ENGR-3000:
Renewable Energy, Technology, and Resource Economics

Wind Utilization, Economics, Impact

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World Learning
SIT Study Abroad

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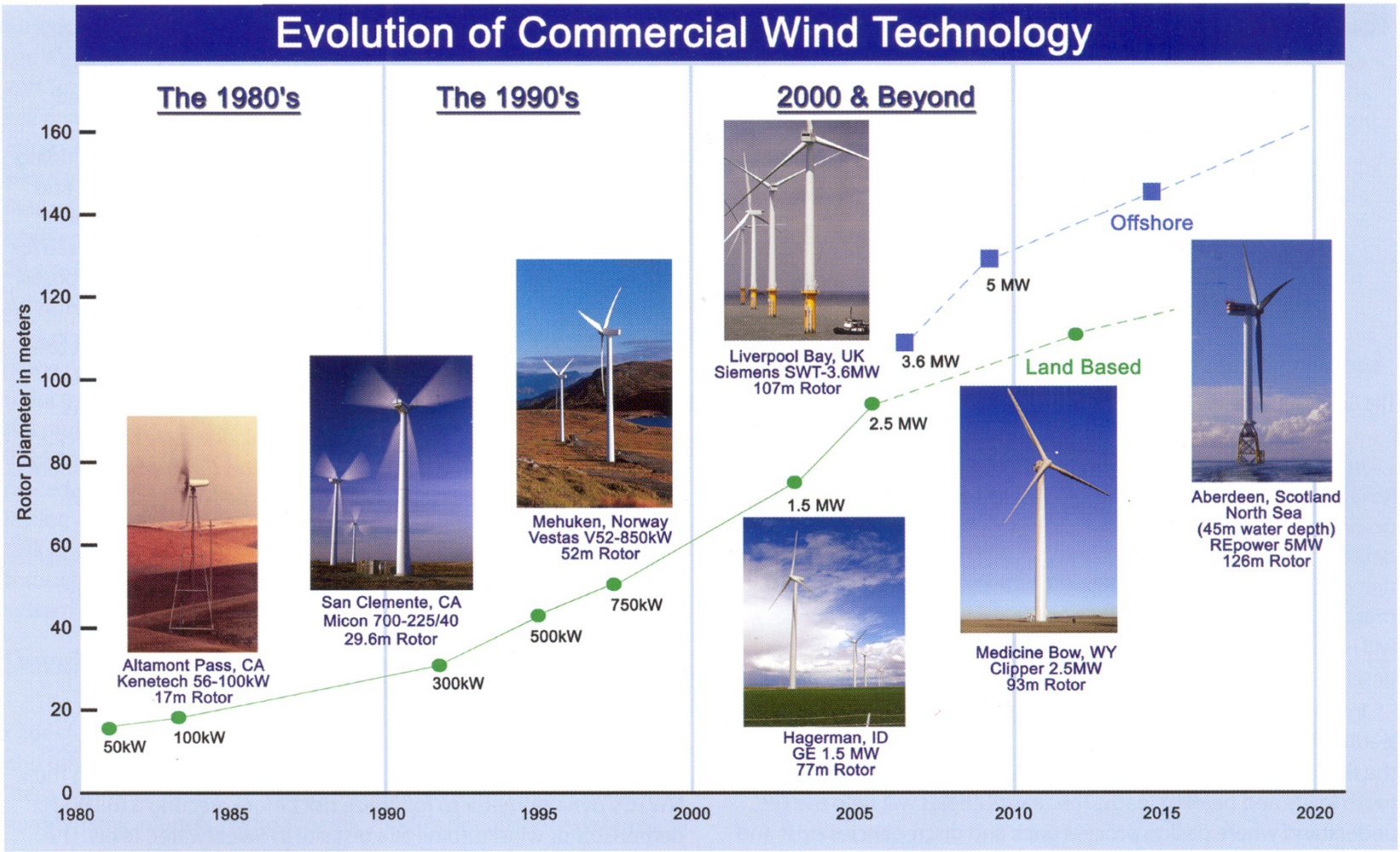
Drivers for Wind Power

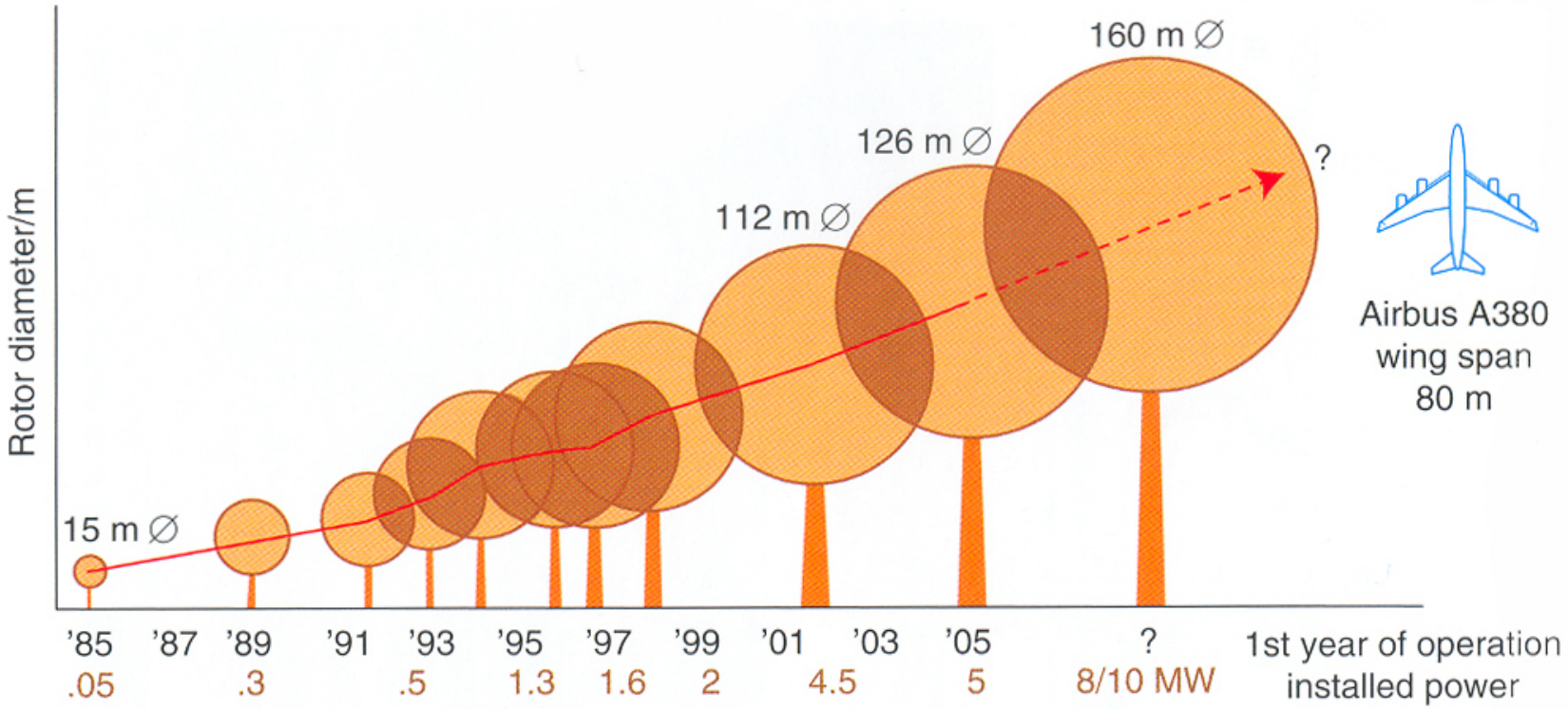
- Declining wind costs
- Fuel price uncertainty, carbon risk, energy security
- Federal and state policies (investment tax credits)
- Economic development (bi-partisan support)
- Environment / water

