



KiteGen® Research

Altitude Wind Energy Generation

Information Dossier (EN)

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1. Foreword

The principles of clean energy with KiteGen® and other renewable sources

by Massimo Ippolito

A ring of 20 km diameter, very similar to a railway bridge, as long as Rome's tangential highway, but built at sea. An ideal spot would be the Banco Avventura in the waters near Trapani, in the Sicily channel.

This ring is the base, or technically the stator, on which rotates the KiteGen® : high altitude or tropospheric wind power generation technology.

Several light power kites fly automatically at up to 10 km height in a controlled formation and, tethered through high resistance lines to the rotor, they provide the traction to rotate the large-scale machinery that converts wind energy into electricity.

The power it would produce is sufficient to feed the whole of Italy's electrical grid, more than 60 GWe, even on less windy days.

It might appear to be an unwise start, but I do remember that at a seminary for entrepreneurs we all were advised that it is necessary to venture beyond our standard vision at least with imagination. Otherwise no real innovation can happen.

What does the non-standard vision say? It is a vision that has been underway for more than 8 years, with a certain degree of understandable confidentiality, led by the minds of public and private organizations, Italian and European universities with dozens of master theses and departments at work to validate its base assumptions?

1. *The energy field contained in high altitude wind, that can be intercepted by a similar machine, exists, and its potential is astonishing.*

Earth's atmosphere acts as a giant solar collector: it's available, doesn't need any maintenance, it's already freely installed all over the world and provides us with a noble type of energy, mechanical energy, that easily and without significant losses can be converted into electricity. Unlike current wind turbines, that succeed just in scraping the surface of this energy field, KiteGen® fully exploits the energy that abundantly flows in the upper layers of the troposphere.

2. *To reach and exploit this energy field, intelligent, cheap and most of all scalable machines, can be envisioned, based on a modular design.*

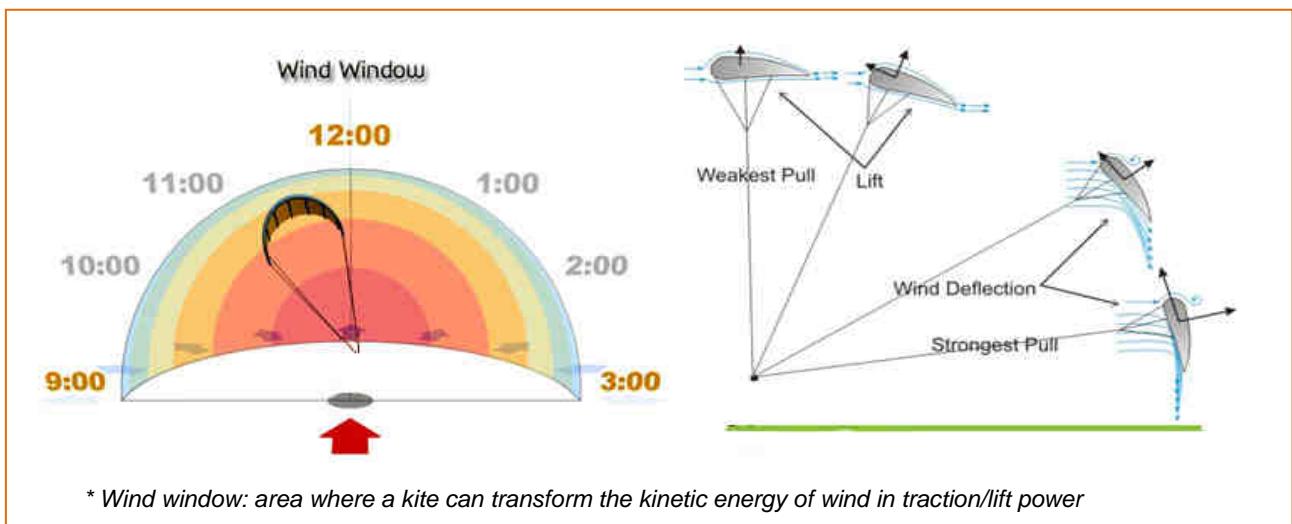
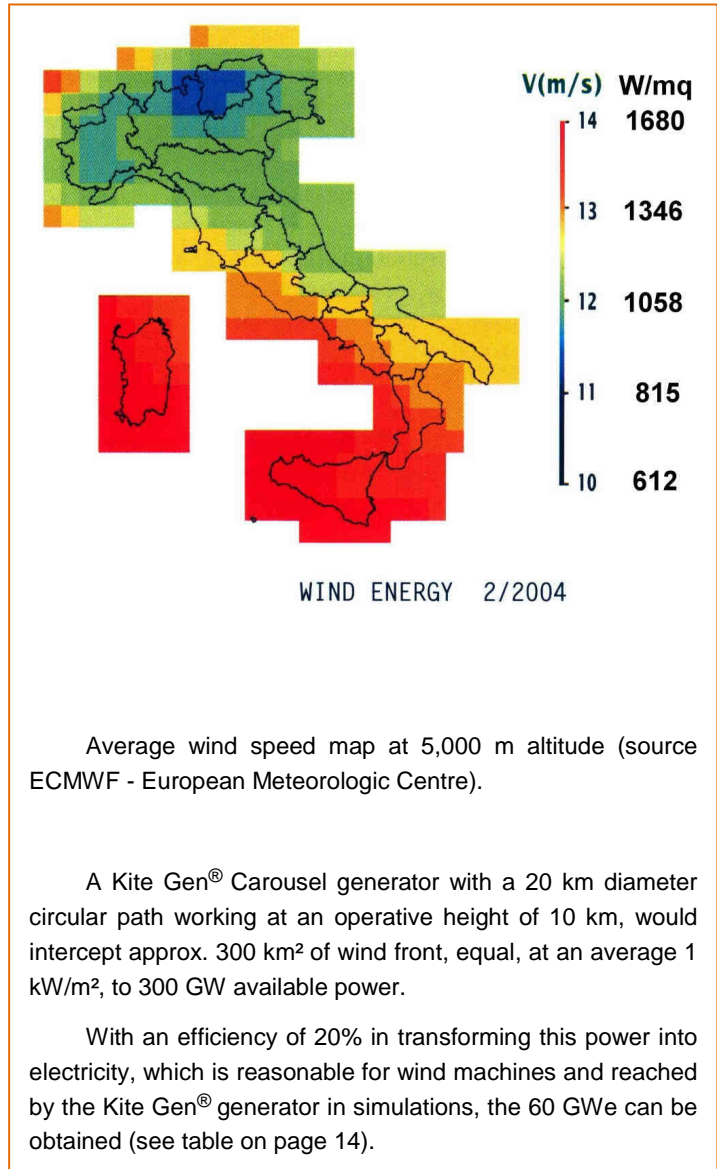
The scalability of KiteGen® is not a structural one, but is instead its very concept that foresees the multiplication of single modules producing energy on the same circular path. The level of the required technology difficulty can be compared to that taken to build a car or a long line of cars. It would be like installing thousands of wind turbines at the same site, something impossible because of the surface spacing needed to maintain a given efficiency. KiteGen® overcomes this limit, as each module exploits different regions of the huge volume of wind window* swept by the machine.

