The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

High altitude wind power II: the reactions

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Tall ships are the embodiment of the fascination we feel for the free and abundant energy of the wind. Already at the time of the sailing ships, it was recognized that it was important to catch the wind at the maximum possible height. So, the main mast of a tall ship could go up to 30 meters. Modern wind turbines reach heights of a hundred meters or more. But Airborne Wind Energy (AWE) can tap winds at heights up to thousands of meters. The present post is a more in depth examination of AWE after a previous post that I wrote on The Oil Drum and which generated a lot of comments and of reactions. (Image from the Imperial College Yacht Club.) .

I came in contact with the idea of AWE (*) (Airborne Wind Energy) for the first time - I think - six years ago when someone named Massimo Ippolito wrote to the mailing list of ASPO-Italy proposing the concept on which he was working. It was a wind power system based on remotely controlled kites. I remember that I wrote back saying that the concept didn't violate any physical law, but that it seemed to me rather difficult to transform it into something practical.

As I followed the development of the idea, which later became known as "kitegen", I saw it growing from just a qualitative concept to a full fledged project, refined in all details. I tried many times to find faults in it, but I never succeeded. Whatever objection I could raise, Ippolito always had a good answer to it. Eventually, I ran out of objections and when Ippolito tested a working prototype, in 2008, I had to count myself among the believers. In the process, I learned a lot about aerodynamics; for instance what is the difference between a "drag machine" and a "lift machine". The latter is much more efficient in terms of energy generation and is the way the kitegen works. Here is the basic concept of kite power.

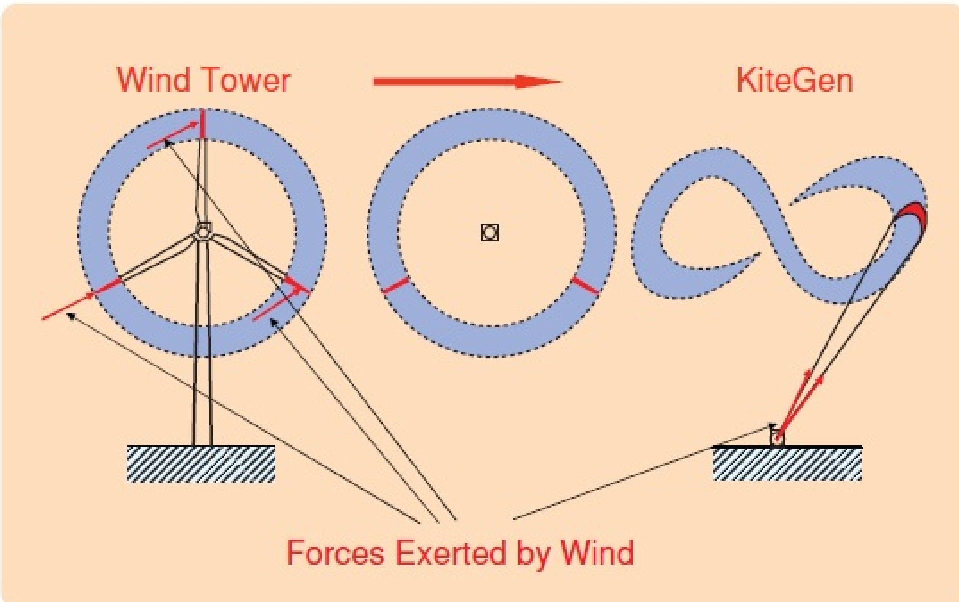

FIGURE 5 Comparison between wind turbines and airfoils in energy production. In wind towers, limited blade portions (red) contribute predominantly to power production. In KiteGen, the kite acts as the most active portions of the blades, without the need for mechanical support of the less active portions and the tower.

Image from M. Canale, L. Fagiano and M. Milanese, "Power Kites for Energy Generation" IEEE control systems Magazine, Dec. 2007, p. 25

The last doubt I had on AWE was related to the environmental impact of high altitude turbines or kites. The recent [paper by Archer and Caldeira]was a small epiphany that dissipated my doubts. We can obtain plenty of energy from high altitude winds with a minimal environmental impact. So, I decided to write [a post for The Oil Drum], summarizing what I knew and the perspectives of the idea.

