Draft: An Alternative Vision for Wind Power

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Abstract

Wind has been used to generate mechanical power for centuries, but the design of these wind turbines has changed very little over thousands of years. Widespread use of wind power is hindered by a number of problems. By using a bio-inspired approach we have developed a vision for wind power that may address these problems and makes use of the substantial wind power in deep oceans. In Europe there are already wind turbines in shallow water and deeper water designs have been investigated. Our potential design uses a different approach; a flat inter-lockable and moveable platform, so our turbine, doesn't get effected by the waves, batteries to store the energy, oil tankers to transfer them to users where they need them. The batteries could be used directly by electric cars. The design is very flexible and allows us to incorporate this design with other renewable approaches including hydrogen production, desalination . In this paper we set out our vision and consider at a high level the economics of such a potential scheme. However it is clear to us that current designs currently do not have the propensity to reduce costs enough to make it competitive with incumbent technologies. More radical or highly innovative approaches will therefore be required.

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1. Introduction

Many new technologies will be needed to solve the problem of reducing dependency on fossil fuels and reducing CO_2 emissions. One of the key technologies especially in the medium to longer term in meeting these goals is wind power. Wind has been used to generate mechanical power for centuries. The first windmills were used to smelt metal from rocks in Sri Lanka` around 700 BCE. Interestingly the design of these wind turbines or windmills has changed very little over thousands of years. Unfortunately current technology to generate wind power is uneconomic with other sources of energy. Additionally there are many other problems and issues associated with using wind power including but not limited to noise, bird strikes, land use, “flicker”, Intermittency of electrical supply to the grid, and reliability especially offshore where the greatest wind is and connection to the existing grid problems.

If wind power is to be an important source of renewable energy over the long term it needs to evolve into something different than an incrementally developed windmill. This paper presents an outline of our vision of what wind power could look like in 2030.

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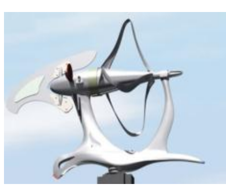
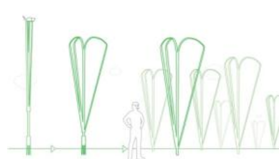
2. Present technology and near term research

Industrial wind turbines are much larger than one you would see in a school yard or behind someone's house. The GE model typically used today is a 1.5 megawatt turbine, with 116 ft, blades a top a 212 ft tower for a total height of 328 feet. The blades sweep a vertical airspace of just under an acre. Instead of having a large wind turbine you can use a smaller wind turbine. Small turbines or micro-turbines have a lower energy output, but can be used on boats or to power homes without connection to the grid, which can be expensive. To be competitive with large coal fired power generation plants (100's of MW) , many of these 2-5 MW turbines are placed together in a wind farm. They are usually spaced out in a rectangular pattern, but recent research has shown that this may not be the most optimal way of doing this. Although wind turbines are usually placed on land, Europe has already installed turbines in offshore waters. They are venturing into deeper waters installing a 2.3 MW turbine in 328 ft of water (tower 213 ft above the surface).

2.1 Novel wind turbine designs

When people think of wind turbines, they think of a long thin rod, with three blades. Some of the near term designs currently being thought about include, airships over New York to pick on higher wind current, kite based designs, helical shaped designs, blades based on a whale fin, to name a few. Turbine designs include the Honeywell wind turbine, Quiet Revolution, Selsam Super Turbine, Salsam Sky Serpant, The LoopWing, The Egg Beater, Kite Turbine, the Laddermill and stealth blades to reduce air radar interference.

Future Designs – Helical, Bird Like and Membranes



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In a major departure from the blade concept Shawne Frayne has used a membrane concept (his so called "Windbelt" http://www.popularmechanics.com/science/energy/solar-wind/4224763) to generate electricity from mechanical resonance. i.e. no blades. In a similar idea a bridge is being used to generate power for its lighting with a membrane embedded in the structure of the bridge (Cross –Wind Bridge Lisbon Portugal). In another solution, scientists are also looking into robot ranchers to maintain wind farms. The robots, would inspect and make sure the rotor blades, are working properly to improve uptime and efficiencies.

