The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Revisiting the 'Fake Fire Brigade' - Part 1 - General Issues

Posted by nate hagens on July 8, 2010 - 8:55am

This is a follow up post to 'The Fake Fire Brigade - How We Cheat Ourselves about Our Energy Future', which gave an overview on how difficult it will be to maintain our current energy systems with renewable energy. The main authors are Hannes Kunz, President of Institute for Integrated Economic Research (IIER) and Stephen Balogh, a PhD student at SUNY-ESF and Senior Research Associate at IIER. IIER is a non-profit organization that integrates research from three different areas: the financial/economic system, energy and natural resources, and human behavior. Their objective is to aid policymakers in developing strategies that result in more benign trajectories after global growth ends. The authors wrote over a 10,000 word follow-up to the questions raised in the original posting and we've broken into 4 pieces for readability - the first installment is below the fold.

(The original post and other related content can be found on the IIER website).

Revisiting the Fake Fire Brigade - Part 1

Introduction

This post follows up on the "Fake Fire Brigades", which sparked a large amount of scrutiny, but also received much positive feedback. We're grateful for both. One of the allegations made to our overview was that our claims were "unsubstantiated": we are afraid they are not, but in retrospect the post may have been misleading. When we wrote it we had a choice between two imperfect options:

- *make our general case concerning the fact that we cannot expect energy systems to deliver what we're used to in the future with the technology we have available, irrespective of effort;*
- *analyze one of the "firemen" we consider "fake", and support our conclusions with all the necessary data, then continue with the next one, and so on.*

We opted for #1 because the problem we face is a general one, with wide boundaries of analysis. When trying to understand an integrated system, we can't just look at the parts but instead have to analyze it in its entirety. This is because we might easily find a solution for each individual problem, but may still fail on an aggregate level. This is why we decided to make this general statement about "fake fire brigades". However, given the abundance of aspects and ideas involved in today's energy debate, and the limited size of an individual TOD essay, we could only do this and provide a few examples, which made some of our statements rather generic.

This dilemma has gotten us into a position of being called out as propagandists, wanting to prove things that are irrelevant, or simply not doing our math properly. We can safely claim that the only propaganda we are trying to make is for one thing: that human societies should undergo extensive integrated analysis on alternative energy before we lull ourselves with the expectation that our energy future will somehow be at the same or higher level of today's.

We offered a follow-up post with more detail, and here it is. It contains four elements:

- a few key aspects we consider relevant when understanding energy and its contribution to society

- an analysis of the potential of biomass as a future energy supply
- a close review of electricity delivery systems
- a Q&A section trying to address the concerns voiced after our original post.

What is the claim we actually make?

Some people walked away from our post thinking that we are against renewables, against nuclear, or against any energy solution. That is not the case. After considerable analysis and effort, we are now simply against the predominant idea that we can more or less continue our fossil-fuel driven lifestyle by slowly replacing oil, coal and gas with other sources and technologies, just by managing them well – maybe coupled with some efficiency gains.

We instead claim that our current expectations for energy delivery systems cannot be maintained, **as soon as we HAVE TO use flow-based renewable sources** (i.e. almost everything nature provides besides dammed hydropower, biomass and maybe some geothermal power) at a rate of more than 20 or 30% of total consumption. The proposed future of energy delivery has three weak points: technical feasibility, cost, and the ability of us humans to act.

A brief sidestep: What about population growth?

Our post also provided some reason for commenters to caution readers about overpopulation. We agree that we likely face a threat from more and more humans on this planet, particularly for our ecosystems. However, our topic is not really related to population, but rather to standard of living. The problems we describe in our post are confined to advanced economies, the countries with the highest population growth today don’t even have access to the stable and reliable energy services we are used to. And in most OECD countries, policy-makers today are more concerned about shrinking and aging populations. Ultimately, even if advanced economies – for whatever reasons – have to make do with 30 or 50% of today’s energy, this will still be enough to feed everybody, provide shelter, heat and other basic services.