Passing the "meat grinder" which is the comments section of The Oil Drum is quite scary. AWE (and, in particular, the kitegen) came out of it somewhat ruffled but, on the whole, it survived the ordeal. Because of the many questions and comments received (more than 260), I think it could be interesting to examine AWE more in depth. I apologize for this post being "kitegen-centered" and I have no intention of disparaging other ideas and projects which are being developed in the world. There is a lot of atmosphere over there and there is plenty of space for AWE in many forms. It is just that the kitegen is the project I know best.

So, first of all, let me summarize how a kitegen works in the configuration called "stem" or "yo-yo". Here "KSU" stands for "kite steering unit".

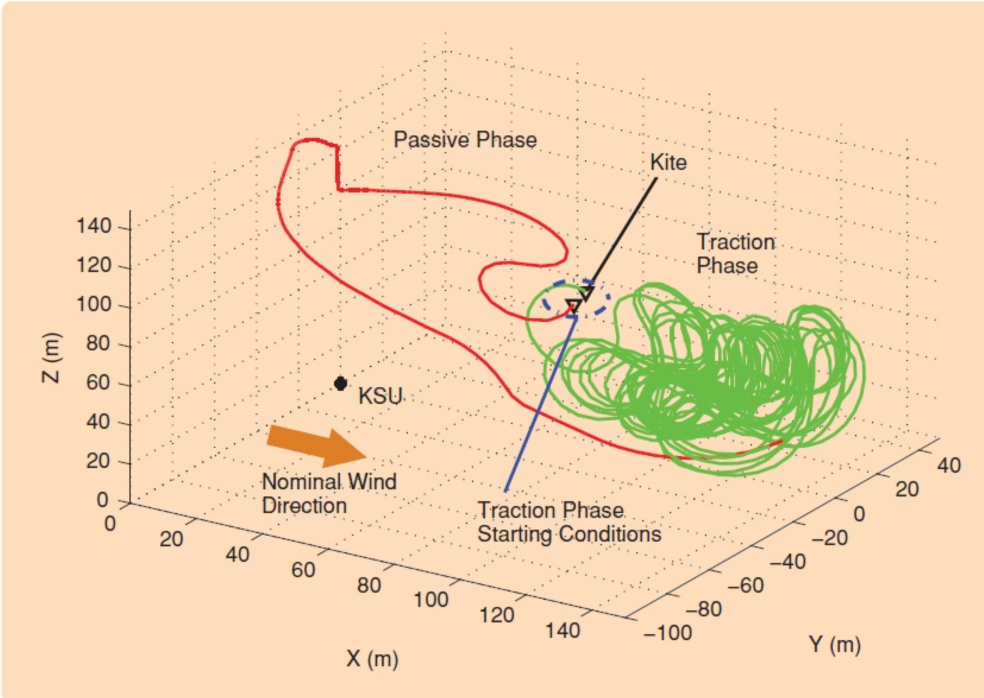

FIGURE 9 Yo-yo configuration phases. The kite steering unit acts on the kite lines in such a way that energy is generated in the traction phase (green) and spent in the passive phase (red). Each cycle begins when the proper starting conditions (circled in blue) are satisfied. In this simulation the effects of turbulence are neglected.

Trajectories of a kitegen in the "Stem" configuration. From M. Canale, L. Fagiano and M. Milanese, "Power Kites for Energy Generation" IEEE control systems Magazine, Dec. 2007, p. 25

As you can see in this simulation, in the simplest configuration a single kite is attached to a power generator on the ground, where also the control system (KSU) is located. During the "traction phase" the kite moves sweeping the wind (green lines) as it pulls on the generator. When it has reached a maximum distance from the generator, the kite is placed in a "stall" position and pulled back (red line). In this phase, very little energy is expended. In the paper by Fagiano et al. you can see also the results of practical tests that confirm the results of the simulation. This system is at present being built in Italy in a version which is expected to produce a maximum power of 3MW.

Now, let's go to the questions and the comments to my previous post. These can be divided in 4 groups (I apologize if I forgot someone's comments - there are just too many of them).

1. Does it work? ("It won't work because the lines will snap off, kites will get entangled with each other, etc..")
2. Is it safe? ("Kites will fall on people's heads, will destroy planes, etc.")
3. How efficient is it? ("Wont you affect atmospheric wind circulation?, etc..")
4. What is it for? ("Do we really need all that energy? What problems will it solve?")