2.2. The physics of wind power

Wind turbines require locations with constantly high wind speeds. An average wind speed of 14m/s is needed to convert wind energy into electricity economically without subsidies. The average wind speed in the US is only 7.4 m/s. Some of the windiest spots in the US are off the coasts, in the mountains and right down thorough the Great Plains. Coastal areas produce about 50% more wind than some areas in land, but the nature of wind climate offshore is very different from on land, with seasonal variations in the sea temperature affecting the wind profile. In addition the average wind speed is greater the higher you go. The wind is not slowed by the drag of the land surface and secondly at higher altitudes jet streams are present that produce continuous high speed air flow. Wind in these jet streams can be as high as 200 mph or 88 m/s. Wind speeds offshore in deeper water are also higher and less variable due to the absence of obstacles. At water depths of 100m wind speed can be 15 m/s ie twice as high as the US onshore average. As the wind power from a conventional blade turbine is related to the cube of the wind velocity (V3) and the swept area it drives, designers naturally look for larger blades and higher wind speeds. Higher altitudes or the location of wind turbines offshore seems the obvious way to improve power output. We will return to this later.

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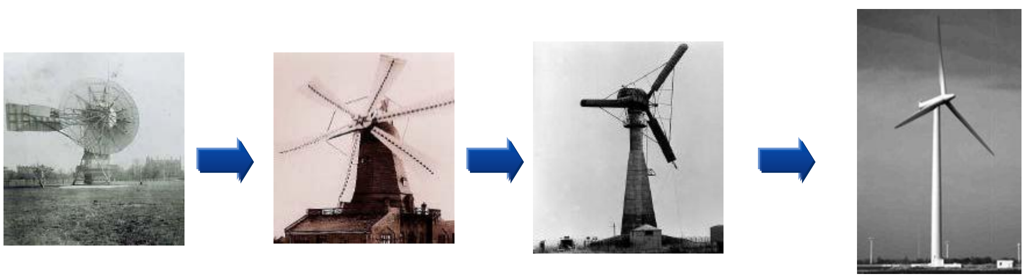
3. History of wind turbines

During the winter of 1887-88 Charles F. Brush (Brush Electric, Ohio) built what is today believed to be the first automatically operating wind turbine for electricity generation in the US. It had a rotor diameter of 50 ft and 144 rotor blades made of cedar wood. The turbine ran for 20 years and charged the batteries in the cellar of his mansion. Despite the size of the turbine, the generator was only a 12 kW model, but the weight of the tower was 36 Tons. The 55 kW versions of wind turbines which were developed in 1980 - 1981 became the industrial and technological breakthrough for modern wind turbines.

Evolution of Wind Turbine Last 130 years



The cost per kilowatt hour (kWh) of electricity dropped by about 50 per cent with the appearance of this generation of wind turbines. Over the period of 130 years (reference Nicolas, Iñigo Martija de. Wind Energy Evolution And Expectations provides an excellent detailed description of these developments) the designs evolved from a complicated wooden flat panel design to a quais-3d aerodynamic design with three blades producing 9 times the energy for the same weight.

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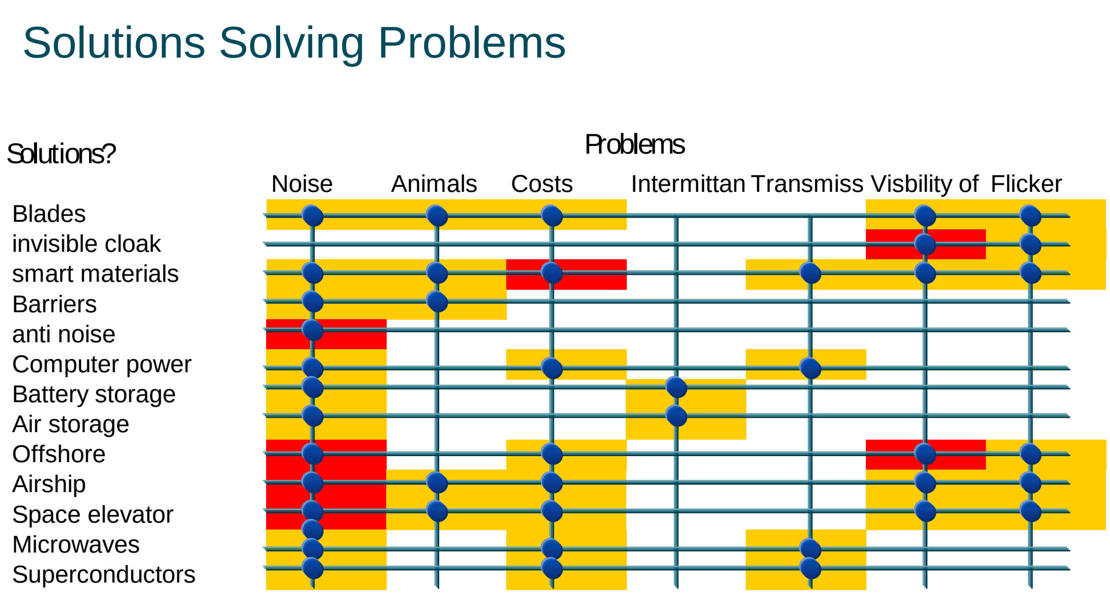
4. Design Process

