



## A North American Wind Energy Scenario

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*This is a guest post from Neil Howes. Neil has recently retired from his position as an Associate Professor at the University of Sydney. Neil's previous guest posts at TOD include "[A North American Energy Plan for 2030: Hydro-electricity the forgotten renewable energy resource](#)" and "[A National Electricity Grid For Australia](#)".*

Would a "50% of electricity generated by wind scenario" work in North America by 2030? In this post, I make a rough cut estimate of what might be required to make such a transition in about 20 years time.

Most proposals that are being made rely on a very big increase in carbon free energy, both to charge electric vehicles (EV's) and to replace oil and natural gas (NG) presently used for hot water and space heating. In this post, I lay out a path by which 50% of North American energy might come from wind by 2030, including replacement of a large share of oil and natural gas use by electricity.

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### Quantity of Additional Low-Carbon Electricity Required

Present electrical consumption is 550 GWa. If the North American countries - Canada, Mexico and the United States - were to replace :

- 70% of their oil usage (by replacing over 90% of the oil used for heating and land transportation with electricity and 50% of the jet fuel used via a combination of conservation measures),
- 95% of the coal used for electricity production (250GWa) and
- half of the NG used for hot water and space heating (60GWa)

They would need to generate an additional 450GWa, but would net out coal replaced of 250 GWa, for a total of 750 GWa production.

In a [previous article](#), I have shown that hydro electricity could account for a third of this (140GWa). Other possible low carbon energy resources are [solar](#), wind, [geothermal](#), [ocean](#) (tidal and wave), [biogas](#) and [nuclear](#) power.

What if hydro-electricity can only be increased by 50% by 2030 (from 94 to 141GWa) rather than the 130% increase that I have previously suggested, and if other additional low carbon energy sources can only account for an additional 50GWa ?

This would mean that either more than 5% of today's thermal coal would be needed to generate electricity or an additional 372GWa would have to come from wind power (50% of total). I am not

suggesting it would be desirable to obtain more than 50% of electricity from wind, but wind capacity can be built quickly, and there do not seem to be any serious resource limitations to expanding wind (a [recent report](#) from the US Interior department noted that offshore wind alone could supply enough power to meet all US electricity needs). This level of wind power has been suggested by some (such as [Repower America](#)) as possible and practical, but many have questioned if wind could even provide 15-20% electrical energy because of the intermittency of wind energy.

For the purpose of the discussion of wind intermittency, I am assuming that an expanded North American grid extending from Alaska to Labrador in the North, and south beyond Mexico City will be built. Such an extended grid would help smooth out fluctuations.

## Electricity from Wind

Although only 9GWa was generated from wind power in 2008 (26GW installed capacity), this represents 1.7% of N America's electricity production and wind capacity addition has growing at about 30% per year over the last decade. The advantage of wind energy is that new capacity can be built quickly (1-2 years), with small incremental low risk investments. Wind energy is less site specific than hydro, has less impact on the environment, and wind energy doesn't require cooling water. The cost of wind power capacity had been declining with technical advances, until the last 2 years with increased costs caused by rising material costs (especially steel and cement) and manufacturing capacity constraints. These costs now seem to be declining from very high levels in early 2008.

	Capacity 2008	Average 2008	Capacity 2030	Average 2030	Lowest production 2030
Hydro	160 GWc	94 GWa	260 GWc	141 GWa	20 GW
Pumped storage	included in hydro	(3 GW)	included in hydro	(6 GW)	(40 GW)
Coal	350 GWc	250 GW	100 GW (weeks)	5 GWa (summer)	0
Natural Gas	450 GWa	100 GWa	450 GWc (days)	40 GWa	0
Wind	26 GW	9 GWa	1142 GW (546 GW max)	372 GWa	312 GW (>98%)
Solar (CSP)	0.5 GW	0.1 GW	50 GW	12.5 GWa	0
Nuclear	110 GW	100 GWa	130 GWc	125 GWa	100 GW
V2G (PHEV)	0	0	50 GW (for 6h)	(100 GW)	(150 GW for 10h)
Oil (Mexico)	10 GW	<10 GW	0	0	0
Total	1056 GW	556 GWa	2147 GW	780.5 GW	

**Table 1: Electricity supply and grid regulating (demand) in N America 2008 and 2030**

High quality wind resources (wind speeds greater than 6.9m/sec) in the US are [estimated](#) to be >5,500GWa, about x10 all of N America's present electricity production of 550GWa. Canada's potential appears to be similar or greater than the US, while Mexico's wind resources are more

limited (these figures do not include deep offshore resources that could be harnessed by [floating wind turbines](#) or [higher altitude wind resources](#) that could potentially be harnessed by [airborne wind turbines](#)).