To operate such a power plant is not for the satisfaction of completing a technology challenge entirely within the reach and capabilities of our industrial society, but it is a precise and inescapable need. In 2025 Europe (its 25 states) will have an electricity deficit equal to half of the foreseen needs, and the same amount will be required by the other nations on the Mediterranean basin; an enormous need that only a clean, renewable and high potential source like the tropospheric wind power could fill.

With KiteGen® technology available, it can be estimated, and not only dreamt about, that the energy mix will be made of more than half the base load coming from tropospheric wind power and the remaining, to cover the recurring diurnal peaks, from photovoltaic, hydroelectric and geothermal sources. Therefore, 100% of energy will be sourced from renewable sources, without emitting climate-changing emissions.

Currently, it is not clear whether evaluations will lead to the building of 60GW KiteGen® power plants, of the dimensions described in the opening paragraph, in the future. One thing is certain enough: the cost of energy produced is predicted to be below €0.03 (Euro) per kWh, cheaper than currently obtained from the best combined-cycle turbo-gas power plants, and is reachable already with a 100 MW KiteGen® , needing a circular path of only 1 km diameter.

This dossier continues with a very pragmatic and reachable objective: building KiteGen® power plants as soon as possible of “small size”, even if with a power unheard of from renewable sources.



2. Energy production from renewable sources: a totally different scenario

KiteGen® is the last evolution of wind energy exploitation. It is a radically new and innovative concept that may be the most practical and sound solution, in the market of renewable sources, to the world's energy needs and problems.

The main news is given by the fact that KiteGen® can exploit an unexploited, virtually endless and almost universally available energy power: high altitude wind.

In order to exploit this huge amount of energy a radical change of perspective has been done: no more heavy and static structures but light and dynamic machines...

Large wings, driven by a high-tech control system based on avionic sensors, fly at high altitude, harvesting the energy of powerful winds, much faster and constant than those available to traditional wind mills.

KiteGen's vision is a new type of electric generation plant, based on a renewable source, suitable for any territory, at costs lower than fossil fuel generation plants, in direct competition with today's conventional production (coal, oil or nuclear), in the GigaWatt class.

3. Altitude wind energy: a huge unexploited energy source

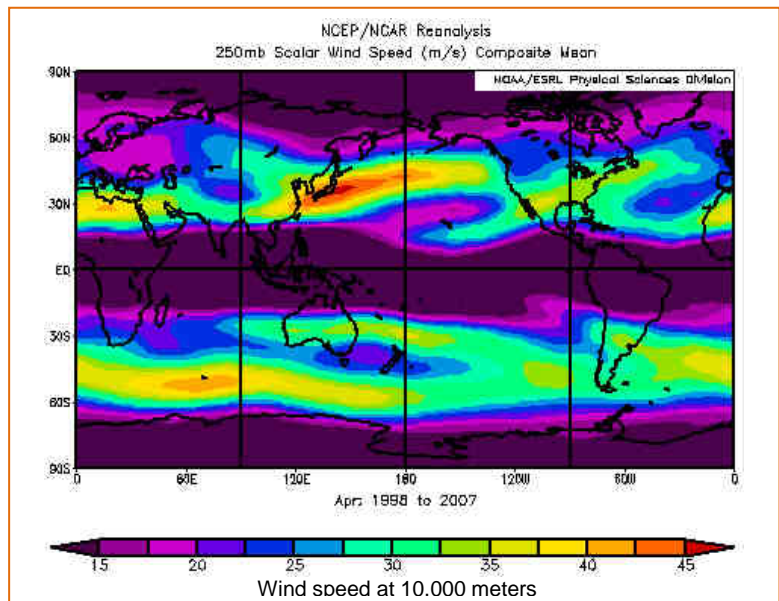
Wind is the Sun's heat transformed into kinetic energy through the greatest solar collector currently available, Earth's atmosphere. Total global wind power is estimated at between 1,700 and 3,500TW, equal to approximately 300 times the primary energy needs of mankind (estimated around 14 TW).

Two ribbons of wind completely encircle the Earth, with the maximum power density available at an altitude of approx. 10,000 m (250 millibar).

Moving towards the ground, wind speed and energy decrease: air masses diffuse heat through friction between themselves and with the surface of the Earth. At 80m, the hub height representative of the latest generation of wind turbines, the average wind speed is estimated at 4.6 m/s, not enough for industrial exploitation; at 10m, it is 3.3 m/s.

Moreover, when harnessing higher-altitude winds, the wind blows for many more hours, more constantly and with only minor changes in direction.

Breaking free from the ground to reach higher-altitude winds is already very beneficial at 800m, where the average wind speed is estimated at 7.2m/s. The resulting power density is almost 4 times the amount available to wind turbines.



Altitude (m)	Wind speed (m/s)	Wind Power Density (W/m ²)
2000	10	600
800	7.2	205
80	4.6	58
10	3.3	22

Doing so would also reduce the problem of locating the power plants. On average, at 800m altitude, each point on the Earth's surface has enough exploitable energy. This is not the case for windmills, whose lower operative height needs a more accurate and severe selection of favourable spots.