Evolution of Commercial Wind Technology



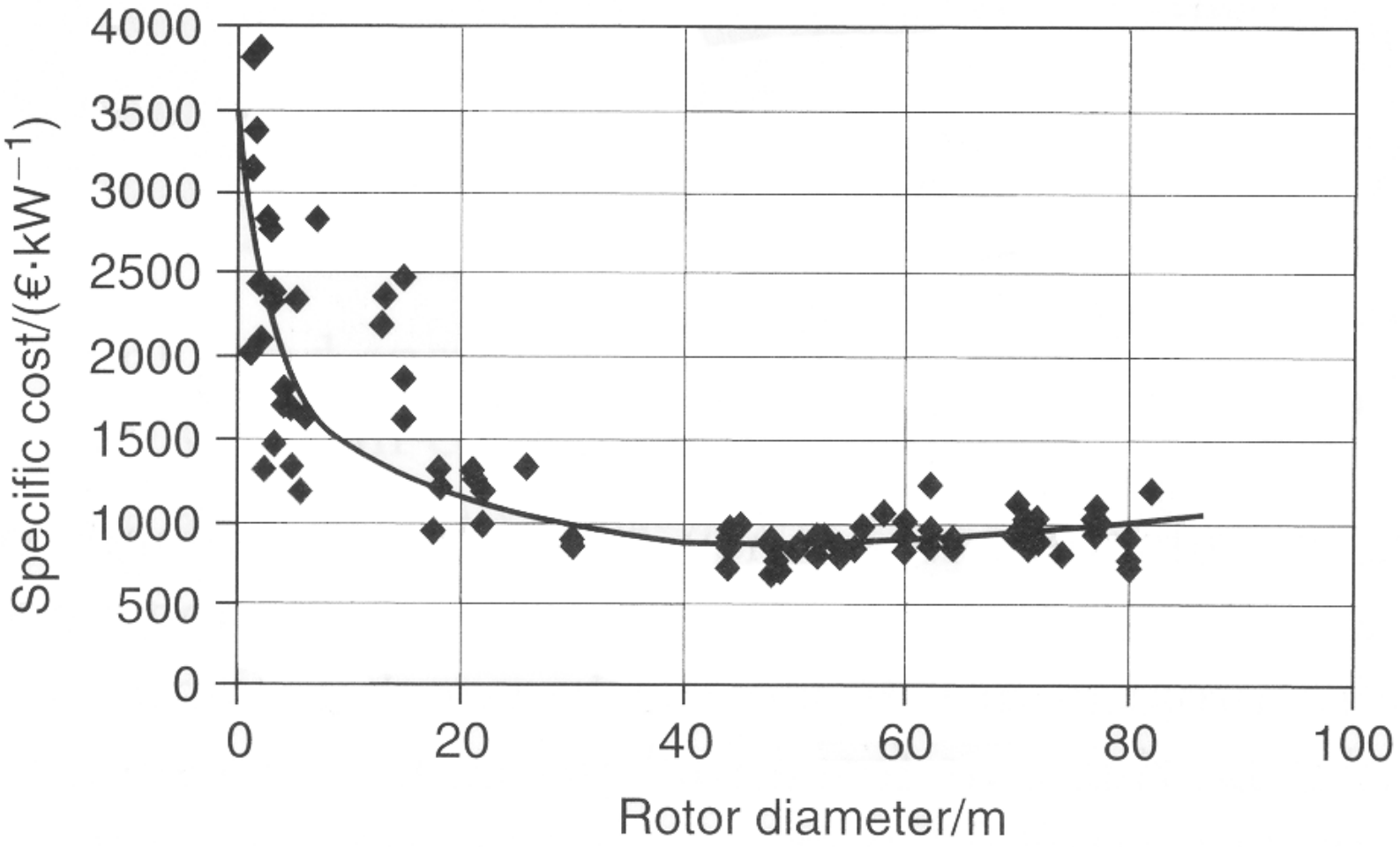
Since 1980, wind turbines have grown in size and capacity, from 100-kW machines with a 17-m rotor diameter to multimegawatt machines with rotor diameters larger than 100 m.

Evolution of Wind Turbine Size



(*Source*: J. Beurskens, European Wind Energy Association, 2005. *Prioritising Wind Energy Research – Strategic Research Agenda of the Wind Energy Sector*)

Wind Turbine Specific Cost vs. Size



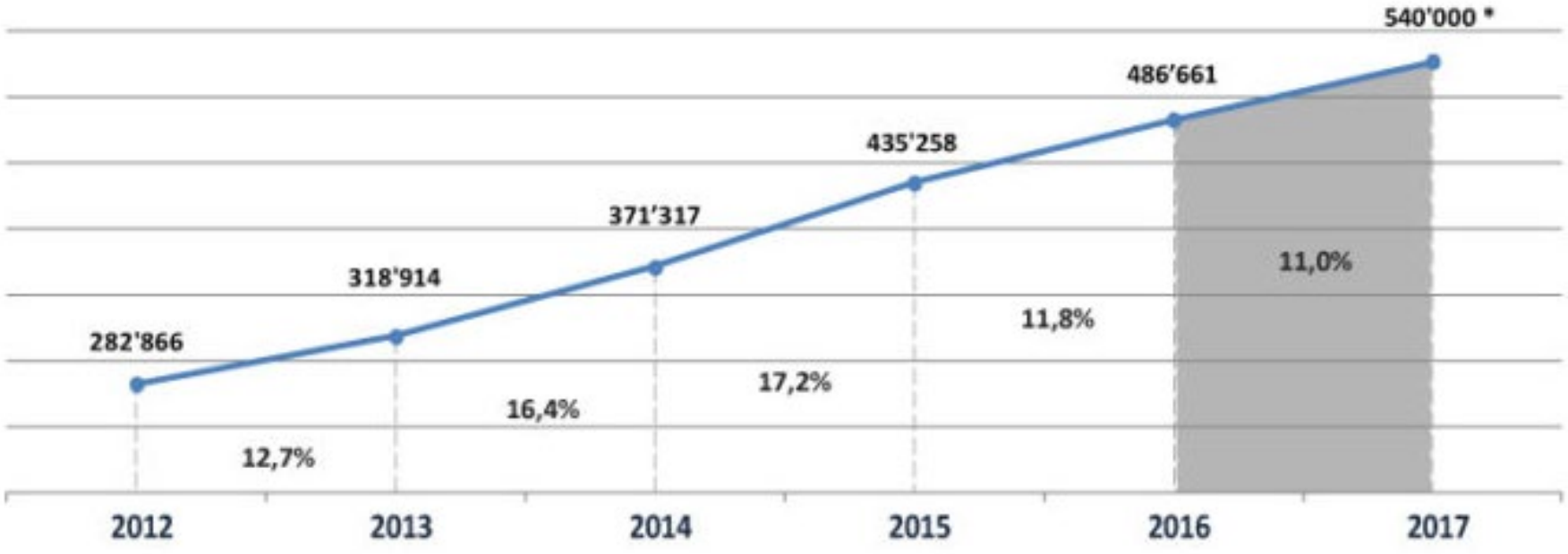
On-Shore Wind: Levelized Costs $/MWh

Estimated Costs for New Generation Resources: Plant Type (Capacity Factor)	Capital Cost	Fixed O&M	Variable O&M (Incl. Fuel)	Transmission Investment	Total System Levelized Cost
Wind (34.4%) AEO2010	130.5	10.4	0.0	8.4	149.3
Wind (34%) AEO2011	83.9	9.6	0.0	3.5	97.0
Wind (33%) AEO2012	82.5	9.8	0.0	3.8	96.0
Wind (34%) AEO2013	70.3	13.1	0.0	3.2	86.6
Wind (35%) AEO2014	64.1	13.0	0.0	3.2	80.3
Wind (36%) AEO2015	57.7	12.8	0.0	3.1	73.6
Wind (36%) AEO2016	39.8	13.1	0.0	2.9	44.3
Wind (41%) AEO 2017	43.1	13.4	0.0	2.5	59.1
Wind (44%) AEO 2018	27.8	12.6	0.0	2.4	42.8

