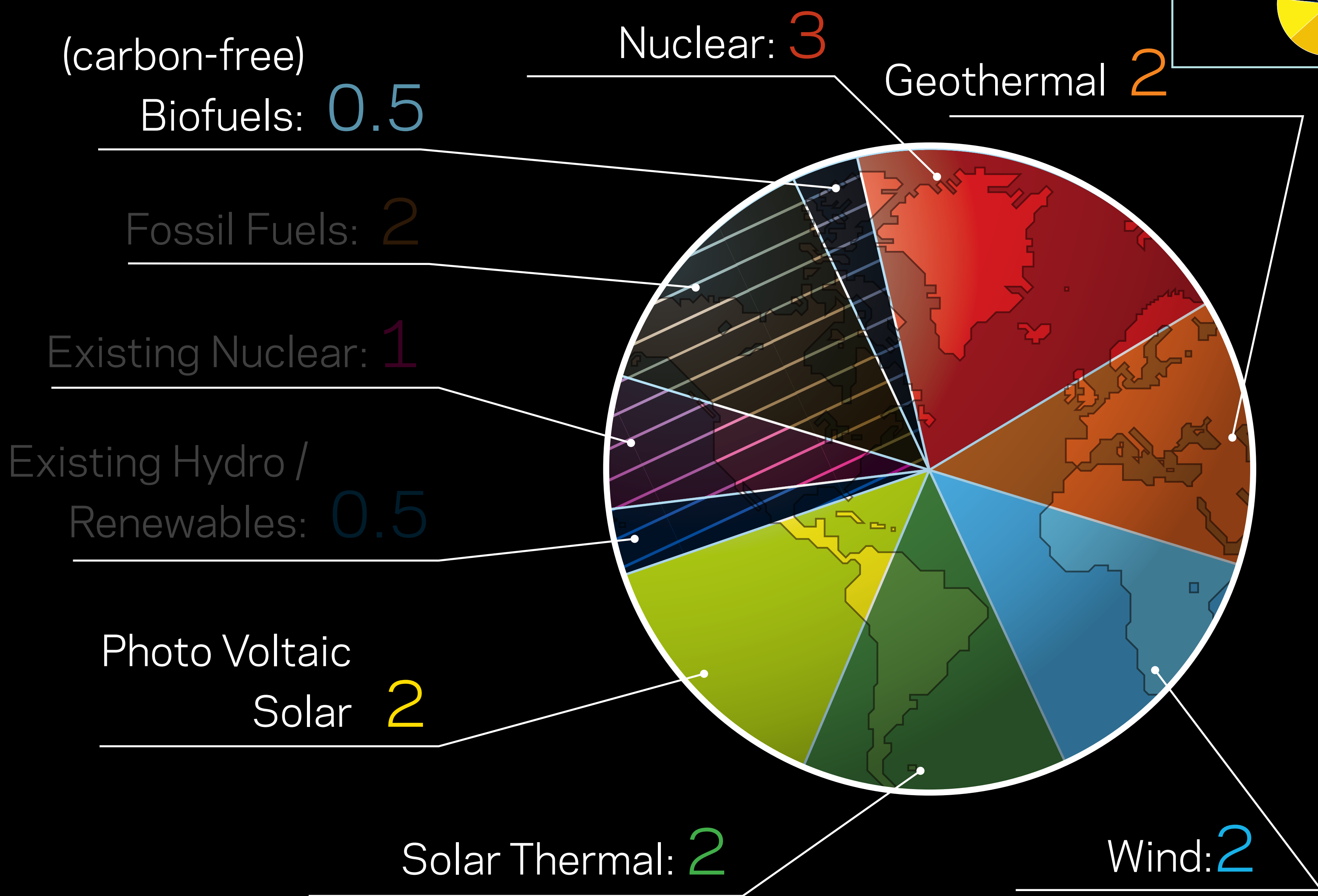
Units shown in Terawatts (TW)

GLOBAL STEP 6

New Energy Mix

15 TW





2TW solar - photovoltaic.

Insert calculations for making 2TW solar from 15% efficient solar cells.

200-250 W/m^2 averaged over 24 hours (or even the whole year) at good locations in southern US or southern Europe.

2 000 000 000 000 / 200 * 0.15 = 67 000 000 000 m^2. That's a lot. And that is not including all of the infrastructure around it, which might include tracking...

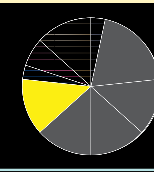
Resources
http://www.sunpowercorp.com/
http://www.pv.unsw.edu.au/

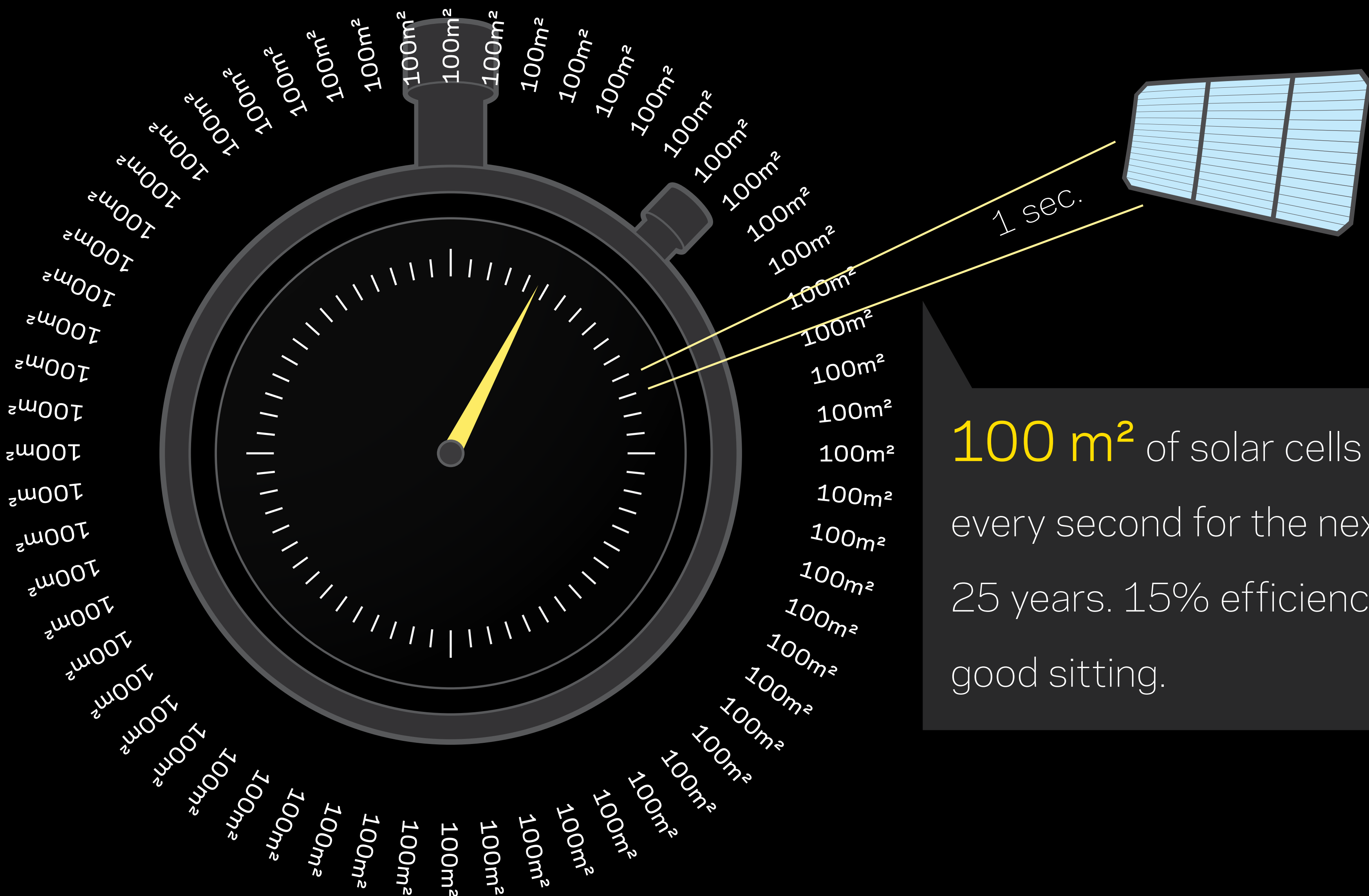
2 TW New Photo Voltaic

GLOBAL STEP 6

New Energy Mix

Photo Voltaic





100 m² of solar cells every second for the next 25 years. 15% efficiency, good sitting.

2TW solar thermal.