For example, the Great Lakes have excellent [offshore wind resources](#), and are close to major demand, with a potential of 321GWa in Michigan waters alone. Wind resources are widely distributed although some regions especially the SE of US, have poorer resources.

If an additional 372GWa was to be generated from wind power by 2030, this would require an expansion of today's 26GW capacity to 1142 GWc. I am using a 0.33 capacity factor although this could well be higher as larger turbines are built and with expanded grid infrastructure, better remote wind sites will be developed including off-shore wind having a higher capacity factor. Such an expansion would require new capacity additions to rise from the 2008 level of 9GWc to 60GWc per year by 2013, and continue at that level until 2030.

This is more than the National Renewable Energy Lab's (NREL) [20% by 2030 wind power proposal](#) that envisioned installing 16GW capacity per year, but the NREL expected much slower growth than has occurred, thus the US alone has reached 2013 expected capacity in 2008. Wind capacity would have to increase by 50% for 5 years to reach 60GW capacity additions per year by 2013, allowing an additional 1110GW capacity to be built by 2030. As the NREL study showed, wind turbine manufacture is suited to rapidly expanding capacity, providing capital and labor are available. Many components, such as large towers and turbine blades can be manufactured locally from steel plate, glass fiber and resins, or casting made using multiple molds prepared from master plugs. Foundations and electrical connects can be built using normal reinforced concrete construction methods that are used for road, bridge and multi-story construction.



Photo credit: [flickr/samballew](#)

## ERoEI and Life Cycle Resources

Both hydro electricity and wind power have high ERoEI, hydro because of the long life of structures (>100years) and wind because of the fast energy payback, even assuming a 20 year

life of turbines. Earlier studies of turbines built in 1990's 100-750kW capacity had an average EROEI of 18:1, but larger turbines (500-750kW) had >30:1. Turbines are now 1.5-3.5 MW and appear to have EROEI of 30-200:1, with energy paybacks of a few months. Life-cycle analysis indicates that wind energy, is low FF use, and CO2 emissions (5-40 g/kWh) about 25 to 100 times less than coal-fired electricity. Oil used for road transport would be 1- 5% of energy use.