About double-counting

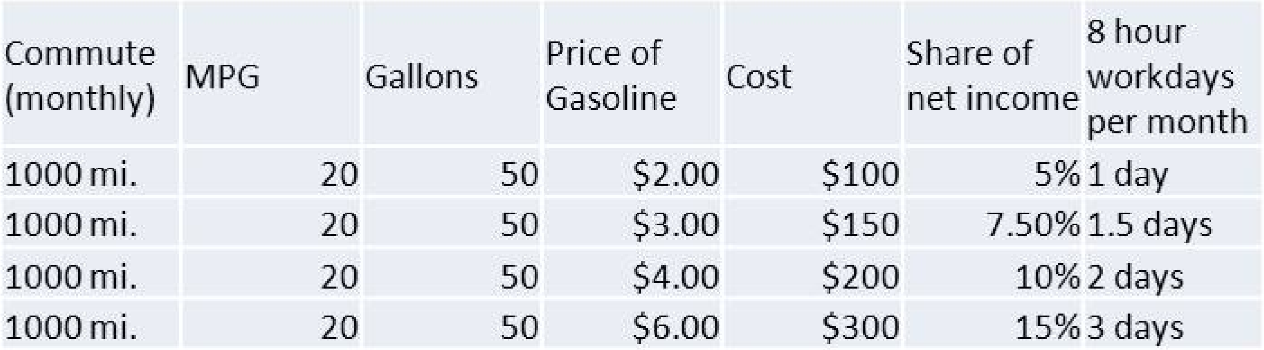
One of the key challenges we see when looking at a systemic view, is that when thinking about future solutions, we engage in double-counting in two ways. First, most tend to ignore the problem that many renewable technologies are still heavily dependent on the application of relatively cheap fossil fuels when it comes to raw material extraction, manufacturing, transportation, installation and maintenance. Those inputs mostly come at relatively low cost. So if these alternative energy technologies (even nuclear plants) will have to be built with renewable sources of power in the future, or with higher priced fossil fuels, this would make these relatively expensive technologies even more expensive. Not taking this into account and banking on past experience about new things always becoming cheaper and cheaper might be a serious mistake.

Second, on societal level, we have a tendency to double-count the few available flexible solutions as problem-solvers for every input that does not deliver its outputs according to our energy demand. In almost every projection of future electricity systems, biomass and hydropower come up as general “fixes”, mostly ignoring the fact that someone else has already claimed the exact same resources for other purposes. That way, each individual system looks theoretically feasible, but when looking at the aggregate, things begin to fall apart, simply because those cure-alls are already spoken for elsewhere in the system, and therefore don’t scale as we would wish them to.

Before going back to that subject, we would like to talk a little bit about the cost of energy.

The cost of energy

We want to introduce the aspect of energy pricing, which wasn't done in our original post. People who commute by car understand that the cost of gasoline has a significant impact on their discretionary income. Someone with a take-home pay of $2'000 per month and a round trip commute of 50 miles each day will have to spend $100 or 5% of his or her income for gasoline bought at a price of $2 per gallon and used in a car that gets 20mpg. If gas prices go up to 4 dollars, suddenly 10% of that person's budget has to be spent on transportation fuels, and at $6 (the norm in Europe) it becomes $300 (or 15%). What this does is reduce discretionary income that could be spent on other things. The cost of commuting reduces discretional spending and is the equivalent of up to three days' worth of work (Table 1).



Commute (monthly)	MPG	Gallons	Price of Gasoline	Cost	Share of net income	8 hour workdays per month
1000 mi.	20	50	$2.00	$100	5%	1 day
1000 mi.	20	50	$3.00	$150	7.50%	1.5 days
1000 mi.	20	50	$4.00	$200	10%	2 days
1000 mi.	20	50	$6.00	$300	15%	3 days

Table 1: discretionary income reductions from changing gas prices

Unfortunately, the methods to mitigate this growing cost incur costs of their own, for example by giving up the job (decreased income), buying a more fuel-efficient car (increased car payments), finding a house or a job involving a shorter commute (cost of moving/changing jobs), or taking public transportation/biking to work (increased time of commute).