30% efficient solar thermal “power towers”

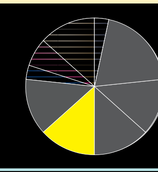
Resources
http://www.nrel.gov/csp/publications.html

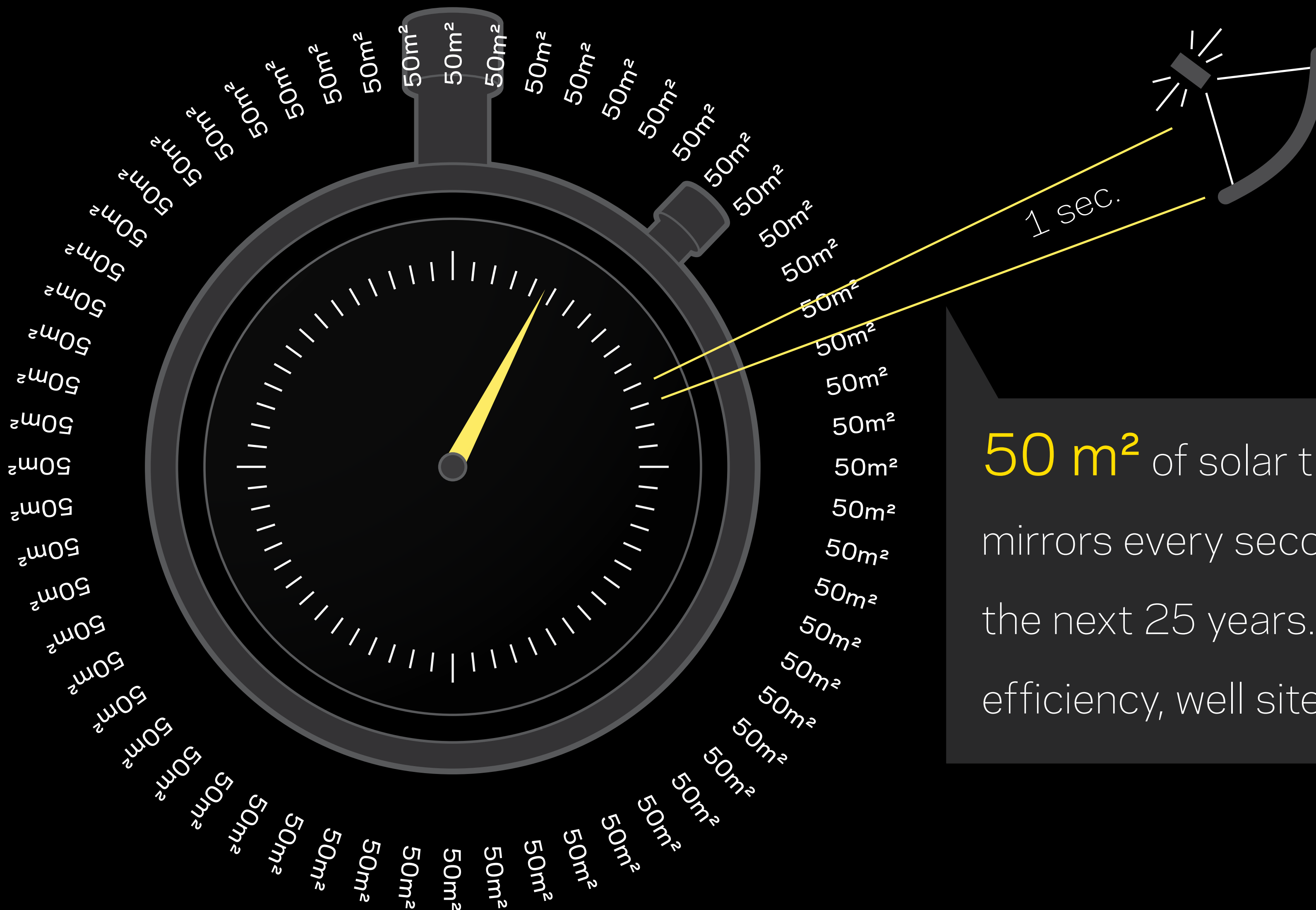
2 TW New Solar Thermal

GLOBAL STEP 6

New Energy Mix

Solar Thermal





50 m² of solar thermal mirrors every second for the next 25 years. 30% efficiency, well sited.

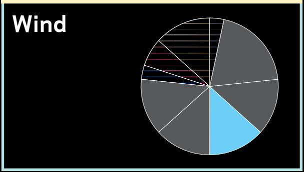
2TW of wind.

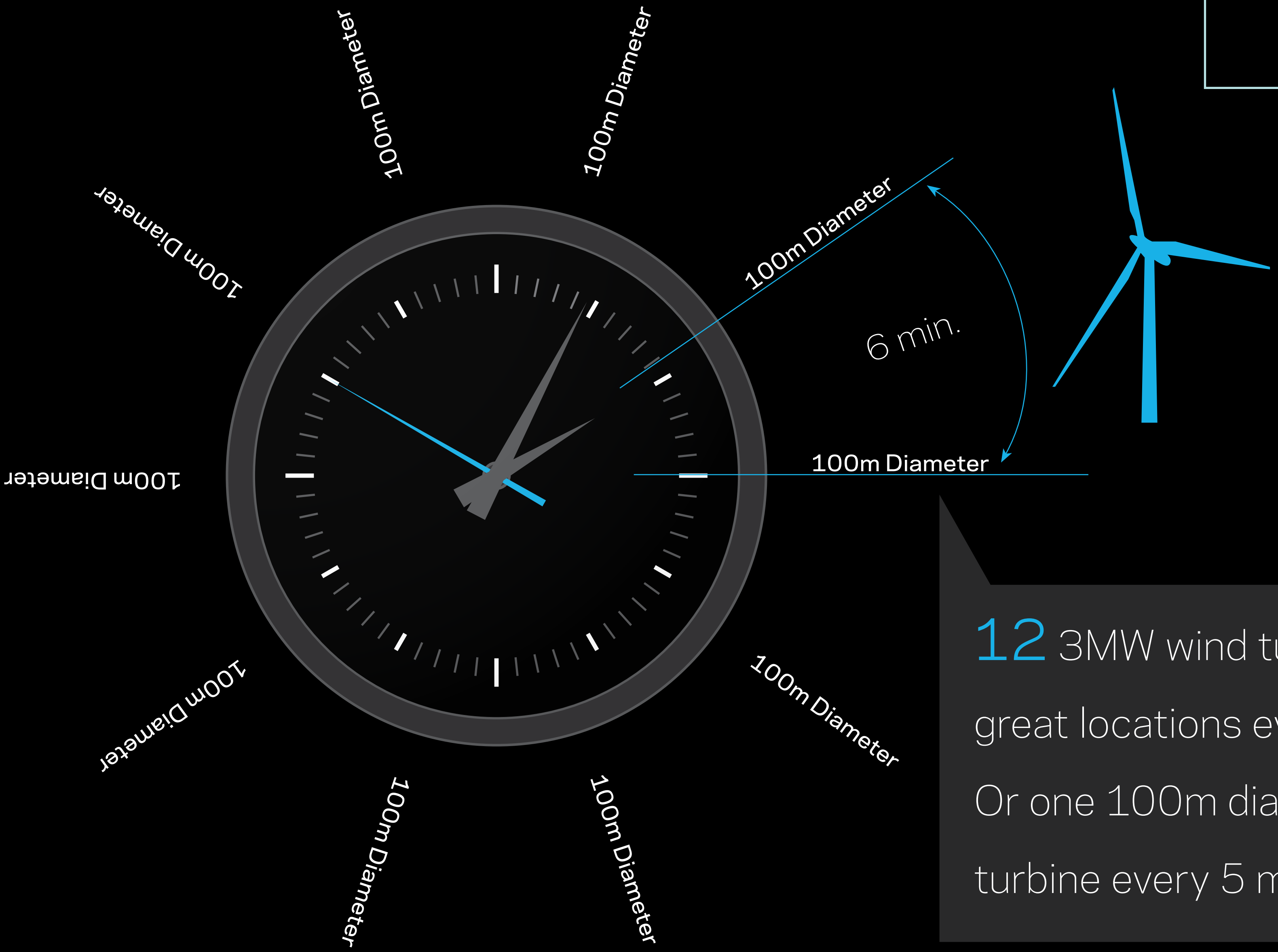
Numbers of wind mills.

Resources

Ref Christina Archer's paper.
Ref. Paper on wind resistance of windmills.
Ref. Study on bird deaths.

2 TW New Wind





12 3MW wind turbines in great locations every hour. Or one 100m diameter turbine every 5 minutes…

3TW New Nuclear.

How many nuclear plants per week?

Problems with storage, terrorism, fuel shortages, etc.