But high altitude wind remains out of the reach of today's and the future's aero-generating towers, already more than 100m high. Above a certain height the structure that holds up the rotors becomes exponentially heavier, more unstable, and above all more costly.



The relatively higher wind availability at lower altitudes at open sea still does not make traditional windmills economically feasible. The high thrust and moment generated by the windmill on the platform during operations require heavy, complex (and costly) platform and mooring systems, in deep water.

4. KiteGen®: a radical change of perspective

To reach and exploit high altitude winds, KiteGen® comes with a radical change of perspective: no longer heavy and static machines, but light, dynamic and intelligent ones.

Power kites, giant semi-rigid air foils, with high aerodynamic efficiency, harness energy from the wind, whilst being automatically piloted. All the heavy machinery for power generation stays on the ground. To connect the two systems, high resistance lines transmit the kites' traction and at the same time control their direction and angle to the wind.



This concept is applied in several configurations, according to the adopted technological solution:

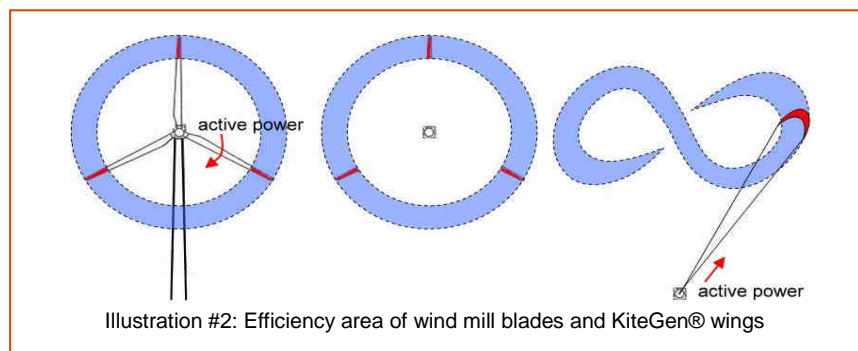
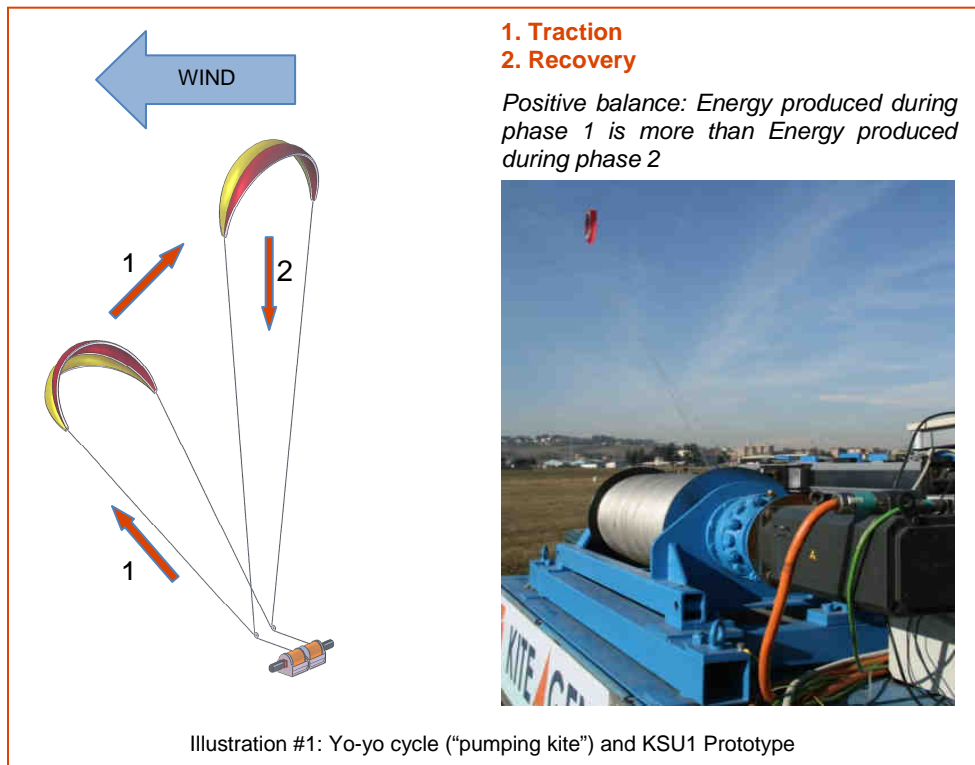
1. Onshore KiteGen® Stem generator
2. Offshore KiteGen® Stem generator
3. Onshore / Offshore KiteGen® Stem generators in “Wind farm”
4. Naval KiteGen® generator
5. Onshore “Carousel” KiteGen® generator
6. Offshore “Carousel” KiteGen® generator

4.1. Onshore KiteGen® Stem generator

KiteGen® has built a first prototype (see Illustration #1), codename KSU1, tested at an altitude of 800m with the authorization of ENAC (Italian Civil Aviation Authority). In this first configuration the electric actuators which hold the lines are fixed with respect to the ground. In addition to confirming the theoretical data, the prototype produced energy thanks to the traction and recovery repeating cycle: 5kW average and 30kW peak power with a ground wind of 4.5m/s.

The wings pull the cables that, through a pulley system, activate the alternators on ground, that produce electricity. When cables are entirely unwound, the wing is guided to a position where it loses its wind resistance and the cables are wound in. Energy consumption of the winding phase is a minor fraction of the energy generated during the unwinding phase. At the very core of the project is the software that autonomously pilots the power kites, so that the flight patterns can be controlled and normally directed to maximise the production of energy

Another relevant feature is the higher efficiency of the wings: the wing is flying at speeds of 70 - 80m/s, while in windmills these speeds are



reached only at the tips of the blades. KiteGen® is basically composed of only wings and a generator, the latter conveniently kept at ground level.

Beyond the verification of the theoretical data, the KSU has produced energy, thanks to the unwind/rewind cycle: 5kW average and 30kW peak, with a ground of 4.5 m/s. The prototype has thus proven the concept and its applicability, transforming wind energy present at a 1000m altitude into electric energy.