We've taken a three sided approach to our potential radical design. Looked at solving the many current problems of wind power using a brainstorming approach, looked at how nature has solved similar problems (bio-mimicry) and finally used a evolutionary approach based on genetics/chromosomes to help us generate some radical ideas.

4.1 Problem Orientated solution

Using a brainstorming approach we considered how we might solve the current problems associated with wind power. These solutions ranged from using noise cancelling headphone technology to reduce noise, transparent paints to hide the wind turbines from view to using novel offshore floating platforms to gain from the increase in deeper oceans. We summarize our results in the diagram below. We considered solutions onshore, offshore and in the air.



Analysis of this diagram indicates that there are potentially a lot of solutions for reducing noise. That blade design and the use of an offshore or an air located solution might solve the most problems associated with wind

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turbines. This seems like a good place to start as higher winds usually equate to higher energy output. So we considered many different designs, but essentially ranked them. See below

4.2 Bio-mimicry and Bio-inspired solutions

Bio-mimicry is the science of emulating nature's biological solutions to solve engineering problems. Adhesives motivated by geckos, and resistance-free antibiotics inspired by red seaweed are examples of bio-mimicry.

Shapes from Nature

Nature over millions of years has evolved some incredible shapes – Helical and spirals are very common but why

Part of the current research effort involves the creation of a database with examples, so that we can learn from nature's own made solutions. We have searched for some solutions to the problems we have identified as problems (see introduction) and have come up with the following ideas that might hold some interesting avenues for future wind energy solutions.

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Example	Description	Application to wind energy
Termites	Resonant wind patterns. Termites redirect wind to cool heat their homes using the concept of resonance	Increase and direct energy into turbines for increased efficiency, by wind tunnels – possibly underground
Bees /Ants	Foraging and networked approach	Nature based optimization in the operation of the system. The use of a network of ships or unmanned drones or tankers to ship energy – provides great flexibility
Beak	Wind resistance design – Designs of certain beaks reduces wind drag	Potential to increase wind efficiency
V birds	Wind resistance reduced by certain type of Alaskan migrating birds. Birds fly in a unusual V formation to reduce drag	Increase in efficiency reduction of costs. Wind turbine location pattern
Spiral Patterns	Common in nature – interesting shapes from nature that could be used as alternative blade designs	Better blade design or no blade at all

4.3 Genetic simulation of the potential

Technologies evolve like nature. It is sometimes incremental and at other times or radical. The radical explosions provide the most interesting new species. Unfortunately business designs are not usually that radical and nature takes a long time to evolve. We have borrowed from genetics and have built a chromosome based model of the various options/designs to help us think about these radical combinations.