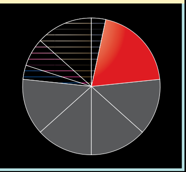
Resources

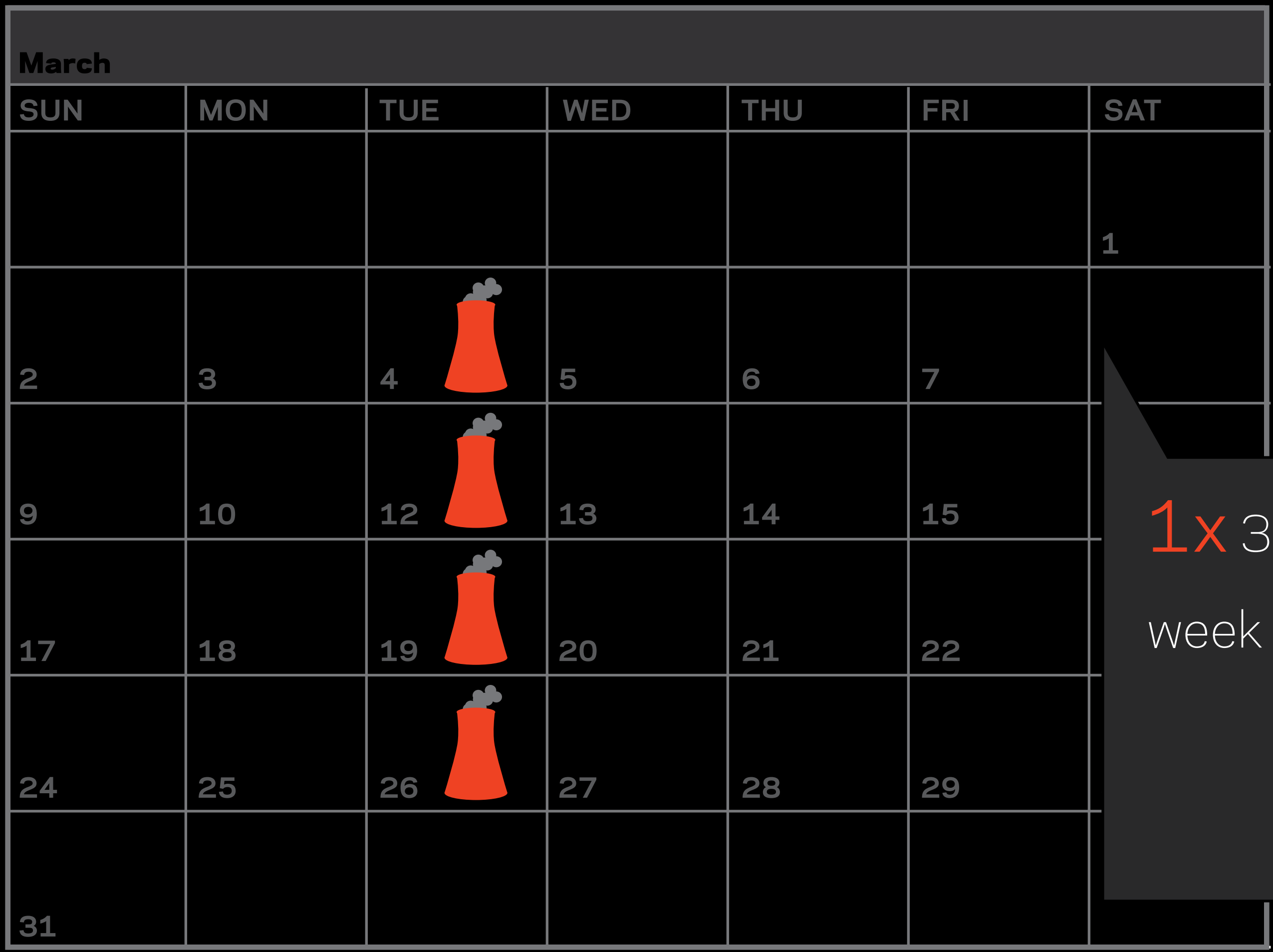
3 TW New Nuclear

GLOBAL STEP 6

New Energy Mix

Nuclear





1x 3GW Nuclear plant every week for the next 25 years.

2TW Geothermal.

Geothermal doesn't necessarily come in 100MW increments, but that is not an unrealistic size for a turbine.

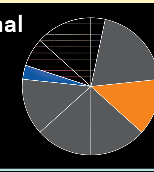
Resources
Reference MIT Geothermal Study.

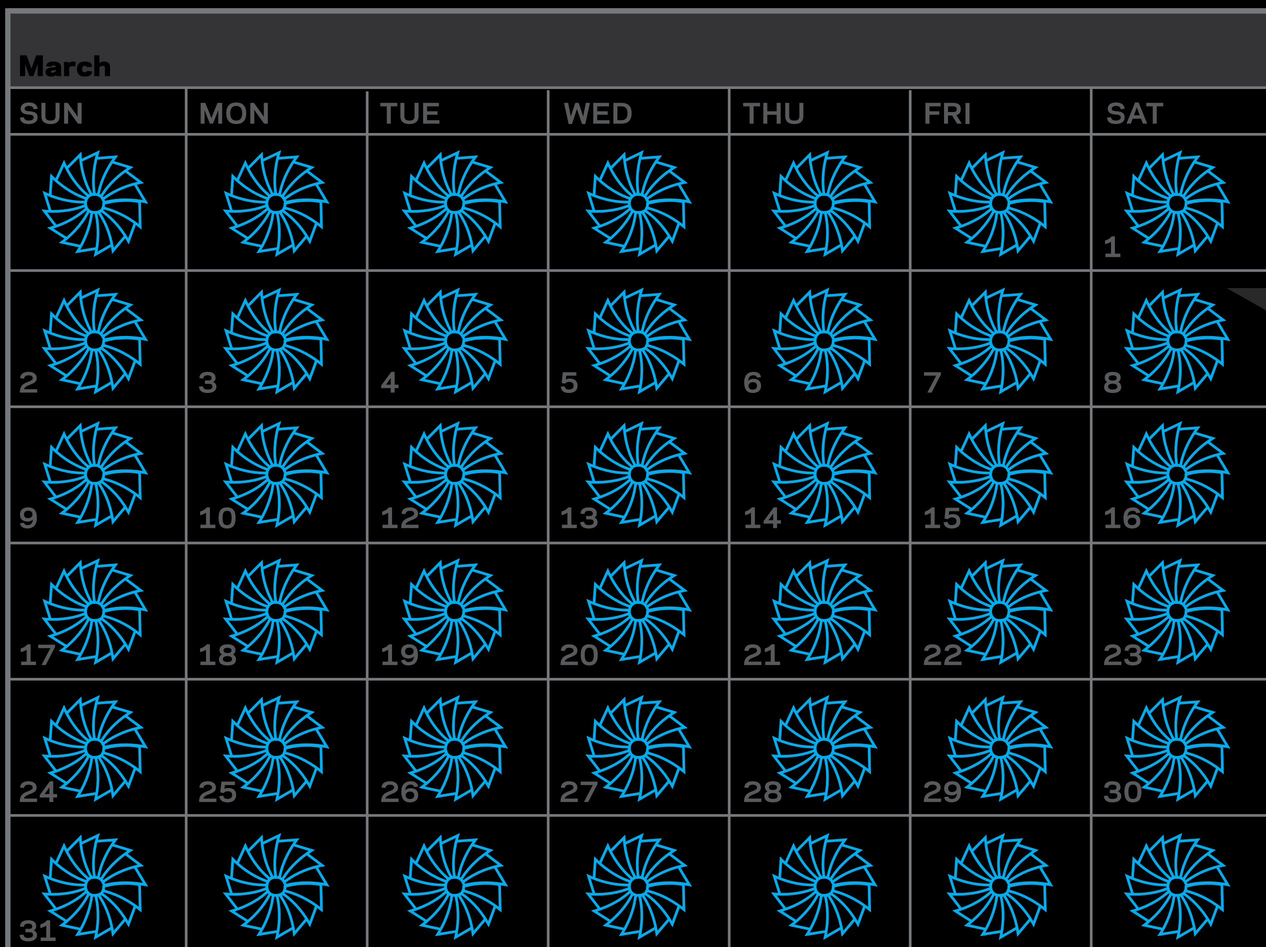
2 TW Geothermal

GLOBAL STEP 6

New Energy Mix

Geothermal





3x 100MW

steam turbines

every day for

next 25 years.

0.5 TW Biofuels, Tidal Power, Wave Power.

We still need a lot of other power.
0.5 TW of biofuels in land area?
0.5 TW of tidal power?
0.5 TW of wave power?

assume a really good 1% efficient algae. recognise this technology isn't ready yet.