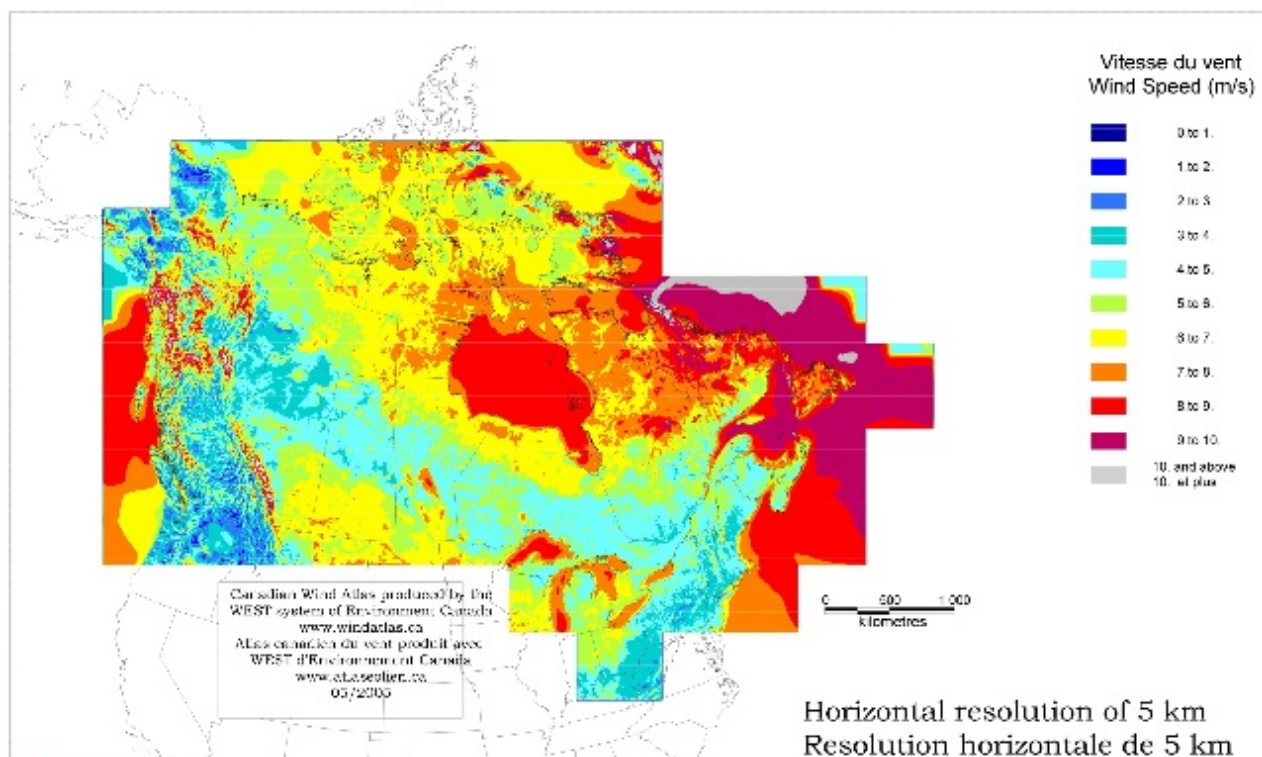
The steel required to build 60 GW capacity per year would be 6.9million tonnes (115tonnes / MW capacity), about half the amount of scrap steel that could be recovered annually from scrapped N American automobiles, using electric arc furnaces.

### Integrating 50% wind energy into a continental grid.

Wind energy is variable at one location, producing less than 30% of the average output (ie. <10% capacity) about 30% of the time, but as the distance between wind farms increases the correlation between power output and locations decreases. Most studies of wind integration into grids have examined relatively small geographic regions, such as Denmark(43,000km<sup>2</sup>), Northern Germany(<50,000km<sup>2</sup>), and the UK(250,000km<sup>2</sup>). A UK study looked at sites up to 800km separation (North/South), and found a low correlation between distant sites, so that >80% of the time a wind grid would be producing >30% average output.

Even more optimistic predictions were made by Archer and Jacobson, when they examined predicted output of up to 19 sites covering a 850x850 km region (700,000 km<sup>2</sup>) in US mid-west. Better information about wind shear at heights typical of modern turbines, and the "nocturnal jet" show that more consistent wind power is available during summer evenings than [originally realised](#). Similar studies in Australia with 9 sites in 3 states, over a 4 year period, separated by up to 1500km, showed energy output was >10% capacity 98% of the time during peak demand summer months.

