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High altitude wind power: an era of abundance?

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The kitegen concept: high altitude wind power based on kites. In this configuration ("stem"), the kite reaches altitudes of the order of 1000 m; pulling on a power generator located on the ground. High altitude wind power promises to be a low cost and widely available technology able, in principle, to provide amounts of energy comparable, and even superior, to the present production based on fossil fuels. (See here an animated representation of how a stem works)

Why should there be an energy problem? After all, there is plenty of energy around us. The sun beams on the earth's surface a daily amount of energy that corresponds to almost ten thousands times the primary energy we generate - mainly - from fossil fuels. And that doesn't include geothermal energy nor the perspectives of nuclear energy, especially in terms of fusion power. Just tap a small fraction of this energy bonanza that surrounds us and we can have more than we need.

But, of course, things are not so simple. We still rely heavily on fossil fuels for our needs and switching to alternative sources is proving to be a very slow and difficult process. Production from traditional nuclear plants is going down (WNA 2009) and fusion power remains far away in the future. Traditional renewable sources, such as wood burning and hydroelectric have very limited possibilities of expansion, while the "new" renewables (mainly photovoltaic and wind power) still produce only a minuscule fraction of the worlds' total primary energy. It was only last year (2008) that for the first time the total power of new renewable plants installed outstripped that of new traditional plants in the US and in Europe (REN21 2009). Renewables are growing fast, but can they grow fast enough to compensate for the depletion of fossil fuels?

We have a problem of cost. That can be intended as monetary costs, but also in terms of energy return of energy invested (EROEI). As shown in Charles Hall's "balloon graph" (2009) the EROEI of renewables can be considered as reasonably good in most cases (with the exception of biofuels). It is around 10 for photovoltaics and around 20 for wind. Similar returns are reported for current nuclear technology. These are good returns on the investment, but not as good as it was for fossil fuels in the golden days. Decades ago, the EROEI of petroleum was of the order of 100 and perhaps even better (Hall 2009). It was this high EROEI that led fossil fuels to acquire the dominance that they have today. Without that kind of EROEI; other energy sources haven't had a possibility to compete. Today, we still need fossil energy to build non-fossil energy plants. But, with fossil fuels starting their decline, it will be more and more difficult to sustain the growth of alternative energies at a rate fast enough to provide a smooth substitution of conventional sources. We can think of an industrialized world that doesn't need fossil fuels, but we don't seem to be able to get there fast enough.

So, we are facing Tantalus' curse: we are surrounded by abundant energy but we can't get it. That is, unless we can develop a technology with a much better EROEI than what we have now. With a very fast energy return on investment, we could free the world's energy system from its dependence on fossil fuels. That is, unfortunately, easier said than done. The internet is full of claims of supposed breakthroughs in energy technologies that promise a lot but turn out to be just dreams; or even outright scams. But there may exist an energy technology that can not only promise, but deliver a high EROEI and that is also based on sound physical principles: high altitude wind power.

The basic idea of high altitude wind power is that wind is more intense as you move up in the atmosphere. The average wind speed increases with height according to an exponent (called "Hellman exponent") which is about 1/7. But the energy contained in a mass of air in movement increases with the cube of speed. From a simple calculation, we see that if we could raise a wind turbine to a height of 800 m, we could increase the power obtained of a factor of 8 in comparison to the same turbine near the ground. Even larger increases are possible at higher altitudes, where winds are also much more constant; easing the intermittency problem of conventional wind turbines. But of course, it is impossible to reach such heights with the current wind technology, limited to about 100 m because of the cost and weight of the tower.

This concept has been clear for a long time and has led to several proposals to tap the wind at higher heights. There are two possible ways for doing that: balloons and wings. You can find a recent summary of the progress in this area in the work by Big Gav (2009) published on TOD. As you can see, there are many ideas in this field, many of which exist only as sketches on paper. In many cases, the energy yield of the proposed systems is only a guess while, for those systems based on aerostats, the need of a non renewable resource (helium) is a considerable limit.