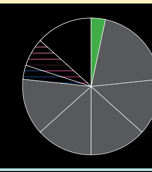
Resources

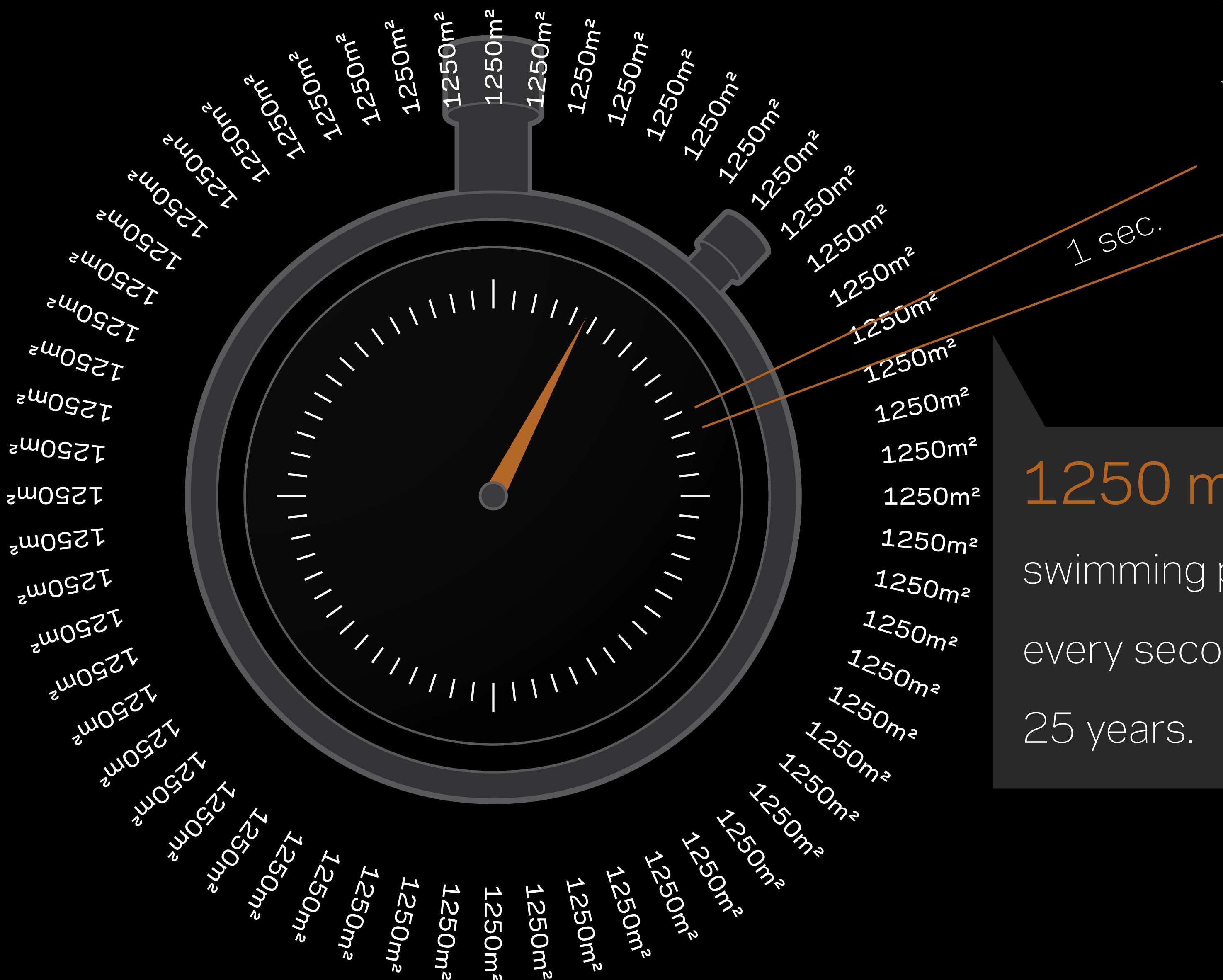
0.5 TW carbon (net zero) biofuels?.

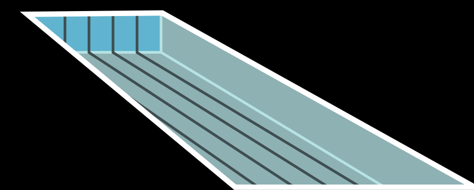
GLOBAL STEP 6

New Energy Mix

Biofuel







1250 m^2 or 1 olympic swimming pool of algae every second for the next 25 years.

Let's revisit the original logic.

We can now look back on what we need to do. It is daunting, but humans and humanity love a challenge. That is why the most popular TV and newspaper events of all time have been things like moon landings, and world record breaking olympic events. We love to be heroic, and here is the most heroic challenge we've ever faced. If we can do what we have outlined here it will truly be the most significant event in history, and more involving than even the great wars. We want thousands of heros of invention, manufacturing, installation, policy, ecology and economics.

You might have chosen higher or lower than 450ppm, but at least you have now figured for yourself the choice, and the consequences. This was arrived at by choosing a temperature increase, remember that a 2 degree increase in global average could mean a 5 or 6 degree increase in your region.

This has shown us that we might be able to tolerate 2 GtC per year of carbon into the atmosphere. Other estimates, less optimistic, are 1.4GtC, or even 0. Personally I'd like to aim at 0. If we can shoot to get to 2, why not overperform, and not just save the climate, but improve it.

From choosing an energy mix we get a sense of the scale of manufacturing and installation effort we need to get this heroic job done.

Resources

Step 1 CO_2 = Climate
450ppm

Step 2 Temperature Choice
+2 C   This acknowledges huge species lost, water shortages, and sea level rises. Risk of vicious cycles (what climate scientists call positive feedback).

Step 3 Allowable Carbon
2 GtC / year into atmosphere.

Step 4 Useable Fossil Energy
2 TW (can go up or down a little depending on source)

Step 5 Clean Energy Sources
There is plenty, and the big players look like nuclear, solar, wind, and geothermal.

Step 6 New Energy Mix
11.5 TW of clean energy. 3TW Nuclear, 2TW PV, 2TW Solar thermal, 2TW wind, 2TW geothermal, 0.5TW clean biomass..

Step 7 Turn off majority of existing carbon fuels.

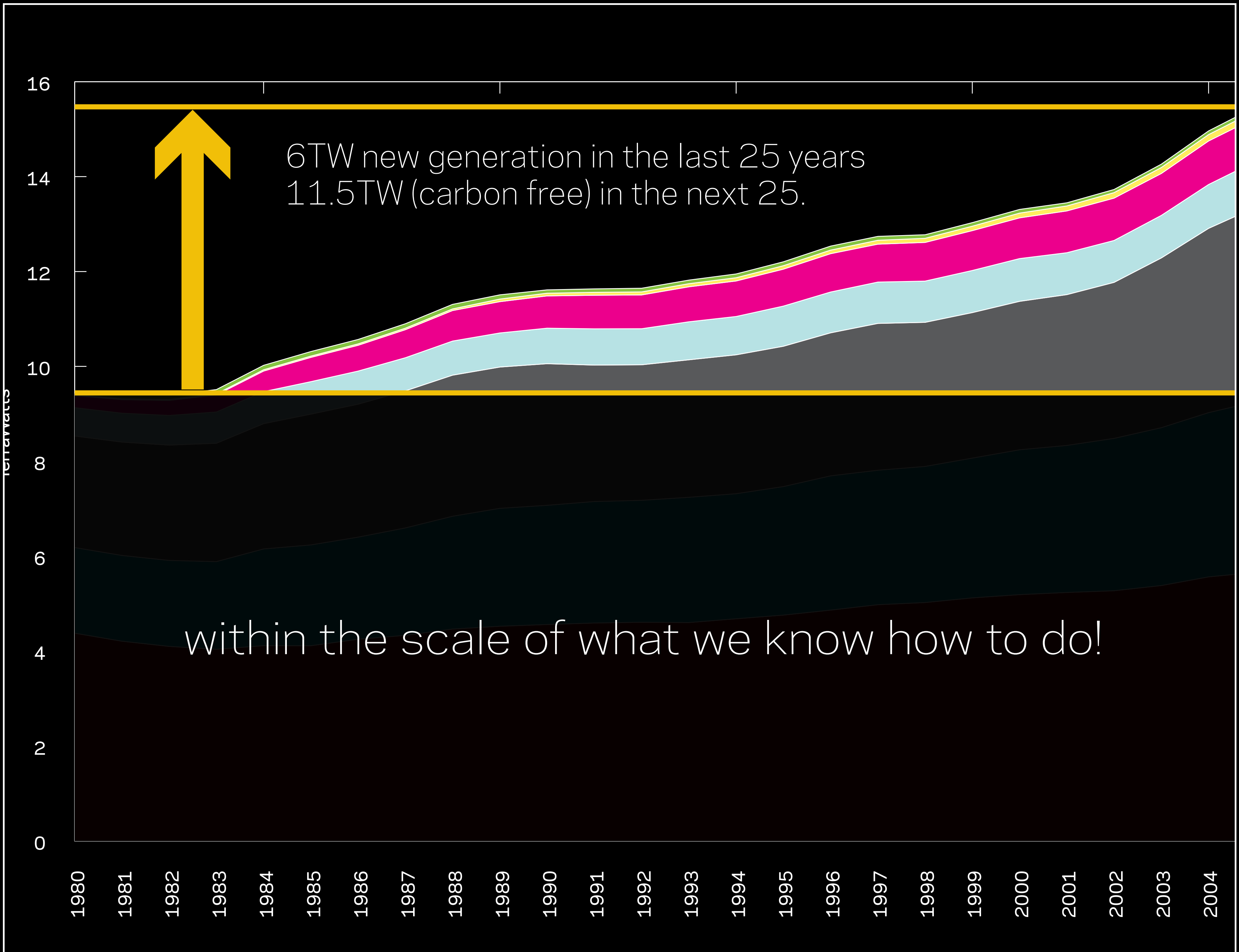
Is it even within our capacity to meet such a challenge?