With the end of the prototypal phase, the industrial pre-series production phase has begun. Initial KiteGen® Stem 3 MW on shore generators are expected to be working within 2011.



Photo #3: Onshore 3 MW KiteGen® Stem generator in construction by Sommariva Perno (ITA – Dec 2010)

4.2. Offshore KiteGen® Stem generator

At deep sea, wind availability is generally higher, both in terms of speed and hours, in comparison with ground or coastal areas. This notwithstanding, the installation of windmills on board floating platforms for deep offshore energy conversion is a difficult task because of the high thrust and moment generated by the windmill on the platform during operations.

Solutions to exploit deep offshore wind energy have been proposed by several competitors. Nevertheless, because of the enormous technical difficulties, it seems there is only one existing prototype (*Blue H*).

KiteGen® overcomes this inherent problem: the position of the centre of mass of the generator is really close to the platform deck and the direction of the main loads (represented by the mechanical pull acting on the cables), practically passing through the centre of mass of the generator, greatly reduce the infrastructure costs.

The KiteGen® take-off tower can in fact be extremely slender and light and can be oriented and lowered after the rare take-off and landing procedures, limited to the first start-up of the plant, to the periodical maintenance of the system and to extreme weather conditions. Both floating and mooring systems may be many times lighter than in other traditional wind generator: like a Judo wrestler KiteGen® uses the wind's strength for energy production, while traditional windmills only arm wrestle with it.

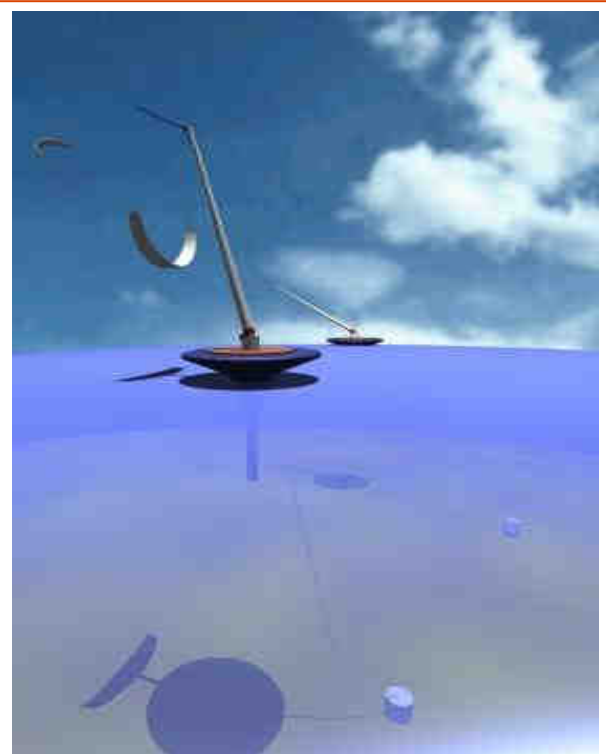


Illustration #4: Offshore Kite Gen® generator

4.3. Onshore / Offshore KiteGen® Stem generator in Wind farm configuration

The KiteGen® generator is a base module, suitable for solutions able to ensure a high scalability of the generation plant. “Wind Farm” configuration consists of a series of generators grouped together on a limited ground/sea space, in order to obtain greater energy production on a single limited site.

This is possible both on sea and on the ground, with significant economies also from an organization and management point of view.

Traditional windmills require spaces between the generators of on average 8-9 times the rotor’s diameter, in order to prevent generated turbulences from reducing efficiencies.

KiteGen® exploits a third dimension (the altitude) and, thanks to the electronic integrated control system, can divide the flying space in order to make the wings fly always on a unbiased front wind in a reduced territorial space.

KiteGen® generators can be placed 100 meters apart, thus enabling, on the same area required by traditional windmills, a nominal power production 4 times greater.