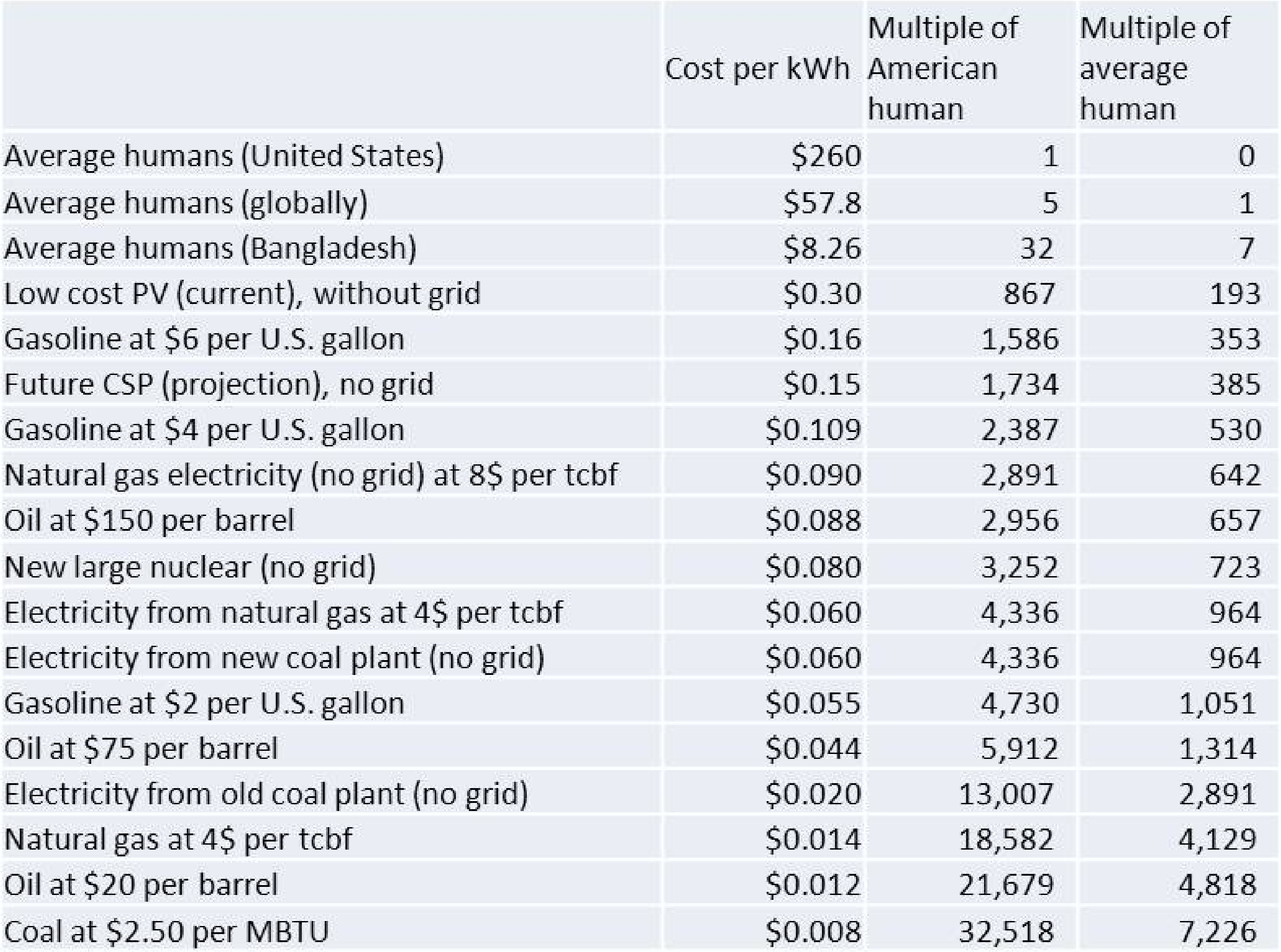
What is relevant for individuals is also true for societies in aggregate. The higher the share of our effort that goes into retrieving the energy that keeps our world going, the smaller the share that is available for investment and consumption. Ultimately, this leads to a reduced standard of living (Hall, et al. 2008). To explain that a little better, we might have to go back in history.