U.S. Energy Information Administration, Annual Energy Outlook 2011 to 2019.
www.eia.gov/forecasts/aeo/electricity_generation.cfm

Total Installed Capacity 2012-2016 (MW)

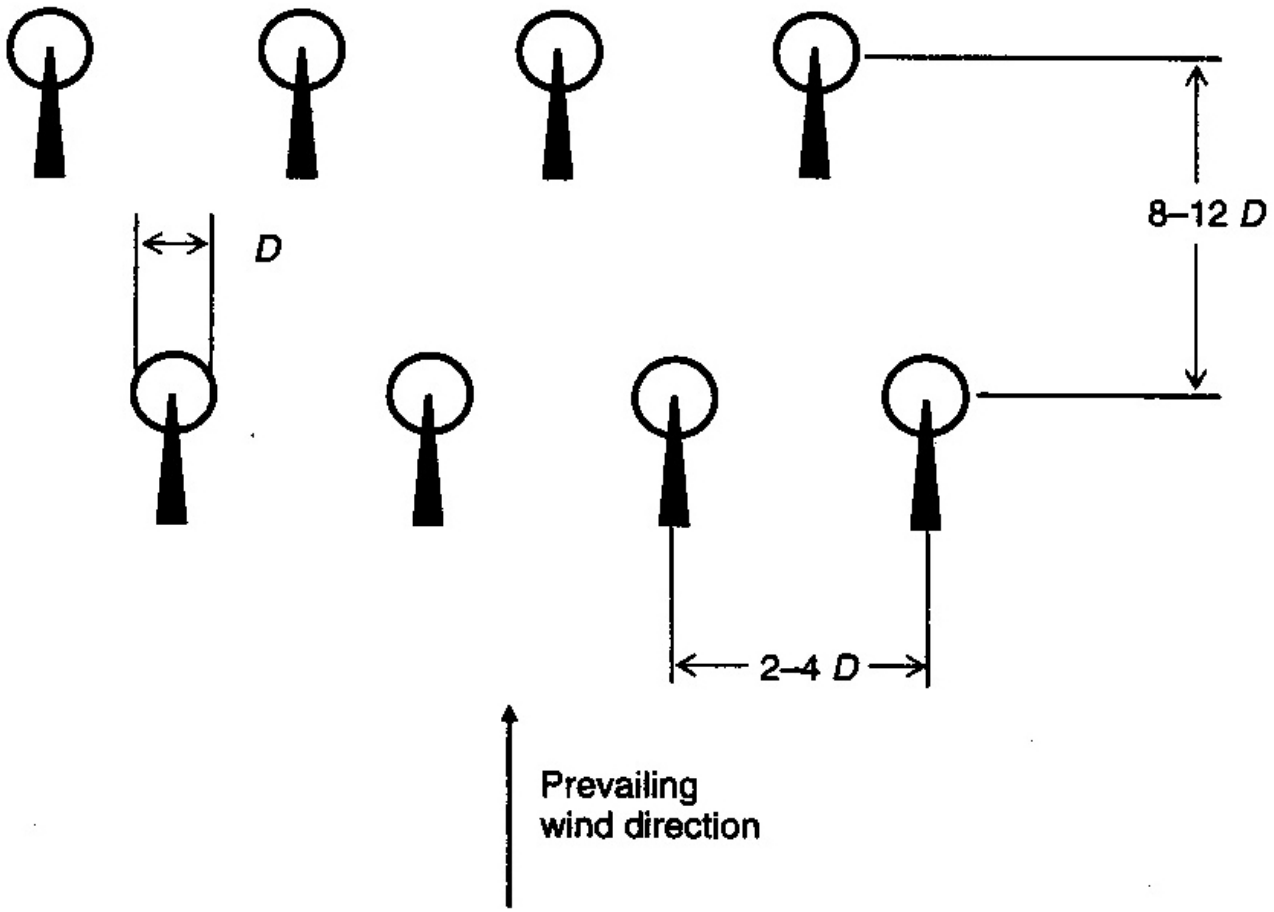
- Worldwide wind capacity now exceeds 500 TW



* Prognosis
Total installed capacity: Includes all installed wind capacity, connected and not-connected to the grid.

Wind Farms

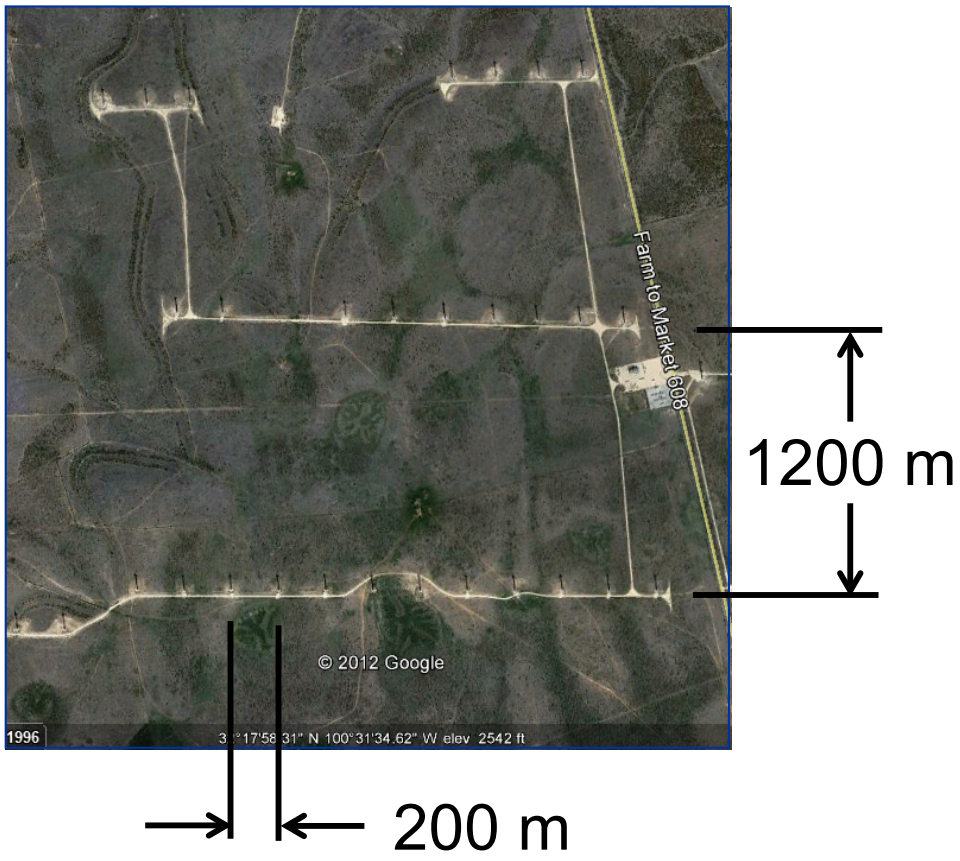
Wind Turbine Arrangement for Wind Farms



Hodge, Alternative Energy Systems and Applications, Wiley, 2010

Sweetwater TX Wind Farm

- Turbine Arrangement:
  - 200m spacing along row
  - 1.2 km spacing between rows