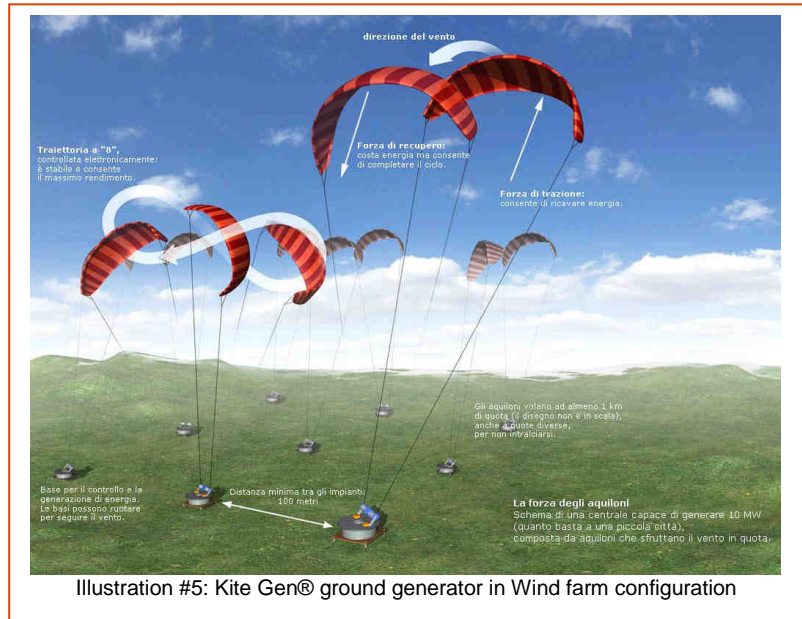


Illustration #5: Kite Gen® ground generator in Wind farm configuration

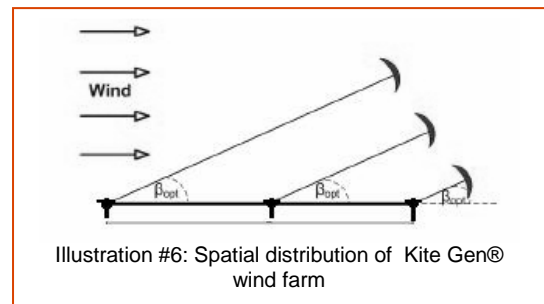
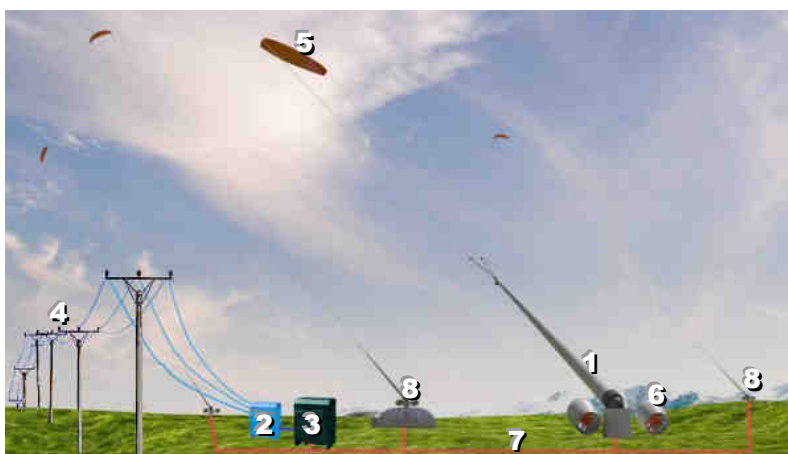


Illustration #6: Spatial distribution of Kite Gen® wind farm

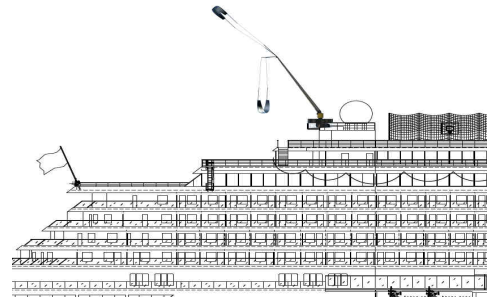


1. Kite Gen® generator 1MW
2. Static converter
3. Short round trip accumulator
4. Electric line VHV
5. Flying Kite with radio datalink.
6. Servo assisted take-off system (Energy needed <2kWh/launch)
7. Bus DC 600V (1600A x Tower)
8. Kite Gen® wind farm

Illustration #7: Wind farm equipped with take off / landing automatic control systems

4.4. Naval KiteGen® generator

Experimental solutions of a KiteGen® generator installed on vessels have been trialed, providing energy to on-board main and auxiliary services and engines (in case of vessels equipped with electric engines), with the potential added function of assisting with maneuvering through the implementation of an especially suited manual control system of KiteGen®. This application is currently being developed within a project (KitVes) financed by the European Union (7th Framework Program).



4.5. KiteGen® “Carousel” onshore generator

The configuration combines a series of KiteGen® generators, considered as a “base” module, where the tension in the cables is maintained constant and their length changes only to grant the wings control, in order to obtain the optimal trajectories for energy generation.