However, a few systems have been studied in depth and some tested in practical experiments. Systems based on rotors are possible and systems based on kites, in particular, do show a lot of promise. Saul Griffith of Makani Power has shown some images of a test done with a three rope kite. Wubbo Ockels, (Delft University of technology) has been also experimenting with a kite, this one using a single rope. In this field, the most advanced system seems to be the "kitegen"; a kite system created by Massimo Ippolito of Sequoia Automation, a company based in Italy. Tests on a prototype system have been completed and a first energy producing plant is being built in Northern Italy.

The Kitegen is a simple aerodynamic system: it uses state of the art kites which create lift dynamically by flying at 70-80 m/sec; this is the speed reached by the tips of the blades of a conventional wind turbine. In the simplest configuration (called "stem"), the system uses a single kite linked to a power generator located on the ground. The kite moves like a yo-yo: when it goes up, it generates energy that is transformed into electric power by the generator. When it reaches its maximum height, it is placed in an aerodynamically non-lifting configuration, so that it can be pulled down at a very small energy cost. Two coupled stems would work like a two-cylinder engine, although the "power" phase would last 90% of the time while the "pull back" phase would be much faster. A single stem could have a maximum power of a few MW. Larger plants could be operated in the "carousel" configuration. In this case, the kites fly at a constant height and at much higher altitudes, pulling a generator that moves on a circular rail. For a large carousel system, the maximum power obtained can be calculated as of the order of 1 GW or even higher.

Since the kitegen has been studied in detail, we can use it to make an estimate of the EROEI involved in high altitude wind generation. Before getting to that, however, let's summarize the known data for the current wind technology. A recent LCA study for a conventional 3 MW wind turbine was reported by Nalukowe et al, (2006). They estimate the total energy input for building and maintaining the turbine as ca. 8000 MWh for 20 years of lifetime. Since the total weight of the above ground part of the turbine is about 400 tons, we can estimate an embodied energy requirement of about 20 kWh/kg. The turbine will produce about 160,000 MWh during its lifetime and hence the final EROEI is ca. 20.

Now, let's see the results of a similar approach for the kitegen. According to Massimo Ippolito (data published on www.kitegen.com), the energy required to make a 3 MW rated power kitegen stem is of 40kWh/kg or 40 MWh/ton. The calculation that leads to this value takes into account all the requirements in terms of the materials needed: steel for the structure, copper for power lines, neodimium and boron for the magnets, machining, transportation, building, etcetera. This value includes also the energy costs involved with having workers at the plant and for the periodic substitution of cables and kites over a 30 year lifespan.

We see that the kitegen requires more energy per kg than a conventional wind turbine; this is expected because it is a more sophisticated machine. But the stem is much lighter: we are talking of about 30 tons in total for a 3MW plant. So, we can estimate the total energy requirement as 30 tons*40 MWh/ton= 1200 MWh. Assuming 5000 hours per year of operation at maximum power, the plant could produce approximately 15,000 MWh per year, or 450,000 MWh in 30 years. The final result is an **EROEI = 375** (!!). If we assume a 20 year lifespan, the estimate should be reduced, but it remains large. For larger kitegen plants of the carousel type it would be possible to reach higher heights, tap into stronger winds and increase even more the EROEI. This calculation is valid for the specific case of the kitegen system, but other proposed systems based on kites or rotors would probably be able to attain similar large EROEIs.