When man began, what he used were his bare hands, plus soon some tools, to recover what he needed from his surroundings. With more humans being around, better ways of exploring nature were required, which led to agriculture as a first development. Introducing draft animals further extended the capabilities of humans, as they were able to convert previously unused energy (for example cellulosic biomass from grasses) into the useful energy from a strong ox. Over time, man added energy provided from water and wind, both for mechanical work and for transportation. These transitions basically followed a single concept: it always made sense to implement a new method once it safely returned more useful energy units than what humans had to invest in the technology. For example, building a windmill would make sense if the effort to haul the materials, to erect the structure, to maintain it and to operate it was significantly less than the effort to accomplish the objective of milling manually or with a simple treadmill or one driven by an ox.

The above is nothing but an early example of describing EROI (Energy Return on Energy Investment). The more of our effort goes towards retrieving the energy we (want to) use, the smaller our benefits from that energy.

The theoretical concept works as follows, as most readers of The Oil Drum know: If a person works one hour and – from a draft animal, a wind mill, or a power plant – gets work worth 10 hours back, a net gain of 9 hours can be directed at other things. The bigger that ratio is, the more available time, and the higher the standard of living becomes. In the example above, a farmer working one hour with an ox plowing the fields can do the equivalent of 5-7 hours of a human working alone. Therefore, the farmer can increase his productivity, or have that much more free time. Early grain farms, based primarily on human labor, required about 373 man hours per 100 bushels of wheat and 344 man-hours per 100 bushels of corn. By 1900, with draft animals and steel plows now an integral part of farming, the man-hours were reduced by more than half for corn, and nearly 70% for wheat, even though during that period yields remained steady. After WWII when mechanical tractors and synthetic fertilizers became prevalent, agriculture efficiency rose dramatically, with man-hours per 100 bushels reduced to 18 in 1955 for wheat, and to 22 for corn (Rasmussen 1962). In the same way a farmer employs an ox, modern humans employ cheap energetic sources of labor.

Let’s now spend some time understanding what this means today. A strong healthy human can deliver about 1 kWh of energy per day (on average it probably is closer to 600 W). Given a median household income of $52’029 in the US in 2008 (http://www.census.gov/prod/2009pubs/acsbr08-2.pdf), the average price for one kWh of human labor is $260. Compared to that, the same amount of energy in oil at $20/barrel (the long-term inflation-corrected average) cost us 1.2 cents (today, at $75, it is 4.4 cents/kWh), and an equal amount energy from coal comes at 0.7 cents. The table below shows how different the price of energy is for many sources.



	Cost per kWh	Multiple of American human	Multiple of average human
Average humans (United States)	$260	1	0
Average humans (globally)	$57.8	5	1
Average humans (Bangladesh)	$8.26	32	7
Low cost PV (current), without grid	$0.30	867	193
Gasoline at $6 per U.S. gallon	$0.16	1,586	353
Future CSP (projection), no grid	$0.15	1,734	385
Gasoline at $4 per U.S. gallon	$0.109	2,387	530
Natural gas electricity (no grid) at 8$ per tcbf	$0.090	2,891	642
Oil at $150 per barrel	$0.088	2,956	657
New large nuclear (no grid)	$0.080	3,252	723
Electricity from natural gas at 4$ per tcbf	$0.060	4,336	964
Electricity from new coal plant (no grid)	$0.060	4,336	964
Gasoline at $2 per U.S. gallon	$0.055	4,730	1,051
Oil at $75 per barrel	$0.044	5,912	1,314
Electricity from old coal plant (no grid)	$0.020	13,007	2,891
Natural gas at 4$ per tcbf	$0.014	18,582	4,129
Oil at $20 per barrel	$0.012	21,679	4,818
Coal at $2.50 per MBTU	$0.008	32,518	7,226