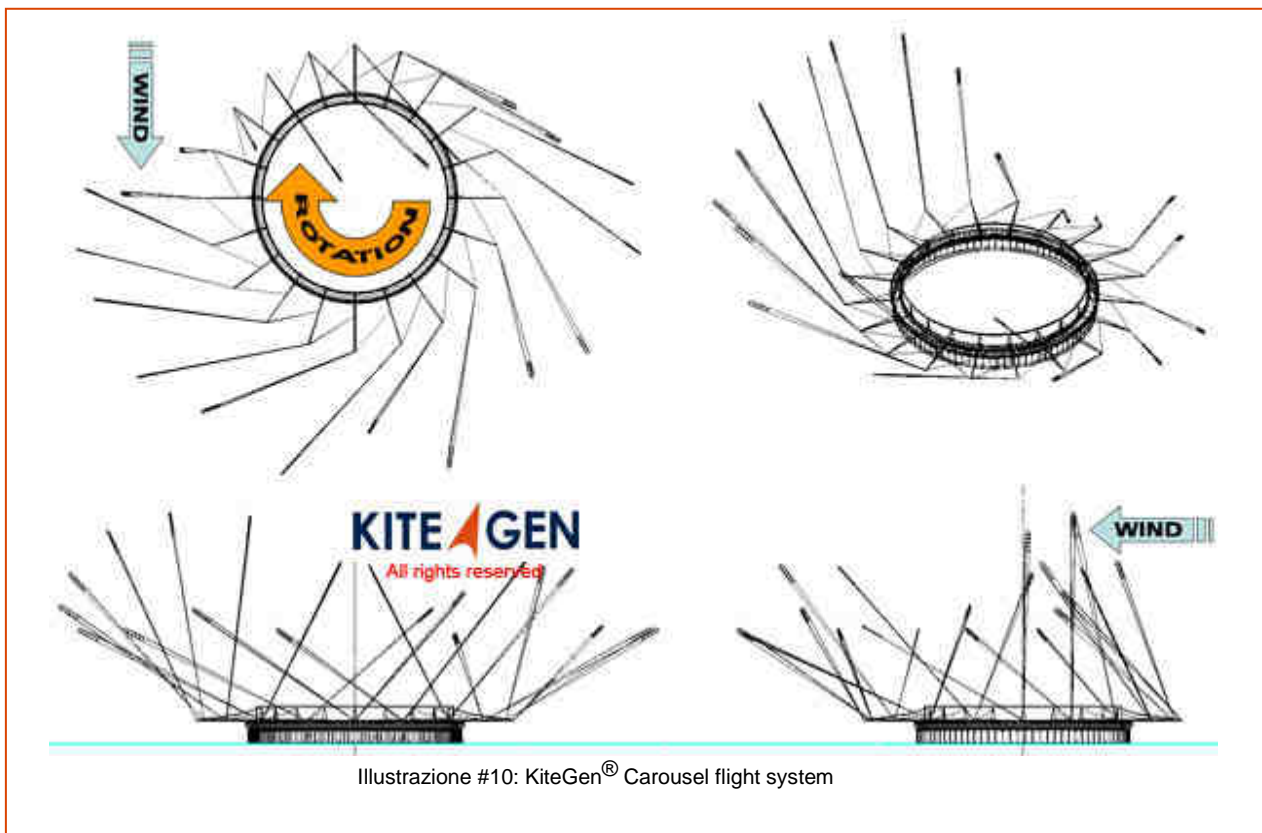
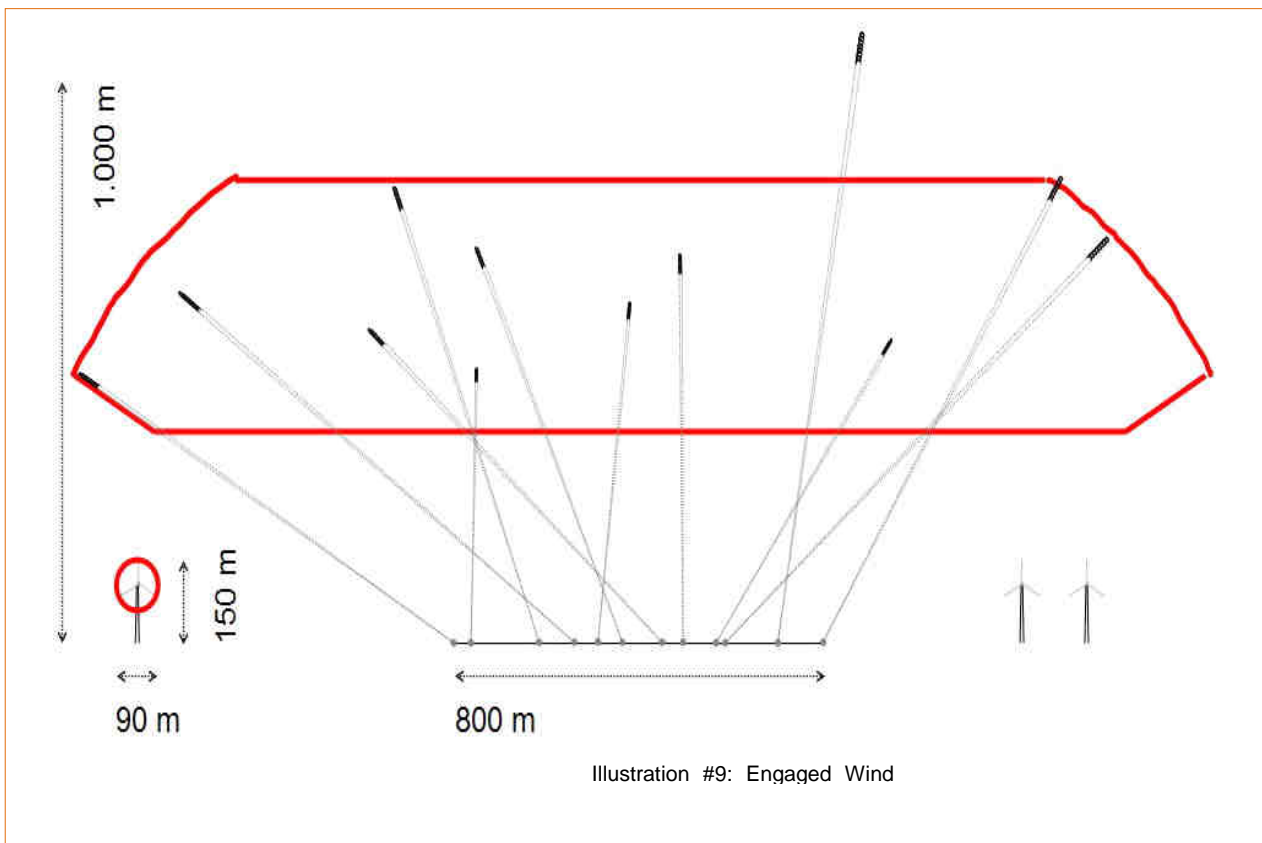
As the power kites circle in the air, at an altitude of 800 – 1000m, the vertical rotating axis of the structure activates large scale alternators, that have been geared down to receive the force exerted on them. At its full capacity the flight of the entire power kites array is guided, so as to turn the carousel at the desired speed, with a capacity factor estimated at 5000 hours per year.



Illustration #8: Art drawing (out of scale: reduced wing's height and augmented cable's diameter)

Maximum reachable size is under study, but first evaluations shows that 1000MW (1GW) can be exceeded, without significant structural risks, with a diameter of approximately 1600m.

This configuration brings the significant additional advantage that the engaged wind front, equivalent to the available energy, is one hundred times larger (approximately 150 times comparing a state-of-the-art wind turbine and a KiteGen® Carousel generator with a diameter of 800m – see Illustration #9).



The capability of the wing to fly upwind is shown by Illustration #11, a picture taken during a flight test session with the KSU1 prototype. The weathercock clearly indicates the wind direction that, with reference to the wing's position, should clarify a flight dynamic of the carousel configuration, dynamic which doesn't appear to be immediate and intuitive.

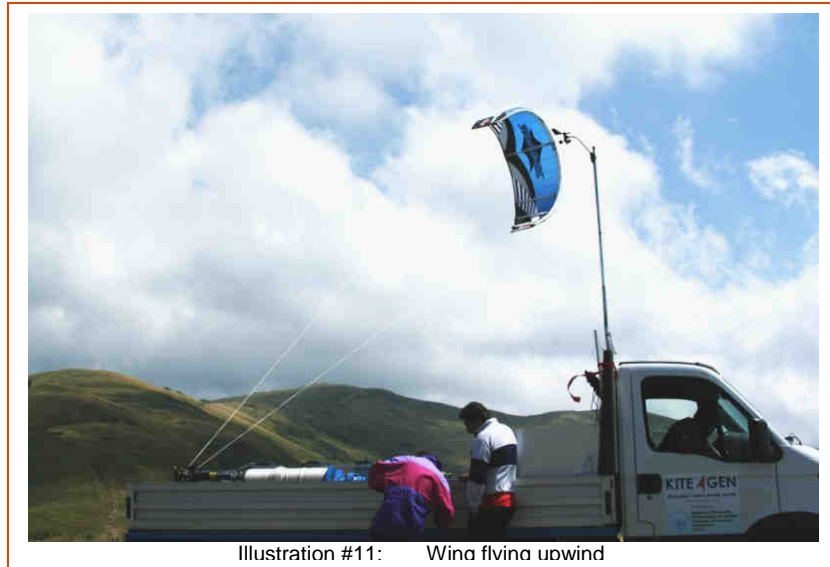


Illustration #11: Wina flvina upwind

4.6. KiteGen® “Carousel” offshore generator

As well as the KiteGen® onshore generator, the Carousel generator finds an ideal application on off-shore platforms. The machine indeed doesn't have thrust moments and requires minor mooring systems, while the huge available sea spaces represent an ideal solution for the generator positioning.