- Mitsubishi 1MW
  - Rotor dia = 61.4m

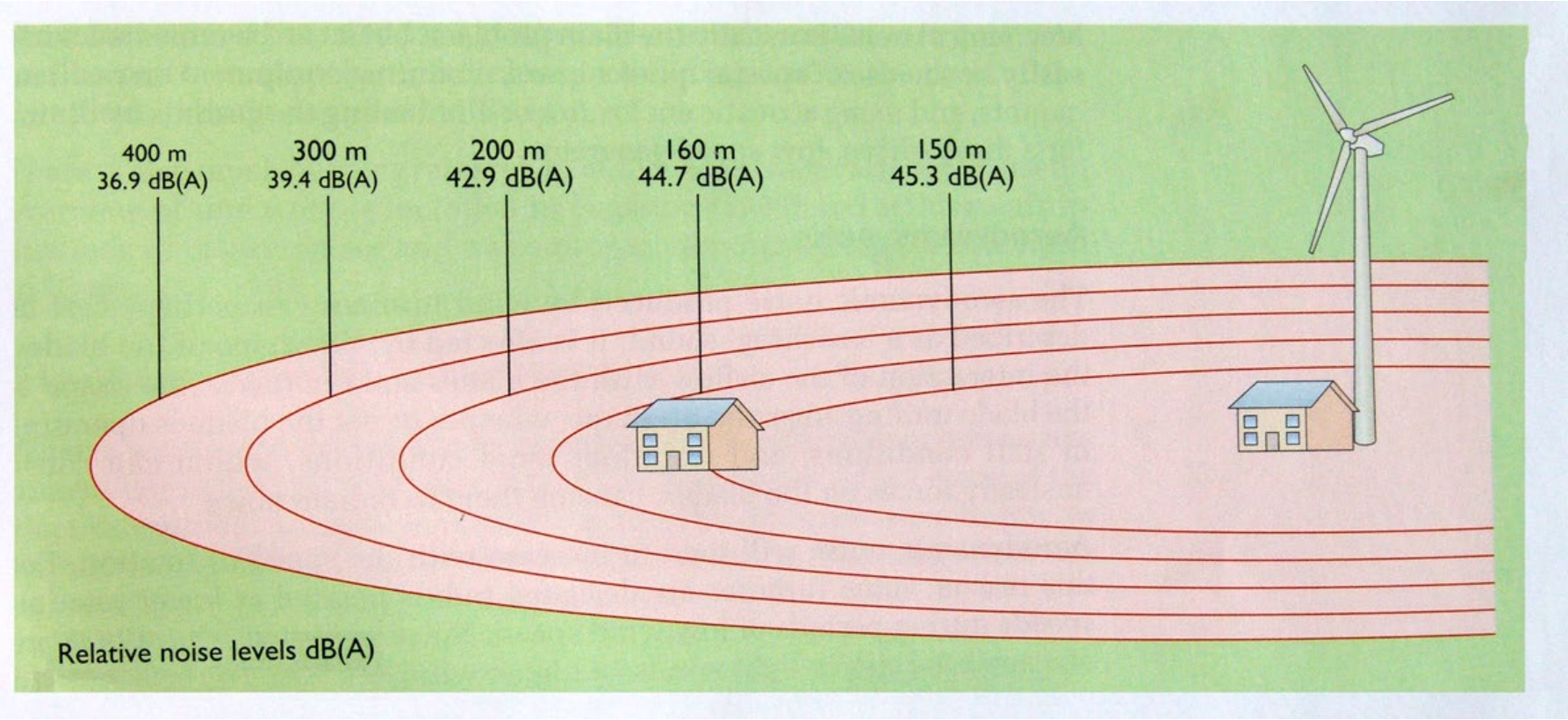
Property Setback Limits

- 150% of turbine height to property line.
- This limit should account for
  - Noise limits
  - Visual effects (shadow flicker)
  - Ice throw

Noise sources and guidelines

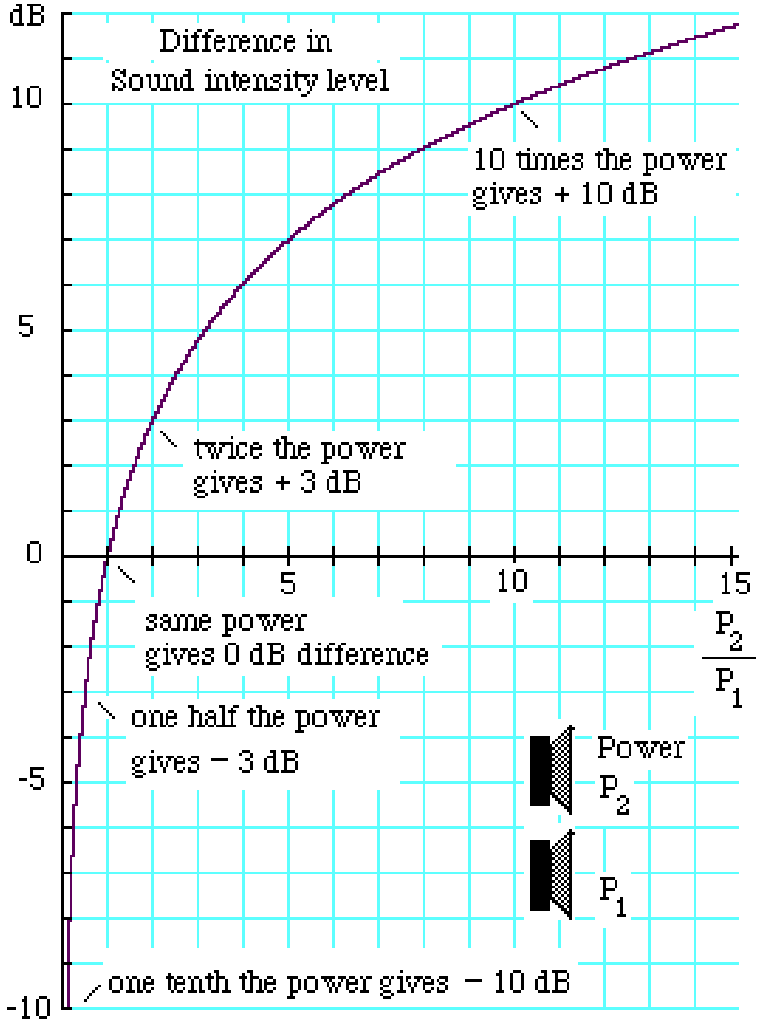
- Sources of turbine noise
  - Gearbox (mechanical)
  - Blade passing tower (acoustic)
    - Periodic
- Modern turbines are much quieter than older models
- Noise limits:
  - In general, 75 db(A)
  - Protected locations: 55 db(A)
  - Residence (within 500 ft) 45 db(A) 7PM to 7AM