Table 2: cost per kWh, cost related the U.S. if not otherwise stated

The challenge is that we have built our Western lifestyles based on the lowest-cost items in the table, and even until very recently have continued to do so by moving almost all mass-production of key industrial goods to low-cost countries (for either lower energy or labor cost, or both).

Aluminum is one good example. Electricity is the single biggest cost parameter in its production. I.e. it matters greatly whether a smelter has to pay 3 cents, 5 cents or 10 cents per kWh, as it may decide between making a profit and incurring a loss (Figure 1).

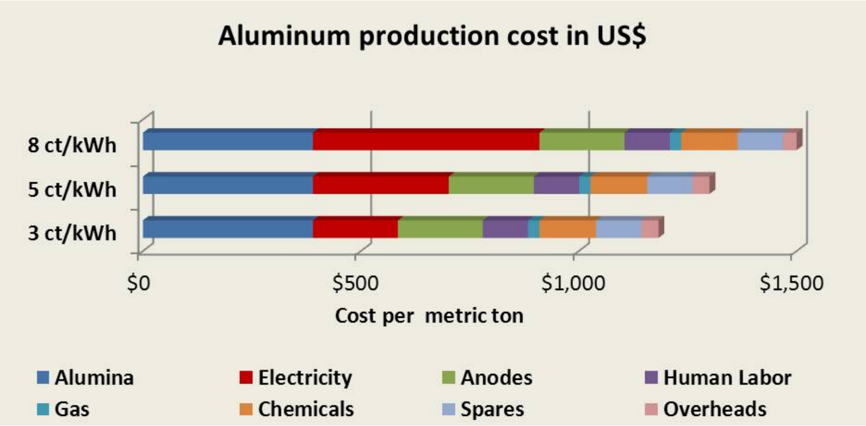


Fig 1: relevance of electricity for aluminum production (Source: Energy Trader 02/09)

So, as energy inputs into all our activities have become more and more expensive, we simply have either reduced their use, or have moved their manufacturing to places where people care less about the side effects of cheap energy from coal (like China), or where they are lucky to have abundant low-cost hydropower (like Norway). Both countries have – for exactly that reason – become key places for aluminum production – even though they are quite far away from where most of the bauxite gets mined.

The biggest challenge is that when building our modern systems we never traded like for like. Transition to lower-cost energy usually came at the price of higher overall energy consumption for the same task, for it involves machinery, and buildings, and other infrastructure. And when we began to outsource to far-away countries, there were extra transaction and transportation costs involved, which further increased the energy used. But since it was cheaper, it did not seem to matter.

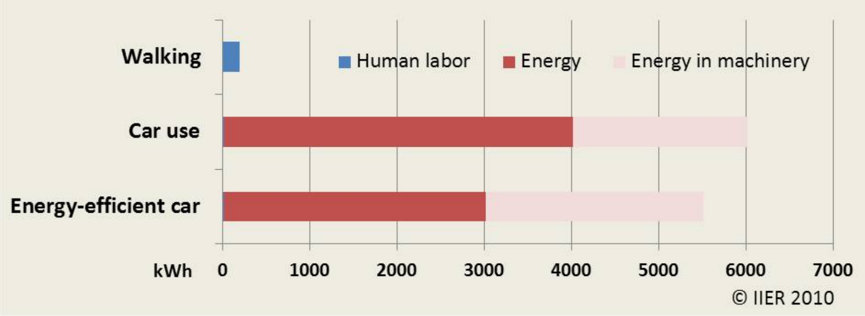


Fig 2: energy use for driving (1 passenger) and walking (Source: IIER)

For example, when we use a car driving one person around, total energy expended is 400-500 times higher when compared to walking, and that doesn't even include the infrastructure required beyond the car itself, such as roads. If this system, which until recently operated at a ratio of 4730:1 ($2 gasoline), gets pushed towards 1586:1 ($6 gasoline), it becomes clear that benefits of driving a car are greatly reduced.