KiteGen® Carousel Off-shore generators represent the last step of the actual KGR work program for the implementation of the KiteGen® project.



Illustration #12: Off-shore Carousel generator

5. KiteGen® Research S.r.l.

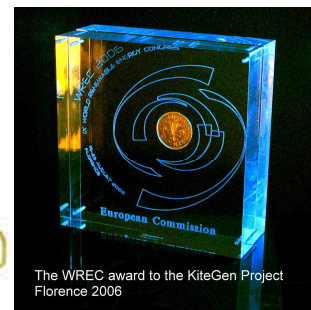
KiteGen® Research S.r.l. (KGR) was created in 2007 mainly to manage the rights of KiteGen® technology. KGR assets are represented substantially by 12 patents, registered around the world, referring to high altitude wind energy generation technology. The founder is Mr. Massimo Ippolito, the original concept creator and expert in mechatronics.

6. Acknowledgements

KiteGen® has been awarded both in terms of academic prizes and grants for the technology development, obtained by public bodies such as Piedmont County, Italian Ministry for the economic development, European Union:

- IMS-SIMON (EP26504)
- HIQU (EP6293)
- REMATOVI (BES2-5513)
- MOSIN
- MEDECOTHER
- ELECTRIC-WASH (Regional POP)
- HYMM (NMP3-CT-2003-505206)
- ECOFIT(NMP2-CT-2005-013989)
- Call Scientific Research Piemonte 2004
- FIT Energy MAP-IT DM16/5/2005
- FIT Digital MAP-IT DM28/7/2005
- EU – FP7-SST-2007-RTD-1

Lastly the President of Italian Republic has awarded Lorenzo Fagiano, of Turin’s Polytechnic, with the **ENI Award 2010** for his PhD on KiteGen project. Furthermore KiteGen has been considered, in the context of the 2010 Copenhagen Summit on climate change, one of the world’s 20 most innovative environmental projects and selected by the Italian Government to represent Italian innovation within the **2010 Shanghai Expo**.



7. Economic analysis

At first impression, the simplicity of the KiteGen® concept is fascinating and even amusing. However, it all becomes tremendously serious when a detailed evaluation of the cost per Watt per hour produced is performed and compared to the other existing power sources.

7.1. Cost comparison

The financial analysis for a 100MW KiteGen® plant project on a 20 year basis gives an energy production cost of less than €30 per MegaWatt hour, with an IRR of more than 60%, without considering possible additional revenues for Green House Gas emission reduction and/or Renewable Energy production credits.

This is an extraordinarily result when compared to production from fossil fuels (approx. €80 per MWh) and of course extremely competitive when compared to other renewable generation systems like solar photovoltaic (approx. 120-235 € per MWh *Source: U.S. Dept. of Energy - Annual Energy Outlook 2011*), and wind turbines (approx 90-160 € per MWh *source IEA – Projected cost of generating electricity, 2010*). This is made possible by exploiting powerful and more constant winds (giving a higher capacity factor) and ground level machinery with basic foundations (overall light building design).

KiteGen® generators estimate nominal power:

Configuration	Nominal Power (MW)	
	min	max
KiteGen® Ground generator	3,000 kW	
KiteGen® off-shore generator	3,000 kW	
KiteGen® “Wind farm”	250MW/sq km	
KiteGen® Ground “Carousel”	1,000 MW	10,000 MW
KiteGen® Off-shore “Carousel”	1,000 MW	60,000 MW*

* Technical limit of KiteGen® Carousel

Financial analyses made on smaller plants (KiteGen® ground and off-shore generators - *wind farm*), show the technology to be highly competitive, and in any case higher than any other energy production system based on renewable sources currently developed. See the table on page 14.

One environmental consideration has to be added: while releasing no pollutant or thermal emissions, KiteGen® scores extremely high as well in terms of territory occupied, thus greatly reducing the visual impact on the landscape, for example when compared to wind turbine farms.

7.2. Risk factors: Airplane collisions

A KiteGen® power plant must obtain from the competent authorities (usually the national administration for civil aviation) the needed flight restrictions on the airspace above, where airplanes and any other type of airborne vehicle should not be allowed to enter. Such restricted areas have internationally uniformed rules and are already granted for other kinds of civil installations (for example nuclear power plants, oil refineries). A typical P (Prohibited) Area, where no flight is allowed and the risk tends to zero, has an altitude above the ground of 5,000 ft (equal to 1,524 m) and a radius of at least 1 nautical mile (equal to 1,852 m); the resulting cylinder has a volume of 16.4 km³ and would suitably fit the largest KiteGen® plants.

7.3. Market

The first production line, an improved and more powerful version of the prototype generator, is now past the pre-industrial phase. The accomplishment of the Carousel will follow. Both configurations will be more competitive than standard aeolic systems and fossil fuel generation systems, with no need to be installed in high ground wind locations.

It is estimated that nowadays the yearly new wind turbines installed will have a total power of approximately 35 GW (it was 15 GW in 2006). Selling more than 100 3 MW KiteGen® Stem generators will represent less than a 1% market share.

In parallel the company will work on scaling up design and looking for solutions for the 100 - 5,000 MW generator, which will compete in the much broader market of conventional fossil fuels power plants.

In perspective, according to the available data and forecast, troposphere wind generation systems may substitute fossil fuel production systems much quicker than, in the last century, oil took the place of coal in the world economy.