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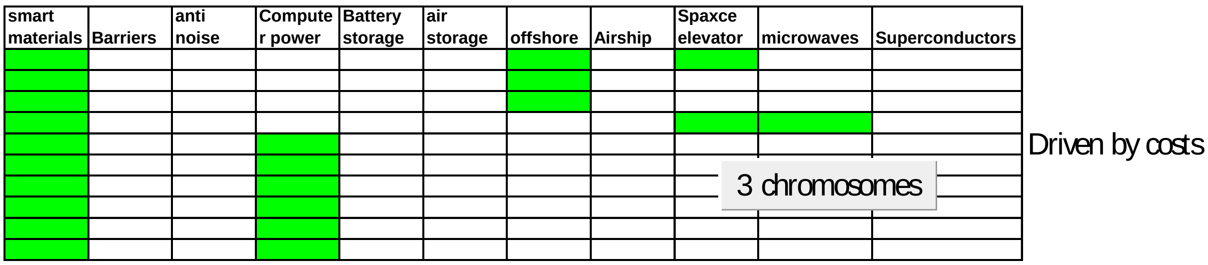
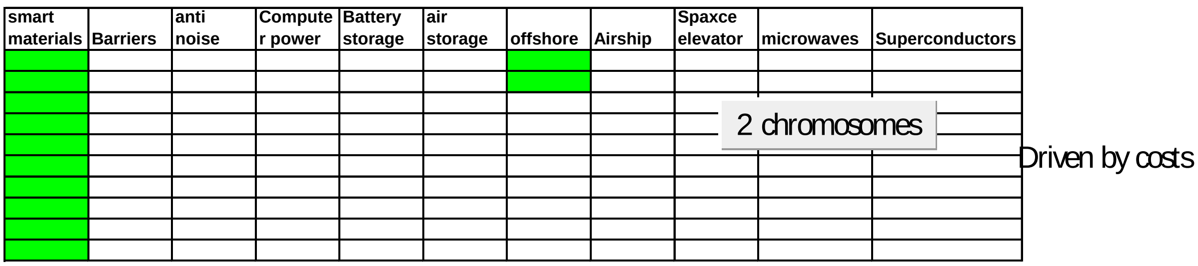
Simplified Chromosome Model





By simulating genetic mutations, we have simulated different possibilities of designs. We then ranked the potential “mutated” solutions against our problems.

The results of our simulation depends on the number of “chromosomes” that we allow to vary and the “weights” we give to the problems. We ranked indicative overall costs and location highly in our final design. Using this approach what have we come up with design that tends to cluster around an offshore or an air based design with smart materials and a novel blade design. Not unsurprisingly. Although we like the idea of an air based solution, we are going to concentrate our efforts on the deep offshore solution as a technology that could probably be developed in the next 20 years. It seems to be more “doable”, although a recent design by a MIT spin off shows promise albeit at a small scale (http://www.wired.co.uk/news/archive/2012-03/29/altaeros-airborne-wind-turbine).

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5. Our Future Vision

Of course- wind turbines will progress incrementally with new blade designs, and lighter materials to reduce costs. But what we wanted to do in this project was to explore more radical designs. This does not mean that there will not be wind turbines of conventional design that live side by side with our design.

5.1 Our vision – An Offshore Turbine with a difference

So what might our vision look like? We show this in the diagram below. Essentially our exploration of some more radical designs yields the following thoughts/ideas. A deep ocean design to make use of the greater wind speed, but one that tries to make use of lessons from nature. That of:

- Flexibility
- Complex and elegant designs
- Positive and negative feedback systems – where required – we have a relatively simple control system in this design
- Robustness (to account for uncertainty and incorrect forecasting/measurement – related to the point above)

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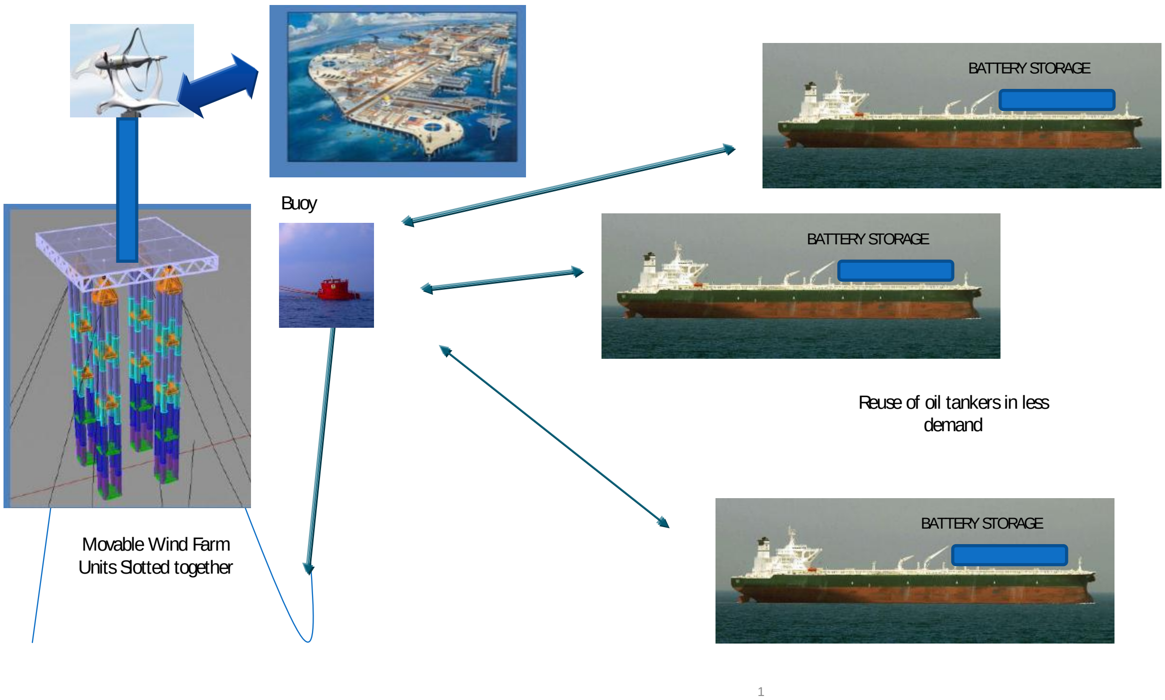
Network of Re-used Oil Tankers to Transfer Power from an Offshore Wind- Turbine Farm