### Mean Wind Speed at 50 m above ground Vitesse moyenne du vent à 50 m au dessus du sol



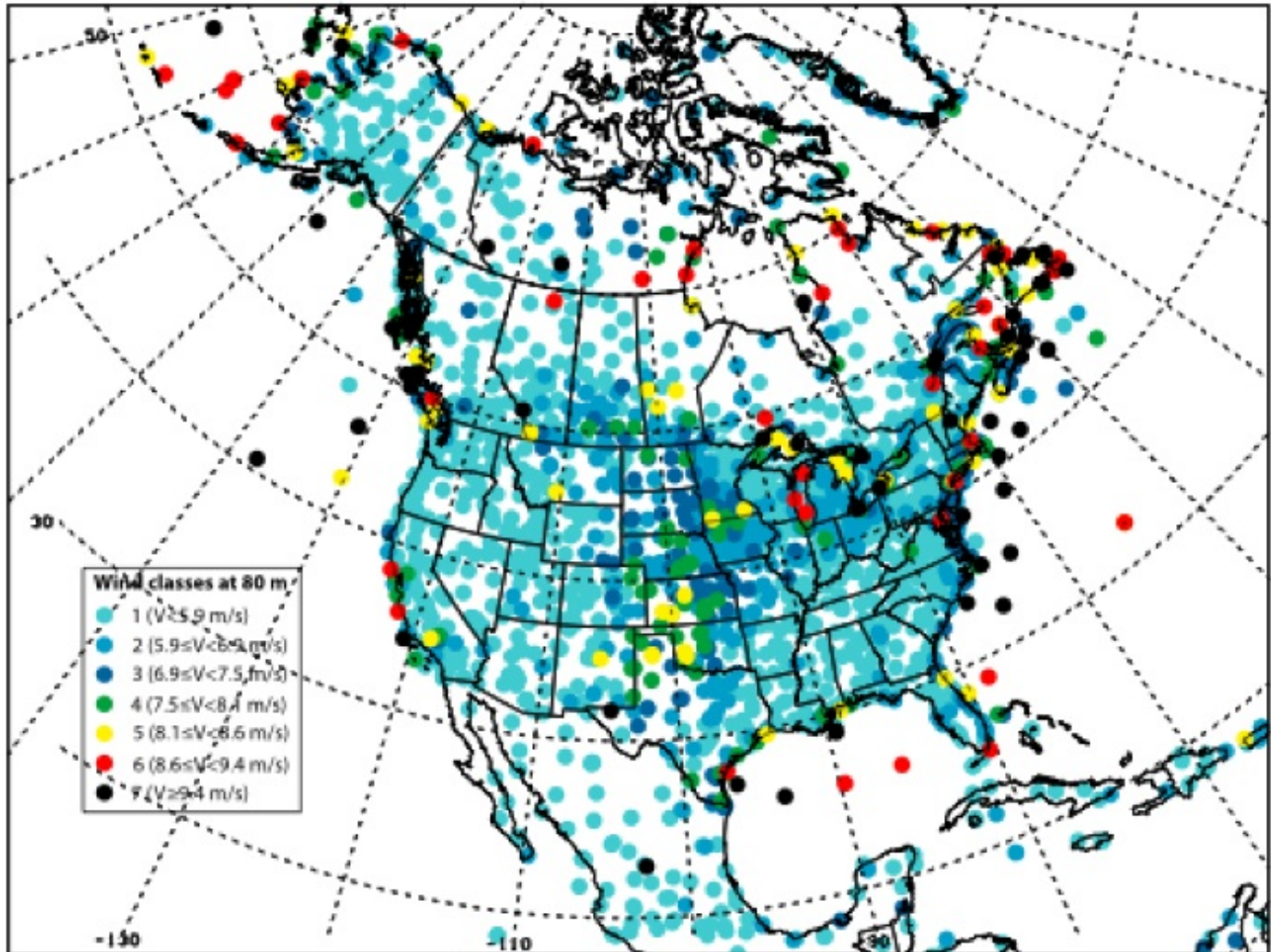
Canadian wind strength - [source](#) (pdf)

Critics of wind energy can cite specific times when wind energy provided little, for example ERCOT in Texas, Feb 2008, 2992MW wind capacity only produced 300MW (6%) or in California on July 24, 2006, during peak power demand, where 2377MW wind capacity only produced 333MW (12% capacity). While Texas (695,000 km<sup>2</sup>) and California (423,000 km<sup>2</sup>) are large by European standards, two sites in California (San Geronio Pass and Altamont Pass) accounted for 50% of CA capacity. North America covering > 22 million sq km, is 50 times the area of California, 100 times the area of the UK, and 500 times the land area of Denmark or Northern Germany. Furthermore, the continent has an East/West width at 50N latitude, of 4,000 km, a critical issue for wind reliability, because weather systems, such as slow moving blocking high pressure systems and low pressure storm fronts generally move from west to east at these latitudes.

There are ten major high quality wind resource regions in N America;

- 1) NE coast and off-shore (QC,NS,NB,NH,ME,VT, RI,SDC)
- 2) West coast and off-shore (CA,OR,WA, BC),
- 3) Pacific coast of Alaska, and Aleutian Islands
- 4) the Canadian prairie extending through the mid-west plains and Texas plateau (SK,ND,SD,NE,KS,OK,TX)
- 5) the Great Lakes off-shore and lake shore regions(ON, MN,IL,WI,MI,OH,PA,IN,NY)
- 6) the Appalachian Mountains(WV,KY,TN,NC,VA)
- 7) Rocky Mountains(NM,CO,WY,ID,MT,ALTA)
- 8) the Nelson River and West Hudson on-shore (MAN)
- 9) James Bay/ East Hudson's Bay on-shore (Northern QC)
- 10) Labrador and Newfoundland on-shore(NFL).