So when we designed the world we live in, we did it with energy cost of below 5 cents per kWh in mind. If that price goes to 10 or 15 cents, that might look like a small change, but in fact it cuts our benefits from the applied energy to half or a third of what they were in the beginning. This is like our landlord doubling or tripling the rent over a short period of time, or the interest rates of our mortgage doubling or tripling. In that case, we would have to move to a smaller place.

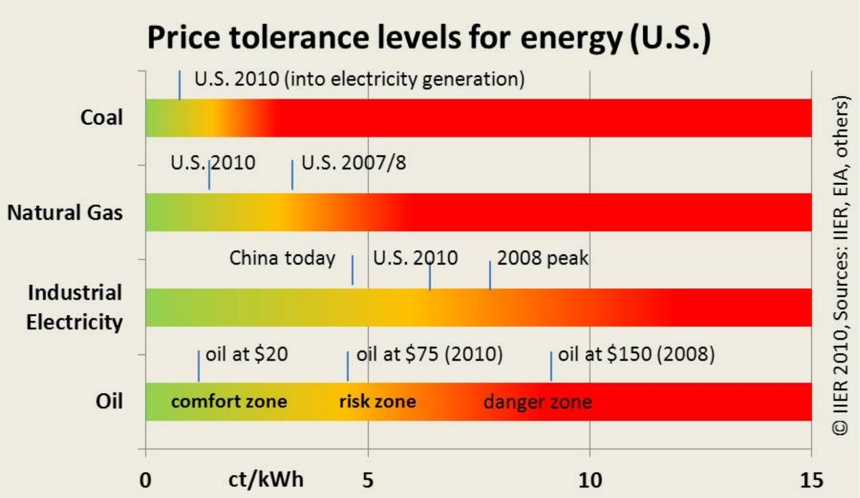


Fig 3: commercial application tolerance levels for energy prices (IIER calculations)

Figure 3 shows at what price levels certain energy sources become problematic for the key delivery systems they support. The green “comfort zone” is the range where our system runs without much trouble, where we can build and maintain our infrastructure, and keep our current lifestyle. The orange “risk zone” is where first applications start to get into trouble and get squeezed out, typically leading to recessions and significant shifts. The red “danger zone” is when it truly becomes problematic, as almost everything becomes unaffordable very quickly, particularly if all energy sources go up in price at the same time (like it happened in 2007 and 2008, in contrary to the 1973 energy crisis, where the price spike was limited to oil).

Important: The price ranges in Figure 3 don’t refer to private household use, but to the applications that produce whatever we need to live our lives, such as food (e.g. requiring natural gas for fertilizers), industrial goods (using coal and electricity from multiple sources), and transportation (mostly based on oil). The relatively significant differences shown in “acceptable” price levels are mostly related to the usability of individual sources, their energy quality and the ability to store and transport it. We will get to that in the next paragraph.

Other than by reducing our standards to a different, lower level, our current system cannot deal with energy prices in the order of 2, 3 or 5 times their long term averages when we built our societies. And energy efficiency brings, as many studies show, typically 20-30% total energy savings across the entire life cycle of a product. And for many industrial applications, this potential is already partly exhausted, particularly in areas with very high consumption. For example, nitrogen-based fertilizer production (from natural gas or hydrogen) using the Haber-Bosch process has a theoretical minimum energy input of 32 GJ to produce one ton of nitrogen, and most operations run at around 40 GJ per ton. Similar efficiencies are also common for steel, copper and aluminum production in Western societies.