While what you have read so far may seem inconceivable you need to remember that in every case we have provided low estimates. It is very likely going to be at least twice as hard. But can we do it?

Aluminum cans as solar thermal collectors.
Cell Phones and computers as solar cells.
Cars and trucks as wind turbines.
Oil wells as geothermal plants.
Nuclear plants instead of coal plants.
We did bring on-line 6TW of energy capacity between 1980 and 2005. All that in only 25 years. This can be done.

It is possible. But the changes that have to happen aren't just profound, they are enormous. What a wonderful challenge though ! What number of exciting careers and large scale engineering efforts to be done.

Resources



6TW new generation in the last 25 years
11.5TW (carbon free) in the next 25.
within the scale of what we know how to do!
Terawatts
16
14
12
10
8
6
4
2
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

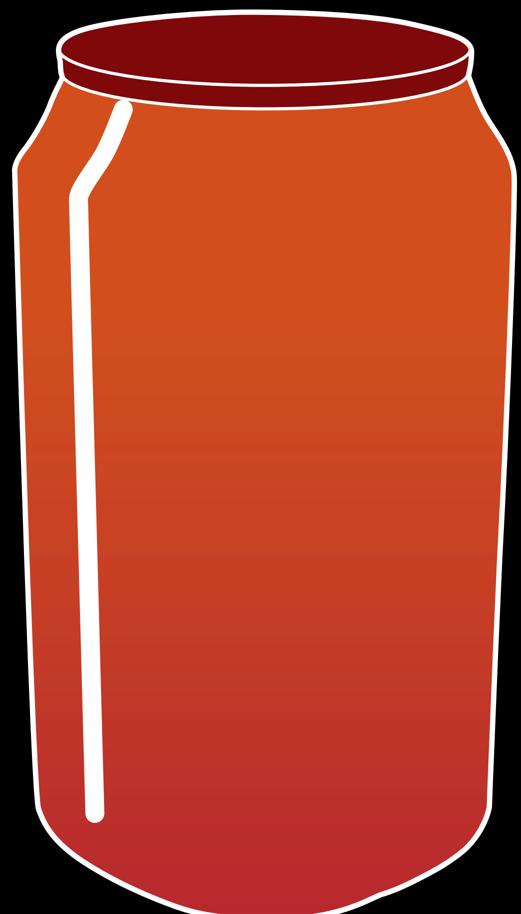
Industrial capacity is there.

I assumed that we were purely going to convert the aluminum surface area of the cans into 85% efficient mirrors for use in a concentrated solar thermal plant with total system efficiecy of 20-25%. Not perfectly accurate, but illustrative of the existing industrial capacity that humanity can throw at this problem.

None of the company names I use here are meant to blame them or request of them that they drop everything and do this. Merely to express that they are examples of the entities that have the industrial capacity to make a large contribution to our challenge.

Resources

110 bn cans / year...
= 200 GW solar thermal / year.

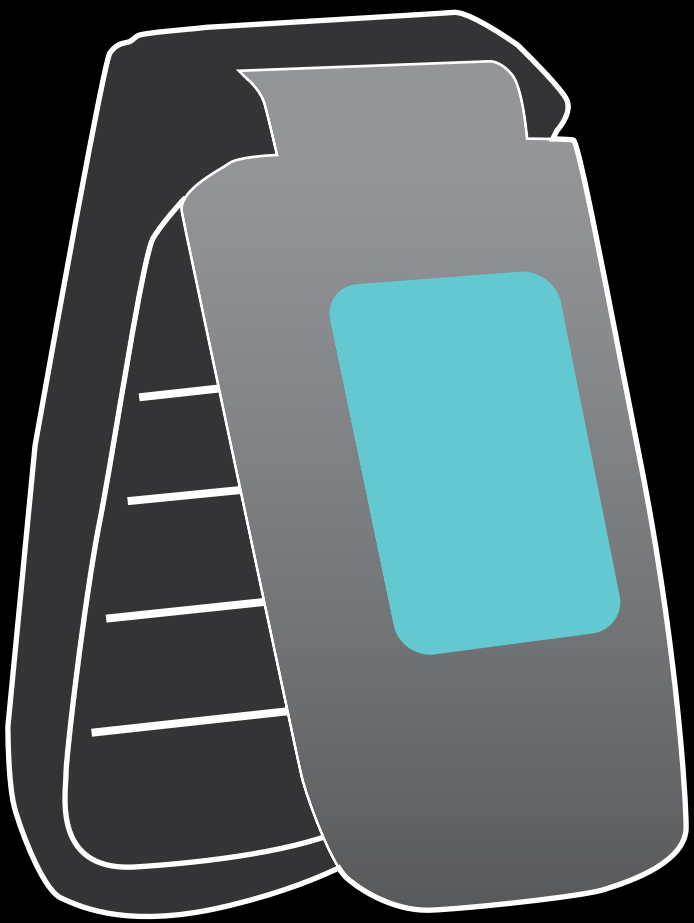


Industrial capacity is there.

Now, we can't expect Nokia (and IBM and INTEL and AMD to all become solar cell manufacturers overnight, but again, as an illustration of our production capacity, these companies could do what we need.

Resources

9 Nokia phones every second.
Nokia + INTEL + AMD + + for solar PV?



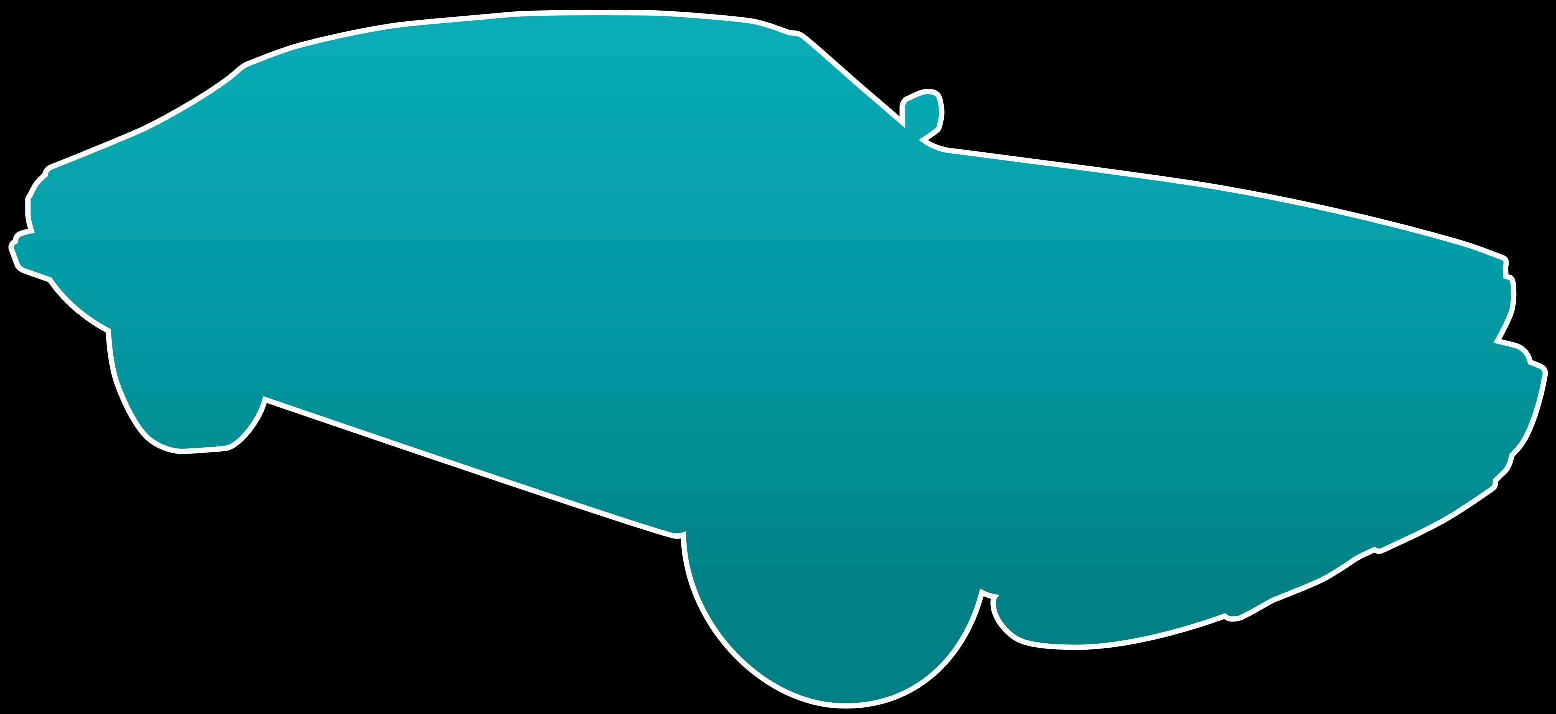
Industrial capacity is there.