Noise Levels



Sound Levels Measured in Decibels

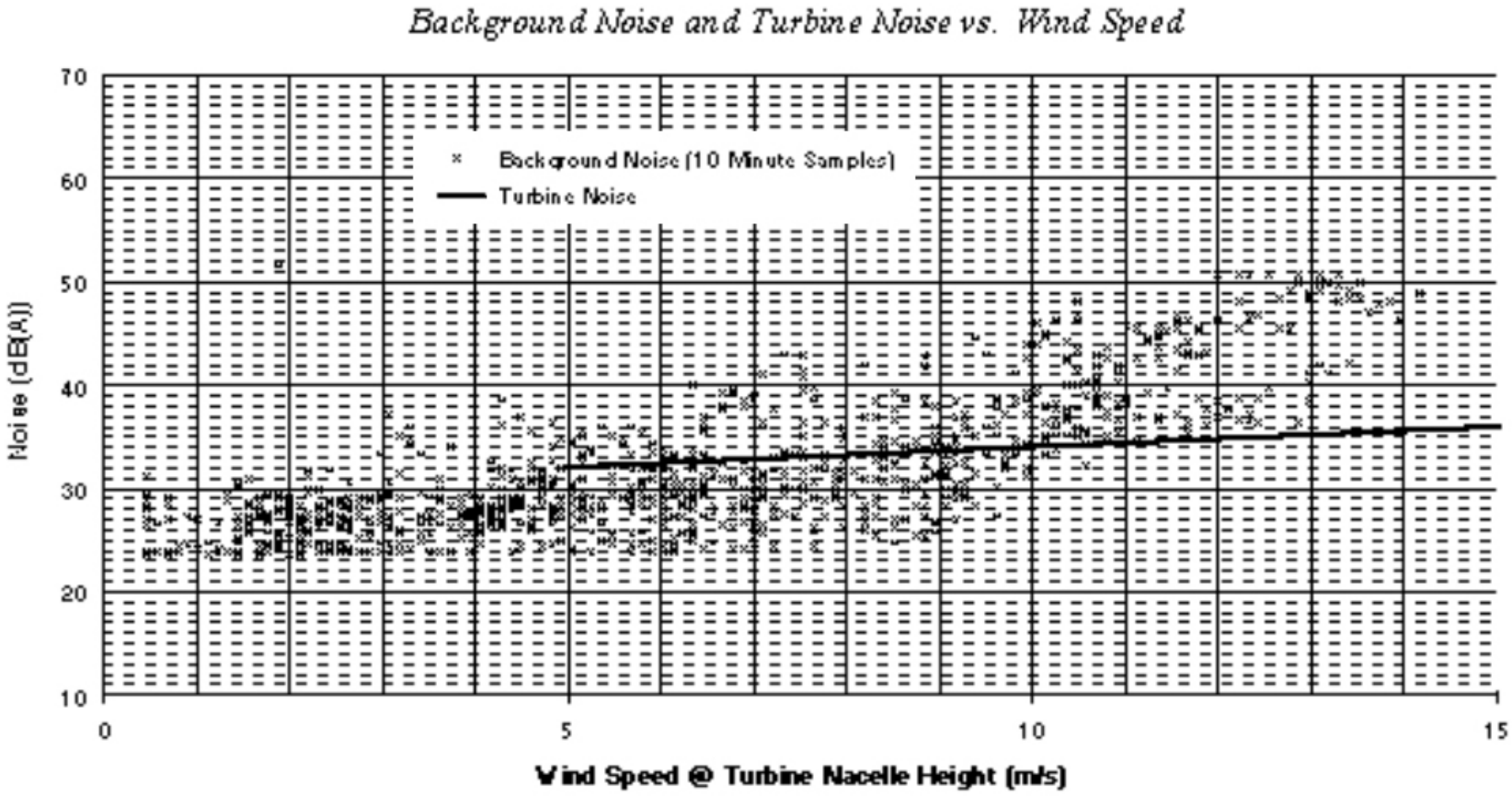
Source/ Activity	Noise level dB
• Threshold of hearing	0
• Rural night-time background	20-40
• Quiet bedroom	35
• Wind farm at 350m	35-45
• Car at 40mph at 100m	55
• Busy general office	60
• Truck at 30mph at 100m	65
• Pneumatic drill at 7m	95
• Jet aircraft at 250m	105
• Threshold of pain	140



The Scottish Office, Environment Department, Planning Advice Note,PAN 45, Annes A: Wind Power, A.27. Renewable Energy Technologies, August 1994

Noise vs. Wind Speed

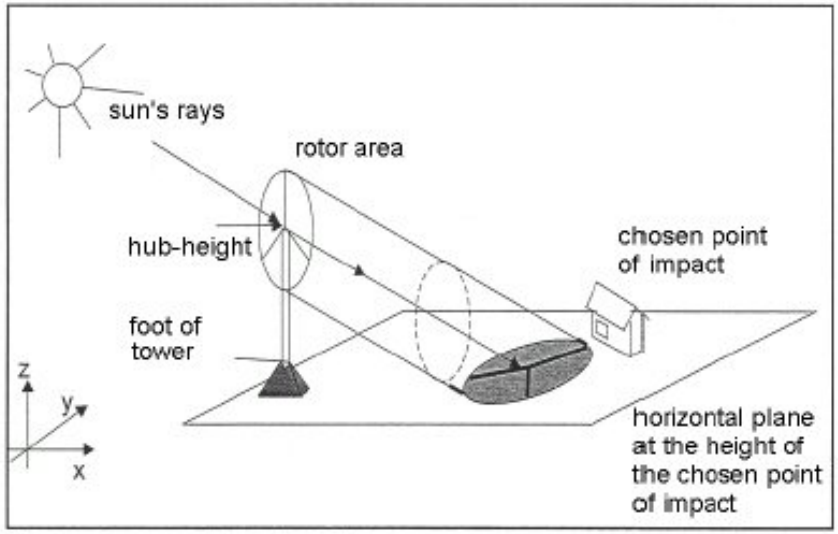
- A comparison of turbine noise and wind noise:



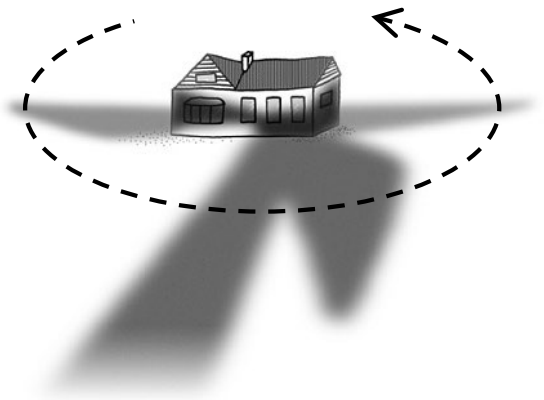
The Assessment & Rating of Noise from Wind Farms, The Working Group on Wind Turbine Noise, September 1996. www.bwea.com

