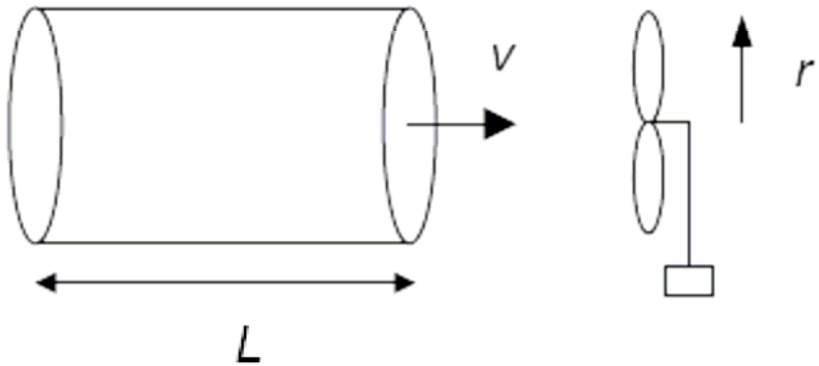
Wind Power

Scroby Sands, Norfolk, UK
http://en.wikipedia.org/wiki/Image:Scrobysands04.11.2005.a.jpg

Energy transformation:
Solar (nuclear → thermal → radiation) → Wind (kinetic, translational) → Turbine (kinetic, rotational) → Electricity

- About 2% of the solar energy absorbed by the earth goes into moving air around. This we call wind, and the kinetic energy resident in the moving air can be captured and turned into electrical energy by means of a wind turbine that turns a generator. In this note we will consider the broad energetics of wind turbines. We will not concern ourselves with engineering issues.

Consider the propellor blades of a wind turbine that each have length r and sweep out an area $A = \pi r^2$. Now let a cylinder of air, radius r, and length L, approach the turbine head-on at speed v.



The mass of the cylinder of air is given by $m = \rho AL$, where ρ is the density of air, about 1.2 kg/m^3. The kinetic energy of the cylinder, E, is:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\rho ALv^2$$

The time Δt taken for this cylinder to pass through the turbine blades is just L / v. Therefore the power P_{in} incident on the turbine is:

$$P_{in} = \frac{E}{\Delta t} = \frac{1}{2}\rho ALv^2 \cdot \frac{v}{L} = \frac{1}{2}\rho Av^3$$

This is continuous if the air continues to flow. Clearly the turbine cannot extract all this power out of the wind, or the air would have to stop dead after passing the blades. The maximum fraction that can be extracted is known as the Betz limit, which is about 60%. Inefficiencies of the generator and transmission lines further reduce the useful power generation.

The v^3 term emphasizes the need for high, continuous wind. Germany, Spain and the USA each have about 20GW of installed wind power capacity (10x Canada's wind capacity). Try to design a set of turbines of reasonable size that could produce 1GW of electrical power under common wind conditions at a site you can choose in BC or Alberta.

References:

Betz limit:
http://www.windpower.org/en/stat/betzpro.htm

BC sites:
http://www.geog.ubc.ca/courses/geog376/students/class05/cskwan/intro.html

Alberta sites:
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6451?opendocument

EarthFirst orders 48 Vestas V90-3.0 MW wind turbines for Dokie Ridge Project in British Columbia, Canada

December 17, 2007
Victoria, BC

EarthFirst Canada Inc. ("EarthFirst") (EF, EF.WT; TSX) is pleased to announce that it has placed an order with Vestas-Canadian Wind Technology Inc. for 48 of its V90-3.0 MW wind turbines to be installed at EarthFirst's 144 MW Dokie Ridge project located in the Rocky Mountain foothills of the Peace River region in north-eastern British Columbia, Canada.

GHG Calculations: Wind vs. Coal

- Coal-fired plants produce about 10,000 tonnes CO_2 per year MWe (see next slide for calculation).
- Natural gas produces about half that.
- Wind turbines cost about $2M for a 1MWe plant.
- With typical capacity factor of 0.3 that's about $7M for real 1MWe output on the grid.
- Maintenance about 2% per year; lifetime 20 years
- Say $10M total per MWe on the grid for 20 years
- CO_2 intensity of German/Danish economy is about 400 tonnes per $1M of GDP. (Canada’s is 600 tonnes per $1M).
- That's 4000 tonnes for 20y of MWe on the grid, or 200 tonnes CO_2 per year.
- i.e. only 2% of the GHG emissions from coal, joule for joule.
- http://earthtrends.wri.org/text/climate-atmosphere/variable-606.html
- http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html

Estimating GHG Production: Coal and Natural Gas

Consider a 1GWe power station operating for 1 year:

Energy content of coal ~ 30* MJ/kg (55 for natural gas)

Electrical generating efficiency ~ 40*%,

i.e. need $2.5GW_{th} = 2.5 \times 10^9 \times 365 \times 24 \times 3600$ J

$= 8 \times 10^{16}$J

- which needs 2.6×10^9 kg (2.6Mtonnes) of coal (1.5×10^9 kg for CH_4)
- C(12) + $O_2 \rightarrow CO_2$ (44)
- which therefore produces 44/12 times as much CO_2, (assuming coal is mostly carbon) i.e. 10Mtonnes (x44/16 → 4Mtonnes for natural gas).
- (Coal is not pure carbon, but this makes little difference to the result)

* high-end numbers