The relevance of energy quality

Many people discuss energy economics referring to energy content and cost of primary inputs. In that view, a barrel of oil that costs $75 and has an energy content of 6.1 GJ, which translates to energy cost of $12.30 per GJ (or 4.4 cents per kWh in energy content).Coal , if we use a market price of $2.50 per MBTU, costs approximately $2.36 per GJ (or less than 0.9 cents per kWh). Natural gas that sells at a spot market price of $4 per tcbf (which on average contains about 1MMBTU), comes at a price per GJ of $3.79 (or 1.4 cents per kWh). Please note that the kWh is used for the raw energy, before being converted to anything else.

Unfortunately, this is only half of the truth, because what counts for us humans is not the pure energy content, but instead, the portion of the energy that can be converted to its intended use. A simple example* might illustrate that. Let’s consider our options for cooking food. Using charcoal or coal is a low-tech, but feasible solution. Coal and charcoal is easily transported and stored, but in an open fire only a small portion of the heat reaches the meat. The rest escapes as heat. Thus, maybe 2% or 5% of the BTUs we have paid for support the purpose of cooking our food. It is possible to improve that conversion efficiency by building a coal stove, but even the most efficient one will convert perhaps 10 or 15% of the heat from the burning coal; the rest simply heats up the stove and its surroundings, which is welcome in winter, but maybe not so much in summer. On top of that, the stove itself contains energy used during the extraction of raw materials, its manufacturing and its maintenance. If we assume an overall efficiency of 10% for this application, a kWh of "useful energy" now costs 8 cents.

If we instead choose to use a gas stove, heat can be much better regulated and directed to the surface of our pan or pot, which significantly increases the overall efficiency to maybe around 25%. Higher overall efficiency rates are unlikely due to the fact that we need quite some infrastructure to get the gas to its place of application, either in the form of pipes or an appropriate container. But still, the cost per applied kWh is 8 cents, so the finally usable energy unit has the same price as from coal. An oil stove might even give us a 30% overall conversion efficiency, as the heat can also be applied directly, but because oil is so much easier to store and transport than gas. However, given its high initial price, one applied kWh would cost us 14.7 cents (nearly twice that of natural gas).

*Please note that this is a theoretical example not aimed at being precise, but at illustrating the concept of delivering useful energy.

So in this context, it greatly matters what kind of energy we produce and when. If our output is 1 energy unit (measured in Joules, kWh, BTUs, etc.) worth of highly versatile crude oil, it has a very different value than 1 BTU in a pile of coal which can only be used for certain things in order to become valuable. And even within one system, things are not the same. 1 kWh of electricity from natural gas at a price of 8 cents that can be produced at our leisure is something very different from the same amount, equally produced for 8 cents, by a wind turbine, which gets delivered to us erratically, just when the wind blows. We will get back to this problem in part 2 and 3.

Summary - part 1

What we've tried to describe above are a few general concepts that tend to get overlooked while analyzing individual technologies. Typically the standard approach used to evaluate and compare energy technologies is EROI, life cycle analysis, or energy payback periods. However, usability and cost – important post-farm gate or post-mine mouth factors – play a decisive role.

Second, equally important, an industrial society is simply not able to provide the same benefits as today once energy inputs into key supplies pass a certain price threshold. Modern societies have been able to steer clear of that reality over the past decades by outsourcing to places where energy is still cheaper, but that potential is now nearly exhausted.

Third of the big mistakes we make when looking at energy cost is that we always talk about small numbers, like "a few cents" without realizing the implications of scale. If the key contributors to our societies suddenly cost 5-10 cents instead of 1-2 cents per kWh, which is (in the best case) where we are headed, this means that our benefits from applying energy to our lives get reduced to one-fifth of what we are used to. That will be a very different lifestyle and one that warrants considerable study.

Our next follow-up post will deal with the potential of biomass as a source for future energy systems.
Revisting the Fake Fire Brigade Part 2: Biomass - A Panacea