1. **Does it work?** Here, commenters correctly identified some critical points of the kitegen system. In particular, the strain on the cables is an important issue and so is the control of the kites. These problems have been studied in detail and - in my opinion - solved. The kites are continuously controlled by a sophisticated positioning system that avoids collisions and entanglement of the cables. About the cables ability to withstand the strain, there have been both theoretical studies and experimental tests. As a consequence, the winch control system has been designed in such a way to maintain a nearly constant load; which will reduce the fatigue problem. It is estimated that cables will need to be replaced every six months of operation but will actually be replaced more often for safety. That is not a problem for the efficiency of the system and, on this point, Ippolito wrote in the "comments" section that:

Let me say, a coal power plant burn 300 tons of coal to produce 1 GWhe. A KiteGen to produce the same amount of energy will wear about 100kg of tether. Then the rope will be recycled and only the 20% of the ply will be discarded because too short.

One point that was raised is that, if it was so easy, it would have been done already. I think the answer is that it is not easy, and so it took some time to produce a working concept. AWE is not something that came out of the blue (although, in a literal sense, it does). It is the evolution of a technological line that started with the sailboats of Sumerian times and that has arrived today to giant wind towers, a hundred meters tall. Technology goes step by step and we shouldn't be surprised if, to have high altitude wind power, we had to wait the maturing of the conventional wind tower technology.

2. **Is it safe?** It was somewhat surprising to see so much importance given to the concern that kites could fall onto something or on someone. Certainly, this is an important point, but also one that shouldn't be overstated. So, first of all, in normal conditions, a loss of lift won't bring a kite to the ground because it can be retracted faster than it can fall.

Then, of course, we can think of a series of failures that might bring the kites down. In case of total failure of the mechanical system on the ground, the kites will lose lift and fall. Other possible causes of kites reaching the ground will be cable failure. That could occur as the result of fatigue or of a sudden gust of wind. The problem of fatigue has been extensively studied and modeled, and the cables have been designed in such a way to minimize the problem. In any case, they will be replaced at regular intervals - as I said in the previous section. About sudden gusts of wind, in case of bad weather, the system can be quickly shut down by retracting the kites. At 25 m/sec retraction speed, it takes always less than one minute to completely retract a kite operated by a stem system. There would be plenty of time to avoid the occasional twister passing by, although one might try (perhaps) to fly the kites into it to slow it down.

I think we may consider kites falling as very infrequent events if the system is carefully designed, as it should be. Take into account, also, that the kites won't be flown over densely populated areas. Even so, there would always be a small chance of falling kites hitting people or something valuable. In such case, the damage is expected to be small. The cables will fall at a speed of 4 m/sec, being slowed down by aerodynamic drag. A stalled kite should fall at an even lower speed. One meter of cable of a 1MW stem weighs less than half a kg while a kite weighs something like 10 kg per square meter. The cables are made of soft materials, while the kite is mostly fabric. If a kite or a cable falls on a roof, the most we can expect are a few shingles broken or displaced. Of course, hitting a person would surely hurt, but it wouldn't necessarily kill.

Here commenters have correctly raised the problem of the "snapping" of a suddenly broken cable. That could considerably increase the speed of the cable and do much more damage. However, snapping is a typical feature of a sudden fracture, as it happens - for instance - for steel cables under stress. But the kitegen cables are made out of multi-strand dyneema fiber. Experimental tests have shown that these cables don't break all of a sudden but tend to "unravel" first and so they dissipate a lot of energy in that process. No snapping worth noticing was observed in these laboratory tests. The cables, therefore, should normally fall "flat" on the ground.

In the end, there exists a worst case hypothesis that someone may get badly hurt or even killed by kites or cables crashing down in an extensive failure of the kitegen system. The data we have show that this possibility is very unlikely and so it can be controlled by known risk management techniques, as it is done practically in all fields of technology. In ordinary commercial aviation, for instance, we don't require zero risk of planes falling from the sky, but we strive to reduce this risk to a minimum. The same approach would work for the kitegen or for any AWE system.