A design that tries to the overcome the current issues with the idea of a cable back to shore. A new floating island concept that we came across that is half the cost of an offshore platform. That can be moved if necessary, for environmental or other economic reasons. A no blade or some unusual nature shape based turbine to reduce weight and improve power output (this may be a membrane concept as discussed above). A V shape wind turbine layout to improve efficiency (based on an Alaskan birds migration concept) – not rectangular that presents less drag. Extensive use of smart and or nano-based materials to reduce costs/weight and potentially be used to generate electricity. Multiple connections from our "wind farm" to multiple shore bases; like a brain – or bees searching and delivering pollen. We will be using redesigned oil tankers (hopefully there will be less of a need for these tankers), that can moved from place to place where needed. The tankers would transport batteries charged from the wind turbines. We thought about connecting the battery power to the electrical grid, but realized that in 2030 – with increased use of electrical cars that these batteries could be used directly in cars or trucks. The use of batteries will also overcome the intermittency issue (wind doesn't blow all the time). Our offshore solution also lends itself to being a hybrid solution. The island could be used to generate solar energy as well as absorbing energy from the waves. In one research paper we reviewed, an experimental

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desalination unit using electrolysis for water production was combined with wind power. Being offshore with lots of water is there potential to generate hydrogen which then can be transported back to land? Or even to produce water as the research paper suggested. In current drought conditions our tankers might be able to deliver water to areas that would need them. This design is radical in the sense that we have changed many component parts of the current wind turbine design. E.g. why blades, why a cable connecting to the grid, why not in a v formation on a floating island.

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6. Breakthroughs

To make our vision a reality, there are number of obstacles and design issues that need to be solved. These include an appropriate offshore platform to stabilize the wind turbine and operate in heavy seas and wind conditions, a new helical nature based wind turbine design, battery technology, ships redesigned to carry the batteries, smart and light materials to save energy and reduce costs and a powerhouse for the batteries or a system for transferring to cars. Many of these technologies exist conceptually today and researchers are working on them. Some like nano and smart material are in their infancy. Others like the floating island have scaled (small test models) prototypes built.

6.1 Why does it not exist?

Current turbine evolution is preceding using standard designs. e.g. a wind turbine located on the seabed, with deeper towers, heavier components that make it expensive and uneconomic. It is easier and less risky to do this than to try and combine lots of new ideas and technologies together. Combining technologies from outside of the normal design is a process that takes time and requires either commitment from a visionary company or the coordination and cooperation of many individuals (see comment above on half the cost but what about the risk). In addition some of these concepts are still in the research phase. The biggest breakthrough we will require will come from the development and combination of these individual technologies and their use together in this new design.

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7. Scoping Economics

We have found some technology that could reduce the wind-power mounting costs by 50%, maybe reducing overall costs by 25%. Deeper waters can take advantage of higher wind speeds potentially in theory obtaining a higher output for the same costs. A quick estimate indicates that this might reduce unit costs ($/Kwh) by up to 50%.

A "Tanker/Battery fleet" would involve a substantial costs potentially more than cabling, offsetting some of these savings – but refits/reuse could be a lot cheaper. Multiple market access though would provide additional value, in the form of optionality. Power can be sold to markets with a greater need and higher prices. The issue is whether the benefits from multiple outlet access exceeds the costs.

At certain times prior analysis by Energy Redefined has shown that this value can be worth as much as 2-3 times the intrinsic value for just selling the power to one market.