Shadow Impact on Residences

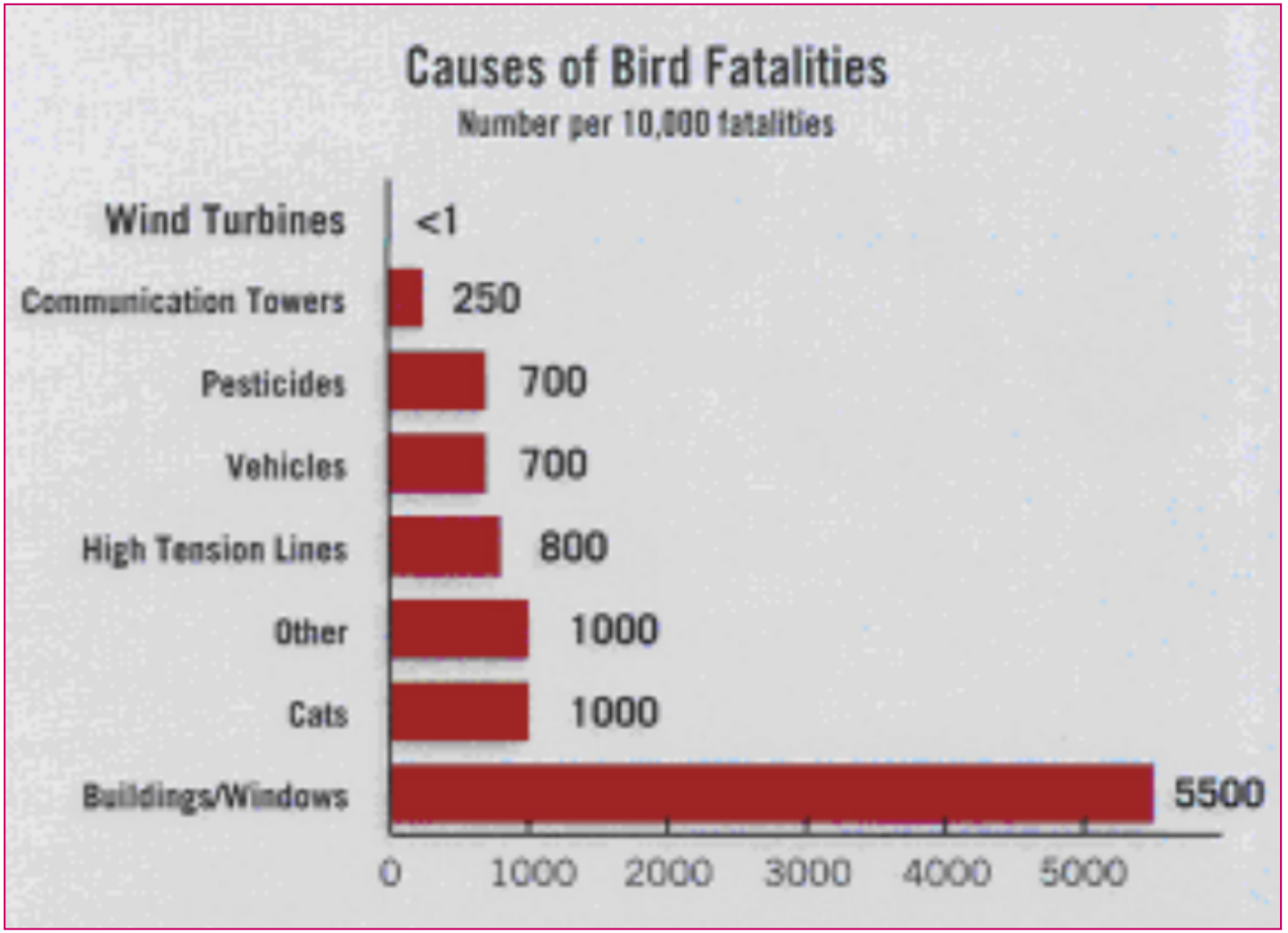
- Problem: moving shadow from blades can cause flicker in residences illuminated by daylight
- The effected area can be calculated from solar position data.
- Model guidelines (Germany)
  - 30 minutes per day
  - 30 hours per year



Shadow impact of a wind turbine

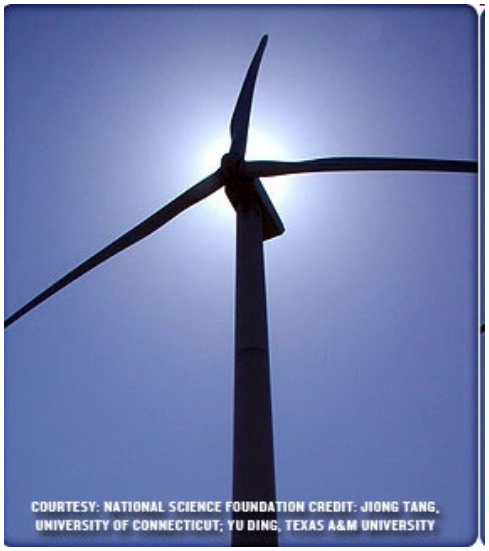


Risks to Wildlife



Erickson, et.al, 2002. Summary of Anthropogenic Causes of Bird Mortality

Community Wind Power



- School District in Wray Colorado:
- 900 kw turbine
- Cost = 1.8M
  - School district = $200k
  - State clean energy grant = $350k
  - Native Energy = $270k
    - Paid in advance for power over 20 years
- Covers districts electricity bill ($80k/year)
- Supplies 20% of towns electricity needs

Island Power

- Fox Island Wind Project, off the coast of Maine

- 3 1.5MW Turbines, $14.5M
- 200 Island customers, us about 50% of the power;
- Other 50% sold to power company via cable

www.foxislandswind.com

Wind Turbines for Remote Power

- El Hierro (Canary Islands) 11,000 residents
- Energy demand = 35Gwh; Available wind energy = 49GWh.
- 5 Enercon E-70 wind turbines, 11.5MW total, with pumped storage (using crater of extinct volcano).
- Renewable energy contribution = 54%

http://euanmearns.com/el-hierro-renewable-energy-project-september-2015-performance-review/

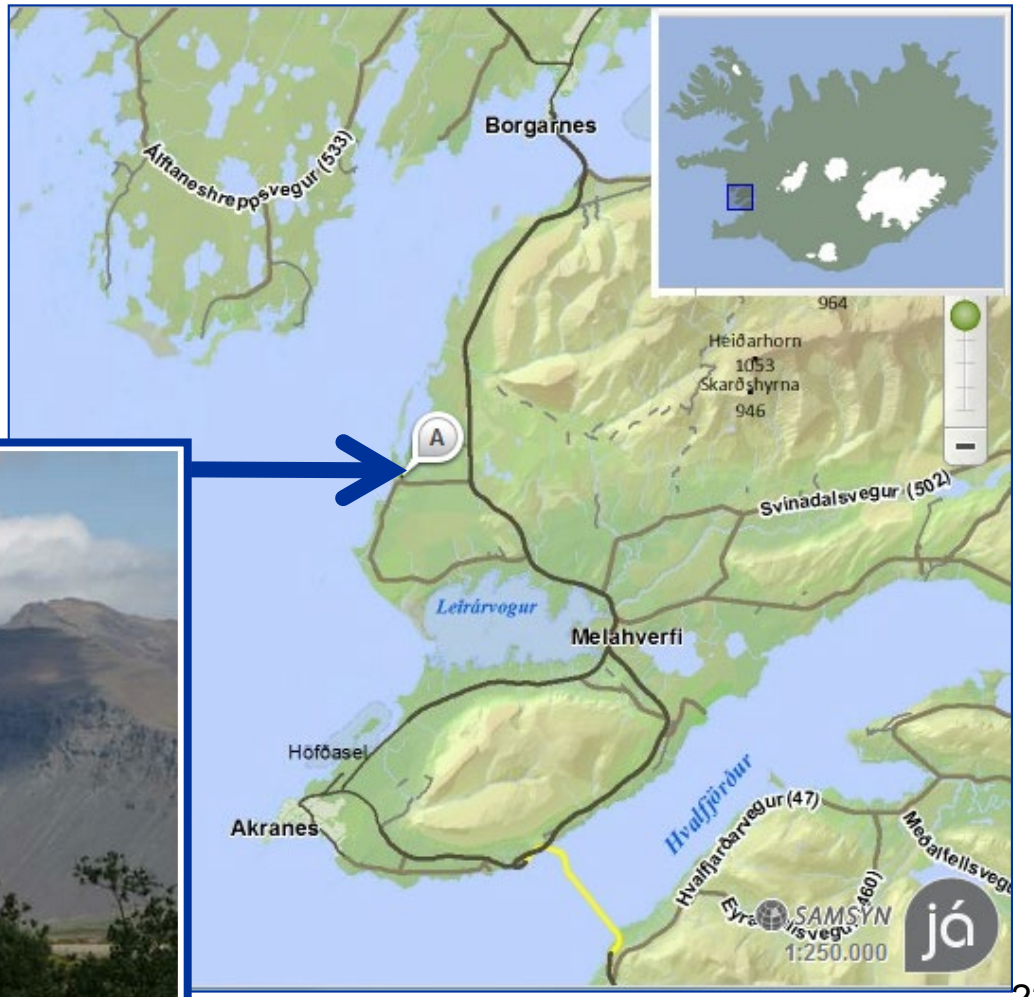
Remote Power in Antarctica

- First wind farm (two turbines) since 2003
- Three 330kw turbines, 990kw total
  - Serves McMurdo Station (US) and Scott Base (NZ)
  - Saves 240,000 gal of oil per year.