Other safety issues were raised in the discussion, such as the kites interfering with plane traffic and the possibility of damage from lightning. The first problem does not seem to be difficult to solve. The atmosphere is crowded with all sorts of flying objects and we seem to be very good in managing air traffic: collisions are very rare. Kites will have their reserved flying area and active avoidance can be practiced by the control system on the ground, which is equipped with a radar. Kites can be rapidly retracted or moved out of the way if an aircraft is detected moving too close to the reserved area. This kind of control could also be used to avoid damage to birds, a point that was not raised in the comments. About lightning, the issue has been studied and it seems to be a modest risk since the cables are not conductive. Of course, in addition, the kites won't be flown into thunderstorms.

3. **How efficient is it?** I have cited Archer and Caldeira's paper estimates the total energy we can extract from the atmosphere without causing a serious environmental damage. It turns out to be at least 10 times (or perhaps even 100 times) the currently produced primary energy in the world. But can we really reach these limits? According to Archer and Caldeira, in order to generate as much energy as we produce today we would need approximately one kite (or other device) per cubic km of atmosphere. This doesn't seem to be a lot: one cubic km is a very large space for a kite to fly. But we can't reserve the whole atmosphere for kites or rotors. So, we would need more detailed studies to understand exactly how much of the atmosphere we can use for generating energy. We can say that the total amount is probably large, but it will be surely limited.

The main point at present, anyway, is not so much what is the ultimate total energy that AWE can provide. It is how fast we can build up renewable power in the face of dwindling supplies of fossil fuels. That is the critical point, and the one which I emphasized in my previous post. With the kind of energy yield (EROEI) that AWE promises, (over 100 according to estimates) we can have the technology grow quickly and replace fossil fuels before we run out of them. That is by no means demonstrated, so far, but it is at least a reasonable possibility.

4. **What do we need it for?** Good question and it is one of the points that I was making in my previous post. In the past few years, we have understood that we have an energy problem and we have placed a lot of resources in developing new gadgets that are meant to solve it. But often we seem to have misplaced our aim. One example may be the emphasis we are giving today to biofuels. We may end up with just a meager source of fuel for our cars in exchange for a serious misuse of agricultural resources which we badly need for producing food.

Airborne wind energy should be a good solution for at least one problem: replacing fossil fuels for the production of electric power. But how is it going to impact on everything else? Perhaps the most worrying observation here is that there has been at least one case, that of France, where the availability of cheap electricity from nuclear plants has *not* caused a reduction of the use of fossil fuels (as described in a post by Eugenio Saraceno). Electricity "too cheap to meter" may free financial resources that people could use to drive their cars more or to buy SUVs. So, it is not completely obvious that AWE would really cut on the use of fossil fuels and, therefore, mitigate the climate problem. With a bit of luck, however, it would make coal plants obsolete and eliminate at least one of the biggest sources of pollution and greenhouse gases we have.

Nevertheless, it is perfectly clear to me that our problem is *not* in the availability of energy or resources; it is in the way we use energy and resources. This problem has a name "overshoot" and, in turn, it is related to our tendency of favoring short term returns over long term ones . Over and over in history, we have destroyed the resources that sustained us because of this tendency. Humans are very good at solving one problem at a time; much less at understanding and caring for whole systems. We are excellent gadget builders but terrible planet managers.

AWE can't do much to change the way we think. Nevertheless AWE on a reasonable scale is one of the most benign form of renewable energy I can think of: it is cheap and relatively simple, so that anyone can use it, anywhere in the world. It generates electric power, which is very efficient and non polluting. It has a very small environmental impact; it uses mostly abundant resources (steel and fabric, the latter could be obtained by natural sources). So, it gives us a chance of a smooth transition from fossil fuels to renewables. Whether we'll be able to do that, is all to be seen, but at least it is a chance - better than no chance at all.

In the end, it is obvious that we still need practical tests, but this discussion didn't evidence fatal flaws in the kitegen concept. This conclusion can be probably extrapolated to all AWE systems using kites, although those which use rotors or balloons will need a different analysis. Hence, AWE emerges out as a very promising technology based on sound physical and engineering concepts. Its development could be stopped only by strangling it with red tape; something that, unfortunately, governments are very good at doing. But renewable energy is already changing the world and it is probably impossible to stop it, by now. AWE would be a further step in the right direction.

(*) Thanks to Joe Faust (kitesystems.net) for pointing out to me the "AWE" acronym for Airborne Wind Power.

references

M. Canale, L. Fagiano and M. Milanese, "Power Kites for Energy Generation" IEEE control systems Magazine, Dec. 2007, p. 25
The kitegen site
kitesystems.net
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