Of course, these values have to be taken with a lot of caution, but this calculation should be enough to show us the enormous potential of high altitude wind power. EROEIs higher than 100, perhaps even much higher, bring us back to the golden age of cheap and abundant fossil fuels, without all the troubles and problems that fossil fuels brought. A further advantage of high altitude wind is that plants can be placed almost anywhere; another is that we can obtain a nearly constant output for most of the time (Archer and Caldeira, 2009). Although the cost of energy storage would not be completely eliminated, it would be much reduced. With high altitude wind, we might really have the kind of energy "too cheap to meter" that was prophesied in the optimistic 1950s. Not only we could have cheap energy, but we could also have it fast. Consider a conventional wind turbine, with an EROEI of 20 over a 20 years lifetime. During this period, the energy generated could be used to build 20 more turbines; an average of one per year. A kitegen, with an EROEI > 200 and the same lifespan, could be the "seed" for hundreds more kitegens, an average of more than one per month. With such a high EROEI, high altitude wind energy wouldn't need fossil fuels as energy subsidy. It could grow by itself so fast that it could replace fossil sources well before we arrive to the last drop. That would also ease the climate problem by rapidly reducing the emissions of greenhouse gases from fossil fuels.

Now, of course, all this should be considered still a dream until it is tested and verified. But, at least, it is a dream that has some solid basis in physics and engineering. So, assuming that the promise of low cost and high EROEI can be really fulfilled, we should still remember that the earth is a limited system. So what are the ultimate limits of high altitude wind power?

It is estimated that about 2% of the Sun's energy that arrives on the earth's surface is transformed into wind energy. The atmosphere is not very efficient as a thermal engine, but there is so much energy from the sun that even a mere 2% is a huge amount in comparison to our needs. The total energy stored in form of winds is estimated as of the order of 2000 TW (Hurley 2009) or perhaps higher according to other estimates. In comparison, the total primary energy generated by humans corresponds to an average of just about 16 TW. So, there is no doubt that wind energy is abundant: according to a 2005 study by Archer and Jacobson, already at 80 meters of height there is enough energy in the atmosphere that it could be exploited by means of the conventional wind technologies to provide a total amount corresponding to the present production. But there is much more energy at higher altitudes and we need to exploit just a few percent of it to be able to produce enough for our current needs.

One problem could be the effect of high altitude kites or rotors on the atmospheric wind circulation. This question has been examined by Archer and Caldeira (2009) by means of climate models. The results are that tapping high altitude winds would reduce precipitation. Also, it would have a cooling effect and could affect climate. The problem would be minimal (around 0.1% reduction in precipitation) for amounts of energy tapped corresponding to our present demand. But this effect does pose a limit to the technology. It may not be advisable to use high altitude wind power for generating more than a maximum of around ten times the present production. It is still a huge amount of energy available for free and generating a very small impact on the earth's ecosystems. It could even be further increased, indirectly, by using wind energy to manufacture photovoltaic panels or other kinds of solar plants. In the end, we shouldn't be surprised of these perspectives. After all, as we said, we are surrounded by huge amounts of energy and if we find a way to exploit it, well, why not?

From these data, we could be tempted to see high altitude wind power as a nearly limitless energy technology. But that would be a mistake. Energy production is not static - it goes with the economy and if the economy is powered by a source of cheap and abundant energy it tends to grow exponentially. Exponential growth is treacherously misleading: we could find ourselves bumping into the ceiling of high altitude winds much sooner than we would expect.

But there is a much more serious problem in the fact that energy is not the only parameter that affects the economy. Abundance of something is not abundance of everything. Abundant electric power doesn't necessarily translate into abundant food, although electricity can surely be used in agriculture in place of fossil fuels. That our problem is not just energy is confirmed by the models developed for the "Limits to Growth" series (Meadows 2004). The models can be run for scenarios that assume abundant (or even infinite) energy available, but the result is that the economic system collapses because of the strain on the environment and on agriculture generated by a combination of overpopulation and pollution. To avoid collapse, we need to stabilize both the economy and the population at a stationary level. Even so, the gradual depletion of mineral ores will make us depending on more and more energy if we want to keep the flux of mineral commodities at the present level (Diederen 2008, Bardi, 2008). So, even with abundant energy, we'll still need to recycle materials and reuse what we manufacture.

So, even with abundant energy we still need to come to terms with the fact that the earth is a limited system. However, high altitude wind power offers us a hope of a future of relative abundance, even of prosperity, if we'll be able to keep the economy and the population stable and avoid overexploiting our agricultural and mineral resources.

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