http://photolibrary.usap.gov

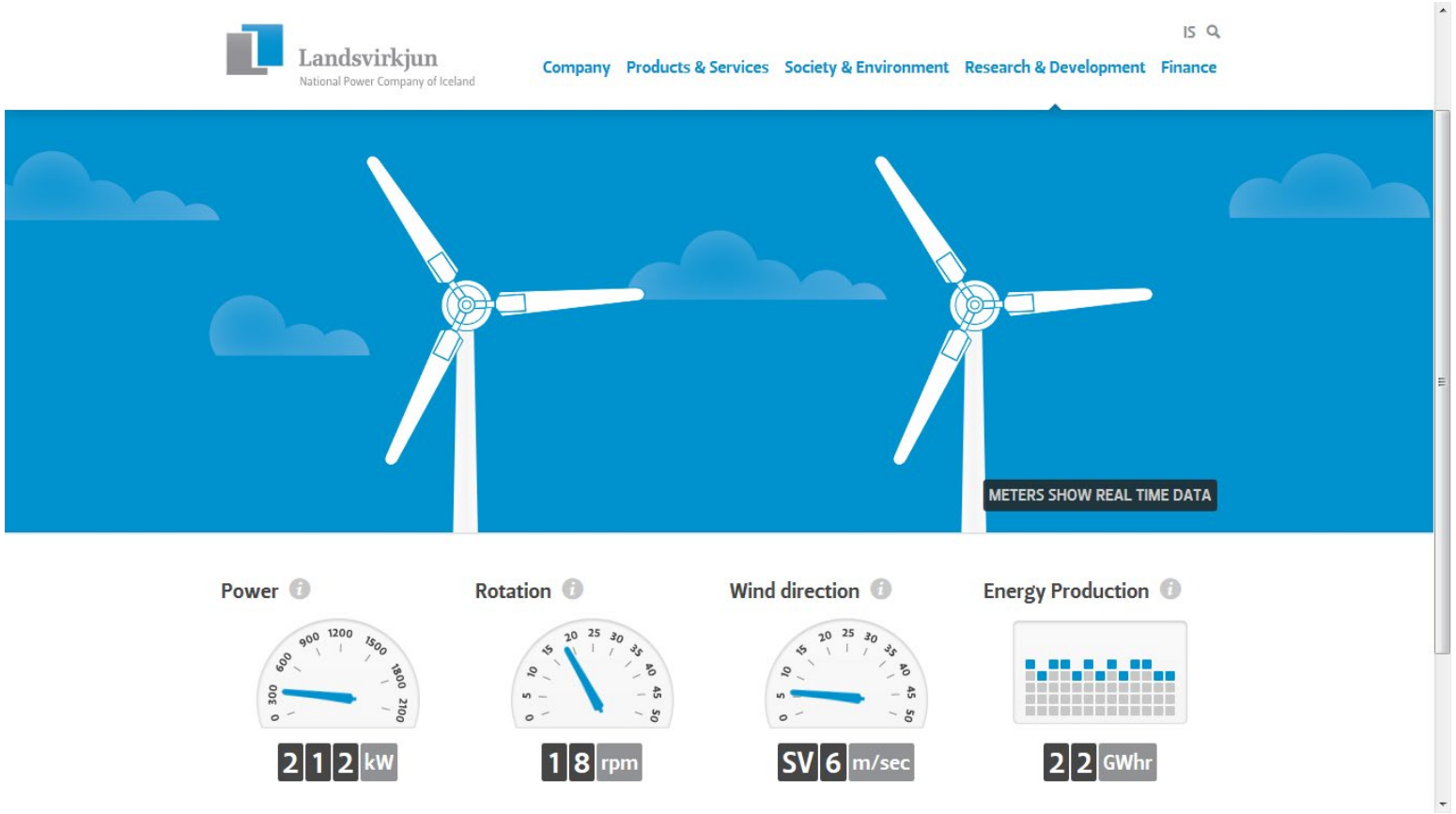
Wind Power in Iceland

- One 30kW turbine installed at Belgsholt
- Operational as of 16 Nov 2015
- www.belgsholt.is