GM produces one drivetrain every 1 minute, and 1 complete car every 2 minutes. (I need to confirm this, but heard it from their Manufacturing people.)

Again, this is conceivably of the scale required to make our 2TW of wind turbines.

Resources

GM = 1 car every 2 minutes.
GM + FORD = 1 wind turbine every 5 minutes?



What to do individually.

Not wanting to put all the responsiblity on indidivudals (everyone and every organisation will have to play a part), but what can we do as individuals?

This document / slide show / book / pamphlet / whatever it is is full of hints at the changes we need to make. In all of those hints is a challenge and an opportunity. Here's a shortlist of the sorts of new businesses to be built to make our new lifestyle actually better and higher quality than our current lifestyles:

Tele-conferencing.
Tele-commuting.
Culture of repair and maintenance.
Design becomes incredibly important.
Better products. Fewer of them.
Services are now more important than products.
Resource sharing by social networking.
Healthier people (more exercise, cleaner air)

The butcher, the baker, the candle-stick maker.

Resources

What do we have to do ourselves?

Emphasizing the positive, there is lots of it.

I have to attribute this quote to Tim Anderson (founder of Z Corporation and good friend. When he first heard me speak he said:

Make it shorter, simpler, and emphasize the up-side.
If people do what they want to do already, the goals will be achieved:
eat less, exercise more, spend more time with their families, live closer together, spend less time commuting.

he followed up with:

Here's a good lecture on the subject by the ceo of Kaiser at the Commonwealth club:
Less than half of patients recieve the correct treatment.
5 chronic conditions cause 75% of U.S. healthcare costs: athsma, depression, diabetes, congestive heart failure, coronary artery disease. Three of those conditions are caused by the same behaviors: improper diet and insufficient exercise.

streaming version:
http://www.commonwealthclub.org/archive/07/07-03halvorson-audio.html

Resources

What to do ourselves

If we do what we want to do already, the goals will be achieved:

Eat less and more healthily,

Exercise more,

Spend more time with my family,

Live closer together,

Spend less time commuting,

Less business travel,

Have higher quality, better designed products.

Breathe cleaner air,

Drink cleaner water.

A closer look at the power of consmption.

I didn't choose this particular product for any reason other than the irony of the drink being named "energy". This image is of the nutrition label. If we have the nutrition label as an acceptable social standard, we should start to think about consumption labels also - the power or energy requirements.

Resources


vitaminwater
GLACÉAU
energy
tropical citrus (b+guarana)
contains no juice
Nutrition Facts
Also contains

What do we have to do in terms of life-style changes?

Consumption facts. This might be one of the most important things we can do. Legislate or force companies through presure to include these labels on all products (and maybe even services).

The good news since starting to prepare this document is that Tescos of Britain has announced that they will do something similar to this. My only concern is that it sounds like they are going to use a unit-less scale of 1-7 (confirm?) and that what we really need to use is a real scale, with actual units and real measured numbers, expressed in power or carbon.

Resources

Consumption Facts

Container Mass 1.58oz (44.9g)
Components per container 3

Embodied Energy Per Container	
Total	**4,609,420 Joules**
PETE 38.81g	3,962,400 Joules
HDPE 4.83g	497,500 Joules
Cellulosic 1.34g	149,520 Joules

Recycle rate	**23%**
Landfill rate	**43%**
Energy recovery rate	**16%**
Lost to environmental waste	**18%**

Personal Energy Footprint	**% Daily Value***
Total	**4.54%**
Transport (avg.estimated)	**0.69%**
Manufacture	**0.46%**
Embodied Energy	**2.67%**
Refrigeration (avg.estimated)	**0.71%**

* Personal Energy Footprint is based on a recommended 2000 Watt lifestyle.

The average US consumer has a 11400 Watt lifestyle.

! Consuming this product daily is equivalent to increasing your energy footprint by 90 Watts.

Also contains	per bottle
Plasticizers	43mg†
Estrogen	0.12mg†
Carcinogenic Dye	0.19mg†

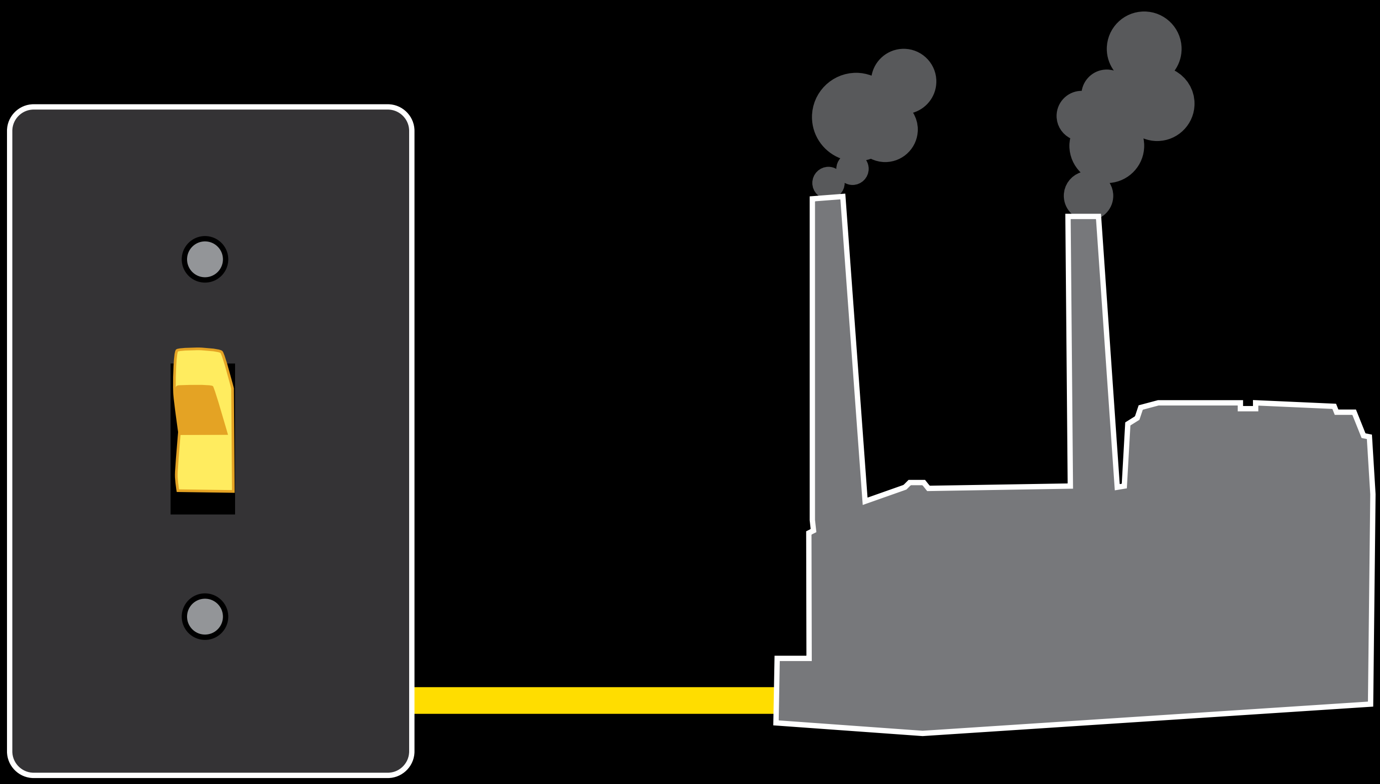
† Safe daily values not yet established.

The hardest part.