Other more remote regions such as, the Canadian arctic (Baffin Island) also have good wind resources that are influenced by circum polar weather systems. The North American grid presently extends to nine of these major regions, the exception being the Alaskan Pacific Coast.



Source: Evaluation of Global Wind Power - Christina L Archer and Mark Z Jacobson

If an installed capacity of 1142 GW wind energy was built at widely dispersed wind locations we would expect to deliver within a range of 27-39% of capacity (expected power 372 GW) over the entire N American continent most of the time. This is a best guess estimate, based on studies of connecting multiple wind farms over much smaller regions, where more connections do not increase total power under high wind conditions but produce more power under conditions of lower wind speeds. Since the 10 regions are up to 4,000 km apart, and can extend for up to 1,500 km, it would be very unlikely for more than three of the ten regions to be producing < 5% capacity at any one time, based on the normally distributed power curve of combined sites. Seven of those 10 regions also have flexible hydro capacity so 7/10 of the wind power would be firm. The other 3 regions each extend >2,000 km (the East and West coast and Mid-West), so it would be unlikely that 2 of these regions would be producing <5% of capacity at the same time. This would mean the grid would be receiving > 27.4% of the expected 33% capacity for the installed national capacity (>312GW). Thus the grid will have to supplying up to 62GW (3.6%) additional peak power in low wind conditions, when those coincide with a peak demand period. Additional reserves of 219 GW are thus 350% larger than expected wind variability.

### **Generating 50% of the electrical power by wind places high demands on the grid.**

Critical to any plan that involves a large expansion of renewable energy is the expansion of the N American grid with long distance HVDC connections between regions of high wind, solar and hydro electricity generation and regions of high electricity consumption. A 3,000 km UHVDV link from Alaska and the Yukon to both the Western and Eastern Interconnections would be

especially important to access both wind and hydro resources and would add extra stability to the grid. Losses by a 800,000V DC line would be 2% per 1,000km, less than existing 1,000km HVDC used today to bring power from Canada to the Eastern Interconnect. Good wind resources along the arctic coasts of Hudson Bay and Labrador would only need short transmission lines to connect with existing James Bay (QC), Nelson River (MAN) and Churchill Falls (NFL) hydro schemes, sharing the same HVDC lines to the eastern interconnect. A southern HVDC line from Arizona/Sonora solar power sites to Mexico City would also link into the Rocky Mountain and Mid-West wind regions.



Using 372 GWa wind power across the continent will require large amounts of electricity to be moved long distances, but not as much as may be imagined. Most of the NG peaking plants are close to demand so this power would only travel short distances. Water impounded behind a dam is the cheapest form of electric power storage, and it can be drawn upon at very high rates for short local demand peaks, reducing the demand on the HVDC interconnects. Pumped storage is 85% efficient, it can be low cost when combined with existing hydro dams, but more expensive if a purpose built facility. All regions with high wind resources, except the Prairie/mid West region also have access to one or both of these storage mechanisms, and because the wider grid will be able to replace hydro use, interconnections between regions can be of limited capacity. Care and maintenance coal-fired generators that are located near demand could be used with 24-48 hour notice, if hydro was not available (due to low water levels) or if longer low wind events persisted in one region.