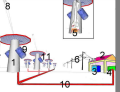








Photo #12: Onshore 3 MW KiteGen® generator in construction by Sommariva Perno (ITA – Dec 2010)

8. Competitors

KiteGen® is today the world’s most advanced energy production system based on tropospheric wind exploitation. Several other international projects can be listed in this field (Magenn, Laddermill, SkySails, SkyWindPower, Briza, Makani Power, Joby Energy,...), and new projects appear every day, but none of them has reached the same level of practicality or performance. Furthermore, because of the patents filed by KGR, many of the most promising technical solutions are unavailable to competitors.

9. KiteGen® panoramic product range - Example data

												
		Mobilegen	Naval KG	Ground KG	Offshore KG	KG Farm	Carousel 50	Carousel ARIA 100	Carousel ARIA 200	Carousel AQUA 1000	Carousel 10 GW*	Carousel Off-shore 60 GW*
Nominal power	MW	0.10	0.50	3	3	3 cad.	50	100	200	1,000	10,000	60,000
Force applied	MN	0.02	0.08	0.17-0.7	0.17-0.7	0.7	8.33	16.67	33	166.67	1,667	10,000
Rotor weight	Tons	1.00	25	20-60	20-60	60	5,000	10,000	20,000	100,000	833,333	4,000,000
Stator weight	Tons						7,500	15,000	30,000	150,000	1,250,000	6,000,000
Electromechanics weight	Tons	0.40	1.00	1.3 - 4	1.4 - 4	4	200	400	800	4,000	40,000	240,000
Operative altitude	km	1.00	1.00	1.0 – 2.0	1.0 – 2.0	2.0	0.75	0.9	1.2	1.86	6.67	10
Machine's Diameter	km	NA	NA	NA	NA	1 ha x mod	1.13	1.34	1.64	2.79	10	25
Number of modules	N	1	1	1	1	1 of 100	44	52	64	120	400	3,000
Power per module	MW	0.1	0.5	3	3	3 x n mod	1.2	2	3	9	25	20
Cost of stator	Meuro	0.00	0.2	0.2	0.3	2.00	15	30	60	300	2,500	12,000
Cost of rotor	Meuro						10	20	40	200	1,666	8,000
Cost Electromechanics	Meuro	0.01	0.2	0.3	0.4	0.3	4,00	8	16	80	800	4,800
Other costs	Meuro	0.1	1.0	1.2	1.4	0	35	35	35	35	35	35
Engineering	Meuro	0.1	0.1	0.1	0.1	0.1	0,5	1	2	10	100	600
Total COSTS	Meuro	0.21	1.5	1.8	2.1	3	64,50	94	153	625	5,102	25,435
Wind Availability	hours/year	4,000	4,000	4,000	4,400	5,500	3,000	4,000	5,000	7,000	7,000	7,500
Energy produced	GWh/year	0.4	2.0	4.0-12.0	4.4 - 13.2	16.5	150	400	1,000	7,000	70,000	450,000
Periodic costs	Meuro	0.01	0.12	0.05-0.15	0.08 - 0.24	0.26	4.5	9	15.3	62.5	510.2	2.543,5
Annual production value	Meuro	0.04	0.07	0.38-1.16	0.42 – 1.28	1.6	14.36	39.06	98.47	693.75	6,948.98	44,745.65
Industrial Cost MWh	euro	70	60	60-50	60-50	38	47	26	17	10	8	6

* Theoretical simulation based on technology scalability

10. KiteGen® Carousel ARIA100 – Feasibility analysis

Site conditions		Estimate
Project name		KiteGen® ARIA100
Project location example		Margherita di Savoia
Wind data source		Velocità del vento
Nearest location for weather data		Brindisi
Annual wind power density	W/m ²	362
Height of wind power density	m	50.0
Annual average wind speed	m/s	4.4
Height of wind measurement	m	6.0
Wind shear exponent	-	0.10
Wind speed at 10 m	m/s	4.6
Average atmospheric pressure	kPa	101.6
Annual average temperature	°C	17

System features		Estimate
Grid type	-	Grid connected
Peak load	kW	100.000
KiteGen® rated power	kW	100.000
Wind speed at 50 m	m/s	6.8
Hub height	m	700.0
Wind speed at operative height	m/s	7.1
Wind power density at op height	W/m ²	397
Wind penetration level	%	100.0%
Wind energy absorption rate	%	93%
Array losses	%	3%
Airfoil soiling and/or icing losses	%	2%
Other downtime losses	%	2%
Miscellaneous losses	%	3%

Annual Energy Production		Estimate
Wind plant capacity	kW	100.000.000
Wind plant capacity	MW	100.000
Unadjusted energy production	MWh	554,537
Pressure adjustment coefficient	-	1.00
Temperature adjustment coefficient	-	0.99
Gross energy production	MWh	548,992
Losses coefficient	-	0.90
Specific yield	kWh/m ²	496
Wind plant capacity factor	%	57%
Renewable energy collected	MWh	496,091
Renewable energy delivered	MWh	496,091
	GJ	1.785.929

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	100.000	
Mean height	m	700.0	
Swept area	m ²	1.000.000	
Wind turbine manufacturer		Sequoia Automation S.r.l.	
Wind turbine model		ARIA 100	
Energy curve data source		Standard	Weibull wind distribution
Shape factor		2.0	
Shape factor		2.1	Da 1.0 a 3.0

Wind Turbine Production data

Wind (m/s)	Power curve (kW)	Energy curve (MWh/an)
0	0.0	-
1	250.0	-
2	2,000.0	-
3	6,750.0	107,565.5
4	16,000.0	225,088.5
5	31,250.0	349,396.9
6	54,000.0	456,019.0
7	85,750.0	539,284.9
8	100,000.0	600,293.6
9	100,000.0	640,932.2
10	100,000.0	663,157.0
11	100,000.0	669,456.0
12	100,000.0	662,853.3

Wind (m/s)	Power curve (kW)	Energy curve (MWh/an)
13	100,000.0	646,525.3
14	100,000.0	623,408.9
15	100,000.0	595,973.8
16	100,000.0	-
17	100,000.0	-
18	100,000.0	-
19	100,000.0	-
20	100,000.0	-
21	100,000.0	-
22	100,000.0	-
23	100,000.0	-
24	100,000.0	-
25	50,000.0	-

Power and Energy Curves

▲ Power ■ Energy