Interviewers often remark upon the discrepancy between Lovelock's predictions of doom, and his good humour. "Well I'm cheerful!" he says, smiling. "I'm an optimist. It's going to happen."
Humanity is in a period exactly like 1938-9, he explains, when "we all knew something terrible was going to happen, but didn't know what to do about it". But once the second world war was under way, "everyone got excited, they loved the things they could do, it was one long holiday ... so when I think of the impending crisis now, I think in those terms. A sense of purpose - that's what people want."

Resources
http://www.guardian.co.uk/theguardian/2008/mar/01/scienceofclimatechange.climatechange

The hardest part of all might simply be turning off the current CO_2 emitters.



Deforestation

Of course, one thing we must also do is stop deforestation as soon as possible. Like yesterday. Then begin serious reforestation. Contributions of deforestation might be as high as one third of our CO_2 emissions.

Resources

http://en.wikipedia.org/wiki/Deforestation

This artwork is by Nick Dragotta, author and illustrator of Howtoons. I hope he doesn't mind what i did with it.

www.howtoons.com

Stop deforestation.

End.

The last slide was the planned ending to this talk and is where I end if giving the talk as a public speech.

In the future I would like to add something about public transportation and it's important role.

I'd also like to add something about Carbon Sequestration its realities and its limits.

I'd like to add something that says we have to do everything that has been described in this document so far, as well as preventing further deforestation and in fact reforesting.

I'd like to add something on power storage and the importance of grid scale batteries whether it be pumped hydro or something else.

I'd like to add something here on transmission and the importance of large scale transmission infrastructure, perhaps including High Voltage DC discussion.

Perhaps add a good graphic that describes the power density challenge.

Resources
Blank.

More apple anecdotes...

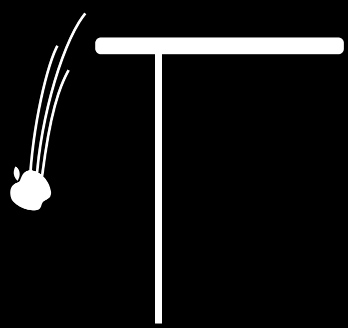
This is here in case I get better ideas for communicating differences between work, power and energy.

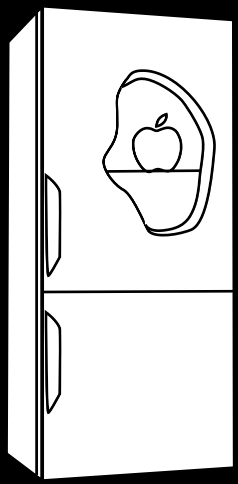
Resources

Apple falling off a table : 1 Joule

Cooling an apple : 1 kiloJoule

Eating an apple : ~ 1 megaJoule





There are different types of energy.

There is something not said elsewhere in this document that I feel compelled to throw in somewhere, so why not here. There are different types of energy, heat, chemical, & electromagnetic. I represent them here in an elegant statement I borrowed from Steve Crandall:
"Let light be light"
"Let heat be heat"
"Let food be food"
The point of saying this is that there is a cost in converting from any one energy source to another. Converting light via a solar cell into electricity and back into light again with a compact fluorescent is a lot less efficient than sitting in the sun to read. Similarly with bio-fuels, there end conversion into electricity or even transport fuels is not as efficient as there use as food for people.
More and more when we design energy systems we'll have to look carefully at what type of energy service we actually wish for, and do the minimum number of conversions to get that service.

Resources
There is a great reference here from Amory Lovins I think. Insert.
http://www.coburnventures.com/Research_Fellows/Research_Fellow_-_Steve_Crall.html

Let light be light

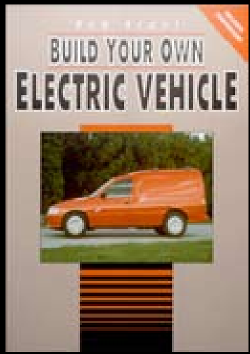
Let heat be heat

Let food be food

Further reading (and watching).

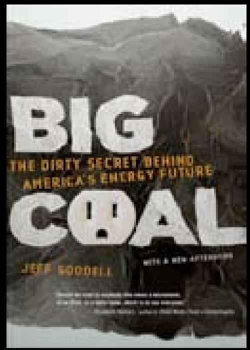
Here is a selection of books on all sides of the debate.

Resources



"Build Your Own Electric Vehicle"

www.amazon.com/exec/obidos/ASIN/0830642315/ref=nosim/wwwhowtoonsco-20



"Big Coal"

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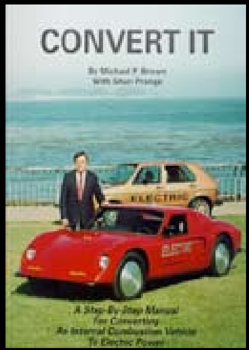

"Convert It"

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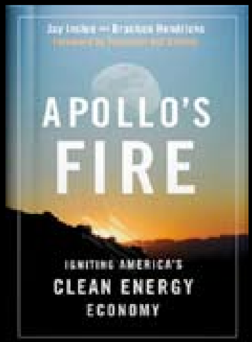
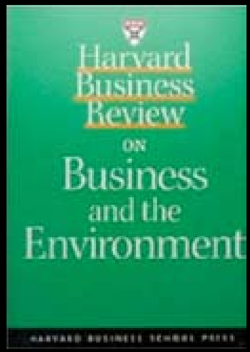


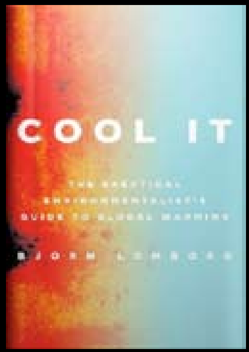
"Apollo's Fire"

www.amazon.com/exec/obidos/ASIN/1597261750/ref=nosim/wwwhowtoonsco-20



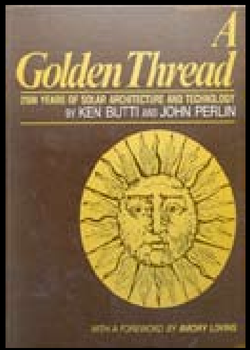
"Business and the Environment"

http://www.amazon.com/exec/obidos/ASIN/1578512336/ref=nosim/deliciousmons-20



"Cool It"

www.amazon.com/exec/obidos/ASIN/0307266923/ref=nosim/wwwhowtoonsco-20



"A Golden Thread"

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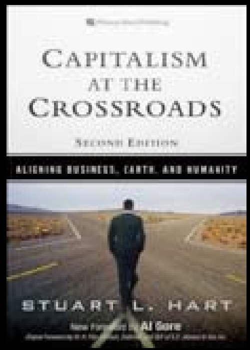
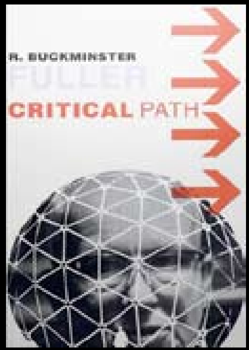


"Capitalism at the Crossroads"

http://www.amazon.com/exec/obidos/ASIN/0136134394/ref=nosim/deliciousmons-20



"Critical Path"

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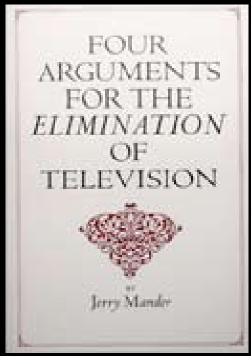
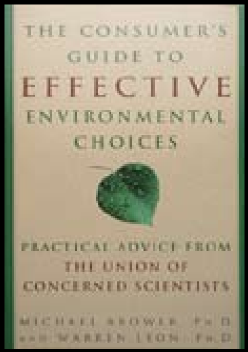


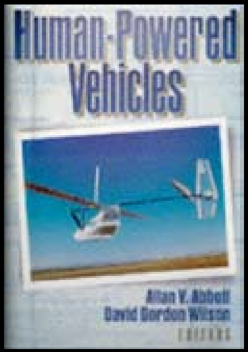
"Four Arguments for the Elimination of Television"

http://www.amazon.com/exec/obidos/ASIN/0688082742/ref=nosim/deliciousmons-20



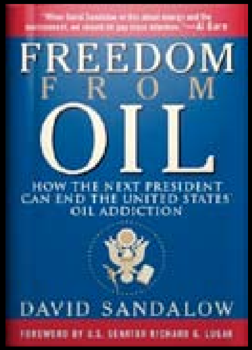
"The Consumer's Guide to Effective Environmental Choices..."

http://www.amazon.com/exec/obidos/ASIN/060980281X/ref=nosim/deliciousmons-20



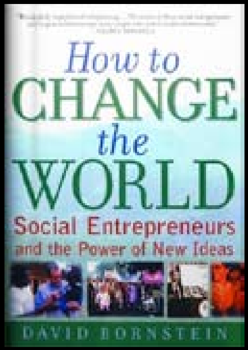
"Human-Powered Vehicles"

http://www.amazon.com/exec/obidos/ASIN/0873228278/ref=nosim/deliciousmons-20



"Freedom from Oil"

http://www.amazon.com/exec/obidos/ASIN/0071489061/ref=nosim/deliciousmons-20



"How to Change the World"