So what does this mean?

In the figure below we show the results from a high level economic analysis using some of our proprietary models. We have estimated the carbon price that would be required in $/te CO2e to make an investment in our type of scheme. As we do not currently have a good grasp on the cost ,we have shown the results for different costs – that is as a reduction on the current offshore wind-power costs. As we intimated above this might be of the order of 50%. We show this for 3 cases:

- Against a standard coal plant already operating with an average cost of 4 cents per Kwh
- Against as coal plant with CCS costing 8 cents per Kwh. This of course could be substantially higher if a new build plant is considered
- And a gas turbine power unit with a cost of 6 cents per Kwh

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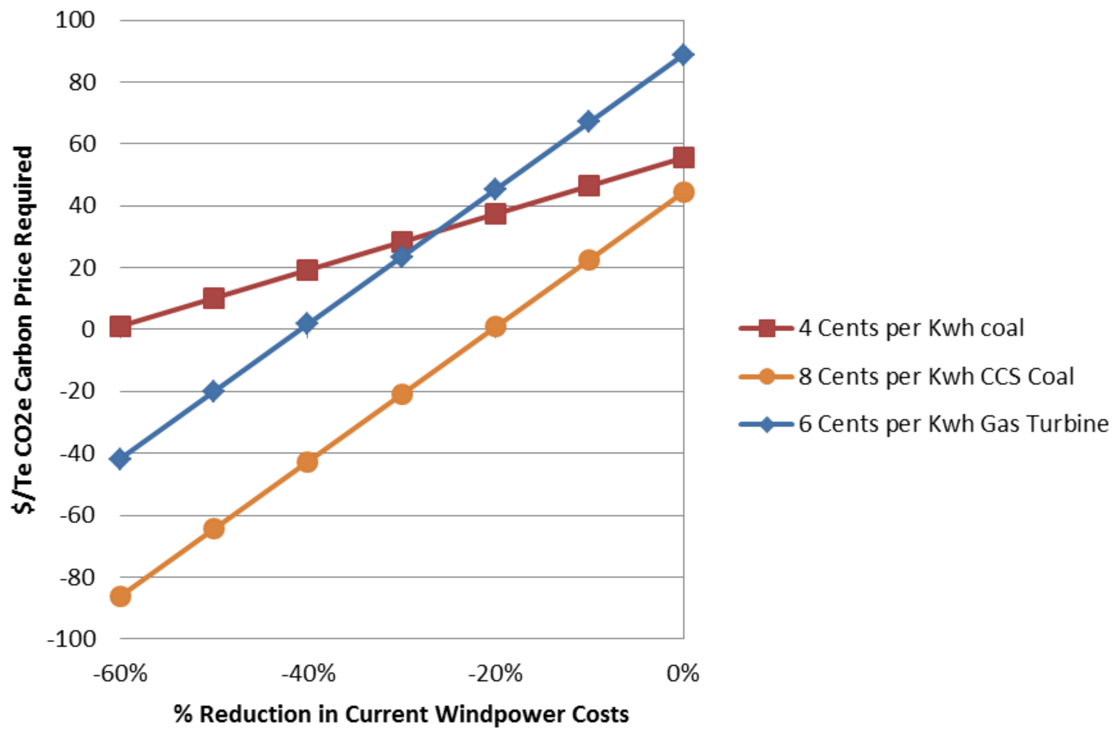

Note this graph takes no account of optionality and there are no subsidies included in the economics. At the current costs wind-power offshore cannot compete with any of the alternatives unless carbon prices are above $40/te. At a 50% cost, the potential scheme could be economically viable with all the schemes, without a carbon price or at best a very low one. Of course what this graph is really saying is that we need costs or the equivalents costs to reduce by at least 30%. This will be tough to achieve with current designs.

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8. Conclusions/Thoughts

By learning from nature and using a chromosome based simulation model we have developed an alternative vision for wind power in twenty or thirty years' time. Such an idea might have the potential to reduce costs by up to 50%. It is not meant to be a definitive view but shows what might be achieved if one takes a slightly different view. It is clear that unit costs need to be reduced by at least 30%, to be competitive with natural gas. This is no mean feat.

The search for new energy solutions and technologies therefore requires cutting-edge innovation, not just engineering brute force. The danger is that incumbent developers continue to invest in the similar solutions, attempting to reduce weights, but not focusing on more innovative ideas. We hope that this is not the case.

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