Hydro:new dams	25GW	\$6000	300
Hydro:additional turbines	55GW	\$1000	55
Small hydro	20GW	\$1000	20
Solar	50GW(av 12.5GW)	\$2000	100
Nuclear	25GW	\$6000	150
Wind	1115GW(372a)	\$1500	1672

<b>Transmission</b>		distance(km)	cost @ 1M/GW.km (billion)
Alaska/Yukon to Grand Coulee	30GW	2000	60
Yukon to Nelson	10GW	2000	20
Nelson to ND	20GW	1000	20
mid-west to SD	45GW		
SD to Chicago	70GW	500	35
QC to East coast	30GW	1000	30
Labrador to NE coast	20GW	1000	20
Local regions	1GW	20000	20
Sonora to Mexico city	10GW	1000	10
Sonora/Arizona to CA	20GW	500	10
<b>Total transmission</b>			<b>225</b>
<b>Total cost</b>			<b>2522</b>
<b>cost/year</b>			<b>126</b>

The assumptions I have used are that the additional hydro and pumped storage capacity is built on existing dams, by adding more turbines, to provide more peak power or new remote dams are built where good wind resources (9-10m/sec) can be combined with hydro sharing the same transmission lines. In sub-arctic regions water flows are high during summer, wind is high in winter. Similarly CSP solar power located in SW of US and adjacent Sonora would provide additional peak power to Mexico, CA and TX.

Thus wind and hydro electricity from Alaska and sub-arctic Canada (Nelson River, James Bay and Labrador) would be 100% reliable, with hydro replacing wind during low wind periods, and water stored during high wind periods. The capacity of the transmission lines from these 4 regions could be 145GWA shared power, from 280GW wind capacity and 135GWc hydro. The mid-west prairie region could share connections to the Great Lakes (sharing Nelson River power), and share solar connections to CA via Arizona or south to Mexico. Thus, the major consuming regions would produce about 60% wind and hydro power locally and import 200GW, representing 26% of total power but < 10% of peak power capacity. Thus if in the future a major consuming region (W coast) were to lose 95% of local wind power capacity of 150GWc (say only have 7GW of expected 50GWA) for 6 hours it would require at most to import about 1/4 of the lost production (11GW) via the HVDC grid from several other regions (Alaska, Rocky Mountains, Mid-West), moving an additional 0.5% of national peak power capacity. The other 32GW, would come from short distances (NG peak, hydro) using existing infrastructure as it does today. Over 1-4 days this loss (192GWh) could be restored by continued higher imports (2-8GW), during off peak periods, allowing local hydro to be accumulated.

A smart grid would enable short term demand reduction reducing refrigerator, A/C or heating



demand by short term on/off cycling. Real cost pricing of peak power would encourage consumers to reduce activities such as dish or cloths washing during peak times. Hot water heating using CO2 heat pumps is especially suitable for grid load management, because of the potential to store energy as hot water over the peak period. Vehicle to grid (V2G) can provide short term [spinning reserve power](#) (pdf) and could provide longer term storage to help reduce long distance power transfers, using as little as 500Wh transfer in vehicles that had completed the days journey (100M vehicles) providing up to 50GWh towards a demand peak due to grid failure, with only a minor change to available EV range.



Photo credit: [flickr/kevindooley](https://www.flickr.com/photos/kevindooley/)

Another potential energy resource is a reduction in electricity consumption due to more efficient utilization. One-third of today's electricity consumption could be saved if all states used electricity as efficiently as the [ten highest GDP/kWh states](#) (pdf). Perhaps N America doesn't really need to rely on more than 50% of its electricity from wind power. Others could make a reasonable case that solar could also provide up to 50% of N America's power.

The most urgent problem is the arrival of "Peak Oil". No amount of low carbon electrical energy is going to directly replace oil used in transport or oil and condensate used for chemical synthesis. Abundant low carbon electricity, however, will allow a lot of additional options during the transition to a low oil economy.

## References and related posts

Archer & Jacobson - [Evaluation of global wind power](#) (pdf)

Danish Wind Power - [Wind power diurnal variation](#)

Peak Energy - [The World's Largest Wind Turbine](#)

The Oil Drum - [Offshore Wind](#)

The Oil Drum - [Making the case for wind, again](#)

The Oil Drum - [Advice to Pres. Obama \(# 4\): Go for Wind Power, Seriously](#)

The Oil Drum - [Energy from Wind: A Discussion of the EROI Research](#)

The Oil Drum - [Floating Offshore Wind Power](#)

The Oil Drum - [Alternative Wind Power Experiments - SkySails and Airborne Wind Turbines \(Peak Energy\)](#)

Peak Energy - [Saul Griffith: Inventing a super-kite to tap the energy of high-altitude wind](#)



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