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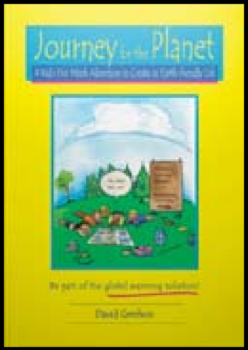
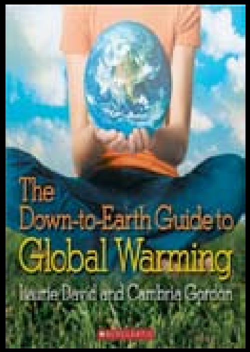


"Journey for the Planet"

http://www.amazon.com/exec/obidos/ASIN/0964437309/ref=nosim/deliciousmons-20



"The Down-to-Earth Guide to Global Warming"

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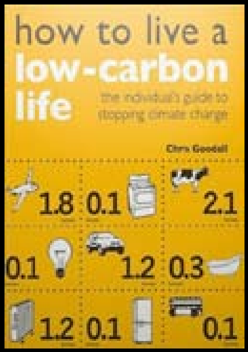
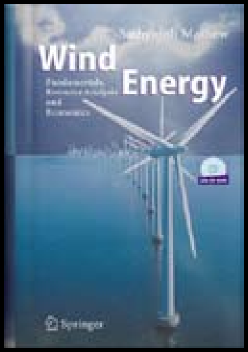


"How to live a low-carbon life"

http://www.amazon.com/exec/obidos/ASIN/1844074269/ref=nosim/deliciousmons-20



"Wind Energy"

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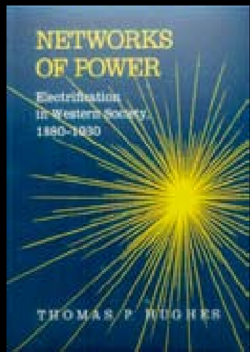

"Networks of Power"

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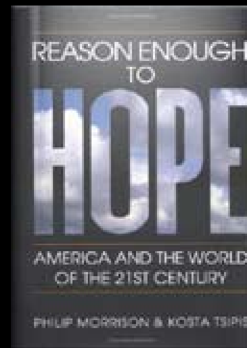

"Reason Enough to Hope."

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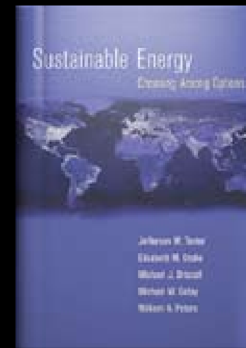

"Sustainable Energy"

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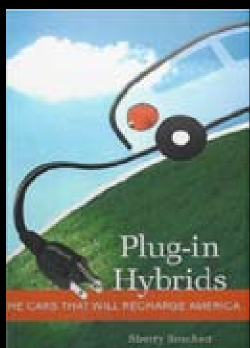

"Plug-in Hybrids"

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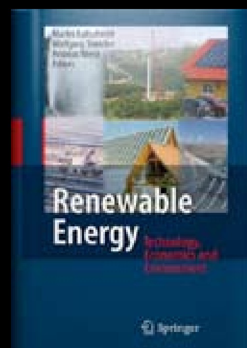

"Renewable Energy"

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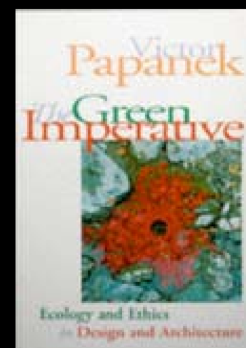

"The Green Imperative"

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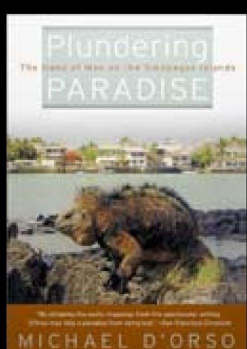

"Plundering Paradise"

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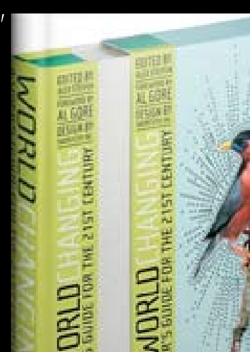

"World Changing"

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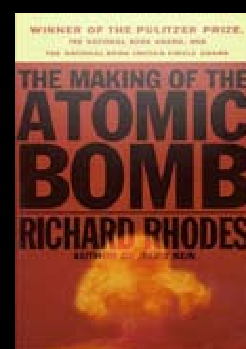

"The Making of the Atomic Bomb"

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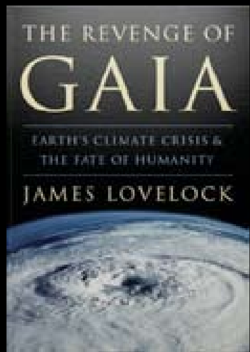

"The Revenge of Gaia"

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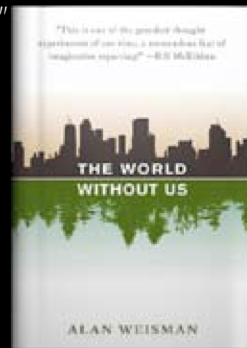

"The World Without Us"

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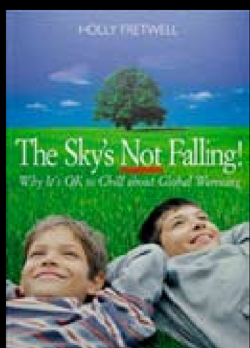
"Windswept"

http://www.amazon.com/exec/obidos/ASIN/0802715192/ref=nosim/deliciousmons-20



"The Sky is Not Falling"

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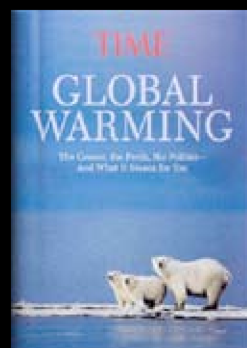

"Global Warming"

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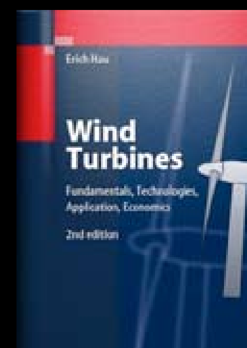

"Wind Turbines"

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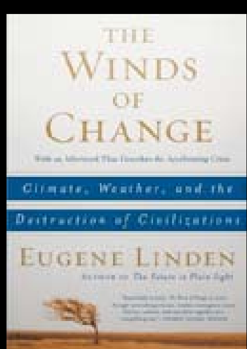
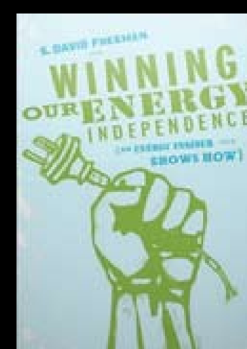


"The Winds of Change"

http://www.amazon.com/exec/obidos/ASIN/0684863537/ref=nosim/deliciousmons-20

"Understanding"

http://www.amazon.com/exec/obidos/ASIN/0967453607/ref=nosim/deliciousmons-20

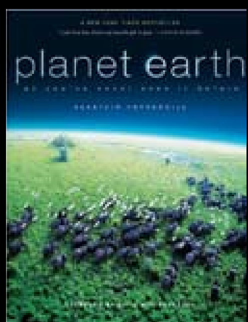


"Winning Our Energy Independence"

http://www.amazon.com/exec/obidos/ASIN/1423601564/ref=nosim/deliciousmons-20

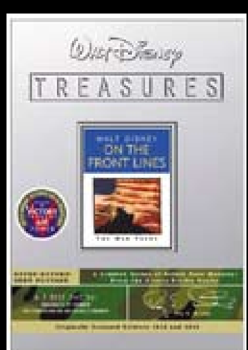
"The Blue Planet"

http://www.amazon.com/Planet-Earth-Blue-Special-Collectors/dp/B000TEUSQ8/ref=pd_bbs_sr_3?ie=UTF8&s=dvd&qid=1204582272&sr=8-3



"Planet Earth"

http://www.amazon.com/Planet-Earth-Youve-Never-Before/dp/0520250540/ref=pd_bbs_sr_5?ie=UTF8&s=books&qid=1204581569&sr=8-5



"On The Front LInes"

http://www.amazon.com/Walt-Disney-Treasures-Front-Lines/dp/B0000BWVAH/ref=pd_bbs_sr_1?ie=UTF8&s=dvd&qid=1204581676&sr=8-1