Wind Turbines at Búrfell

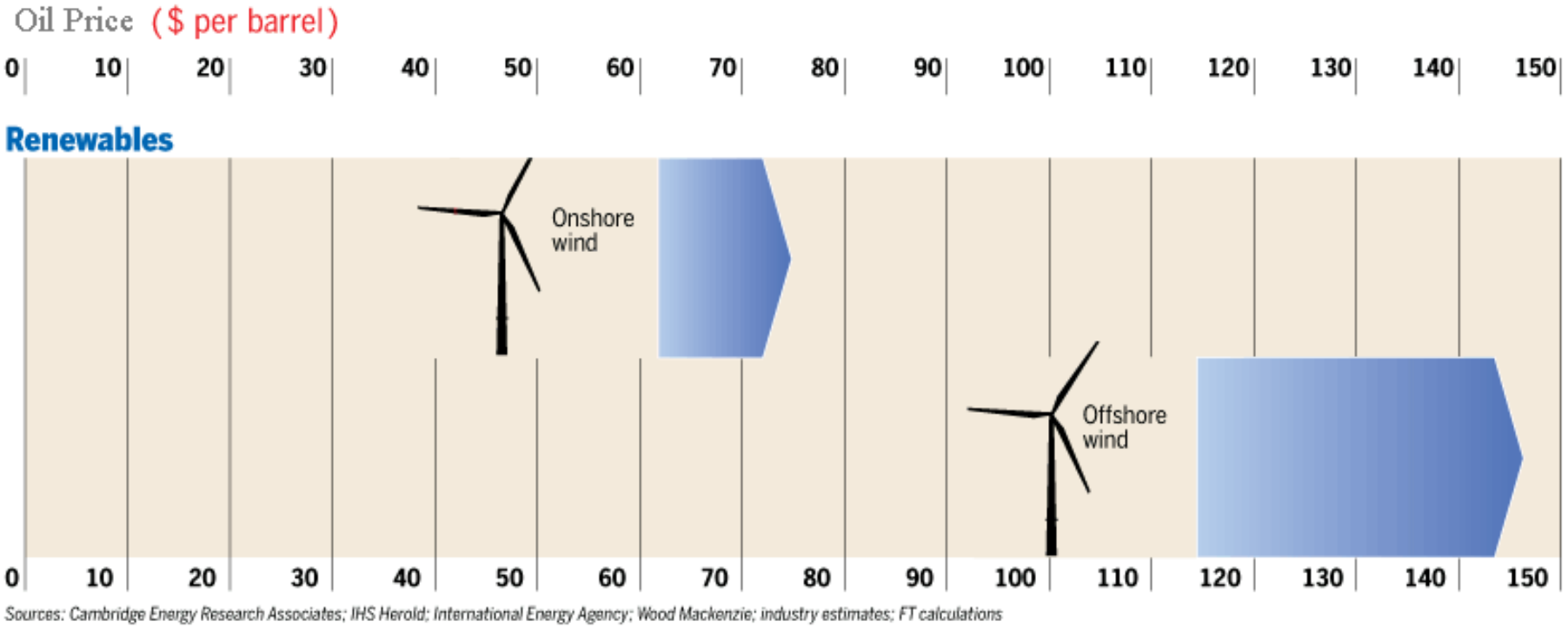
- Two Enercon E44 turbines



http://www.landsvirkjun.com/researchdevelopment/research/windpower/realtimedata/

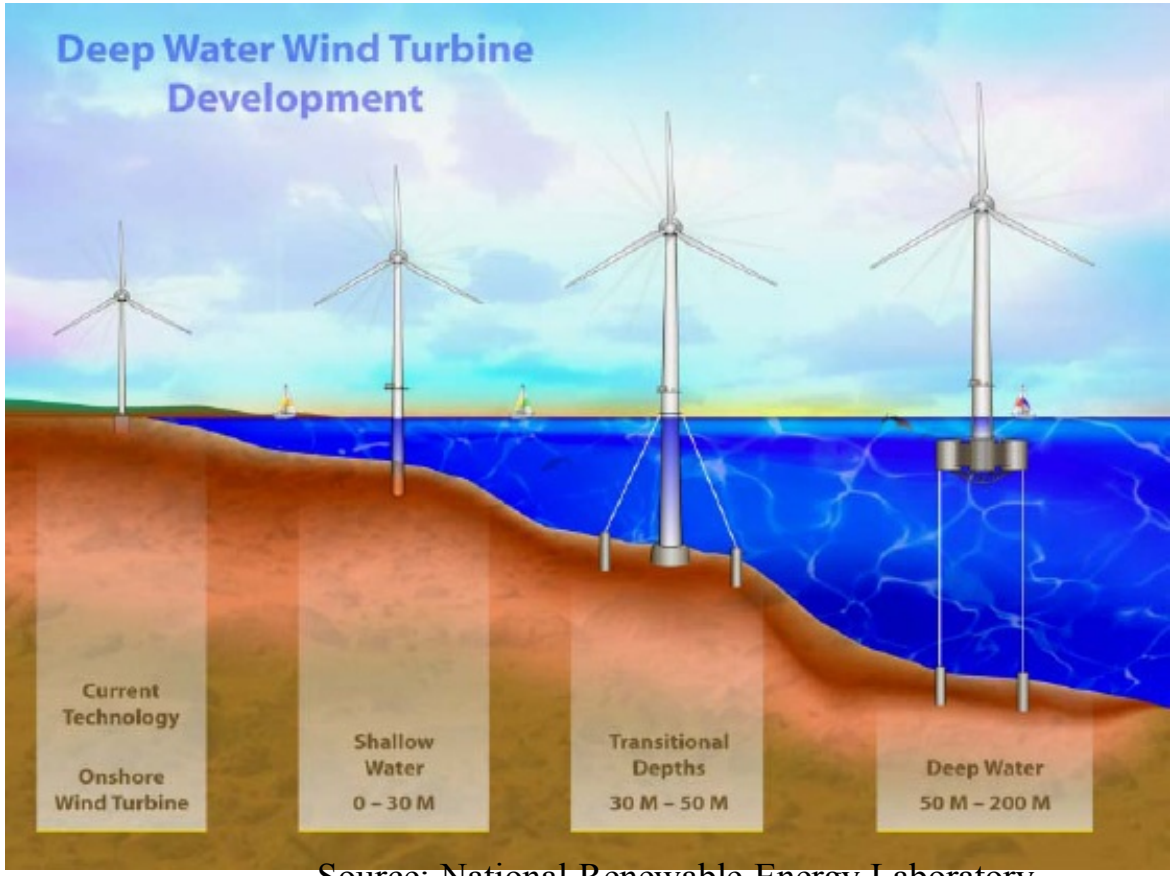
Economics

- Current installed costs (average, on shore) approx $2,120/kW
- Wholesale electricity price approx $50 – 80 /MWh



Offshore Wind

- Capacity factors tend to increase as turbines move further off-shore



Source: National Renewable Energy Laboratory

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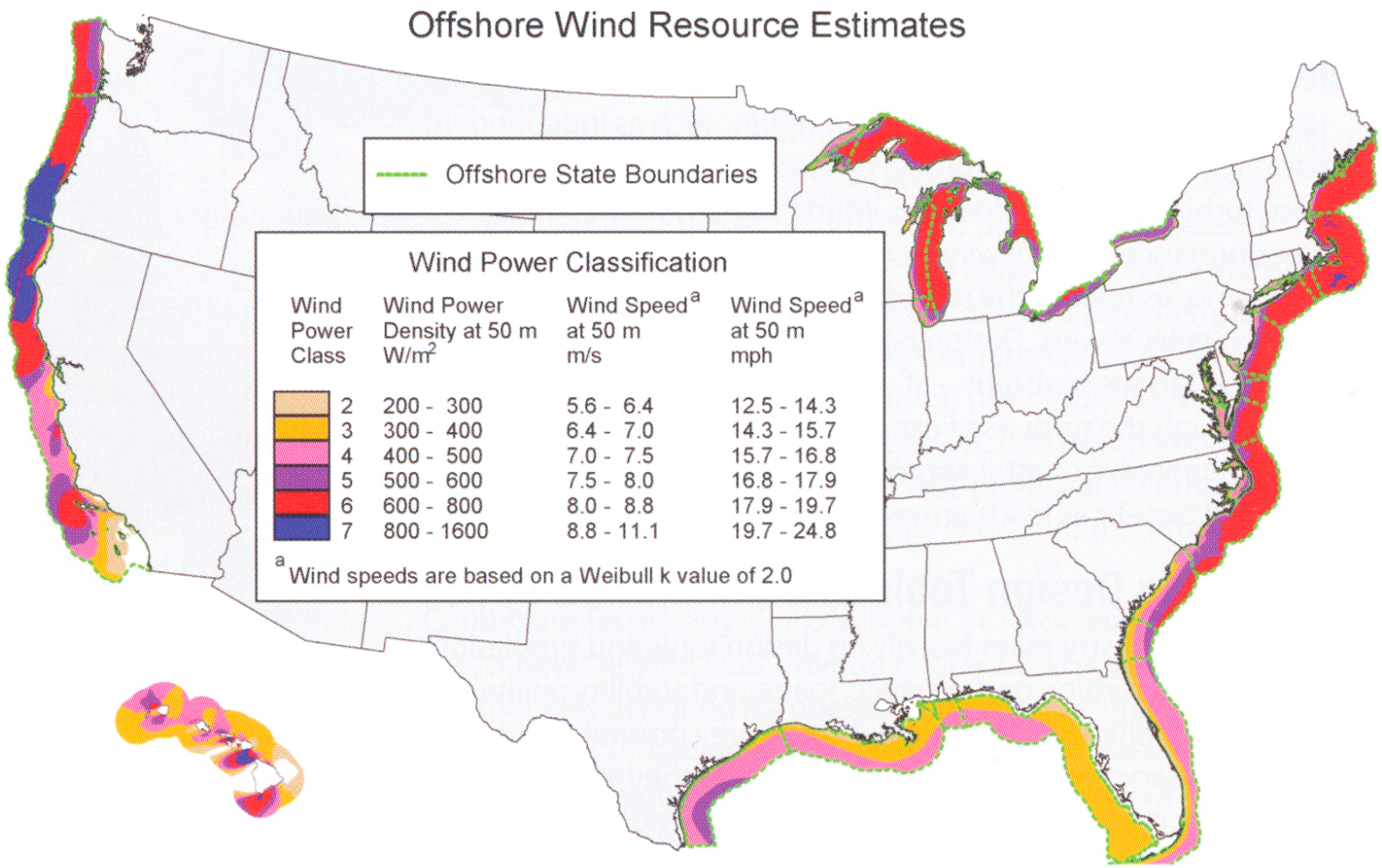
Offshore Wind Resources



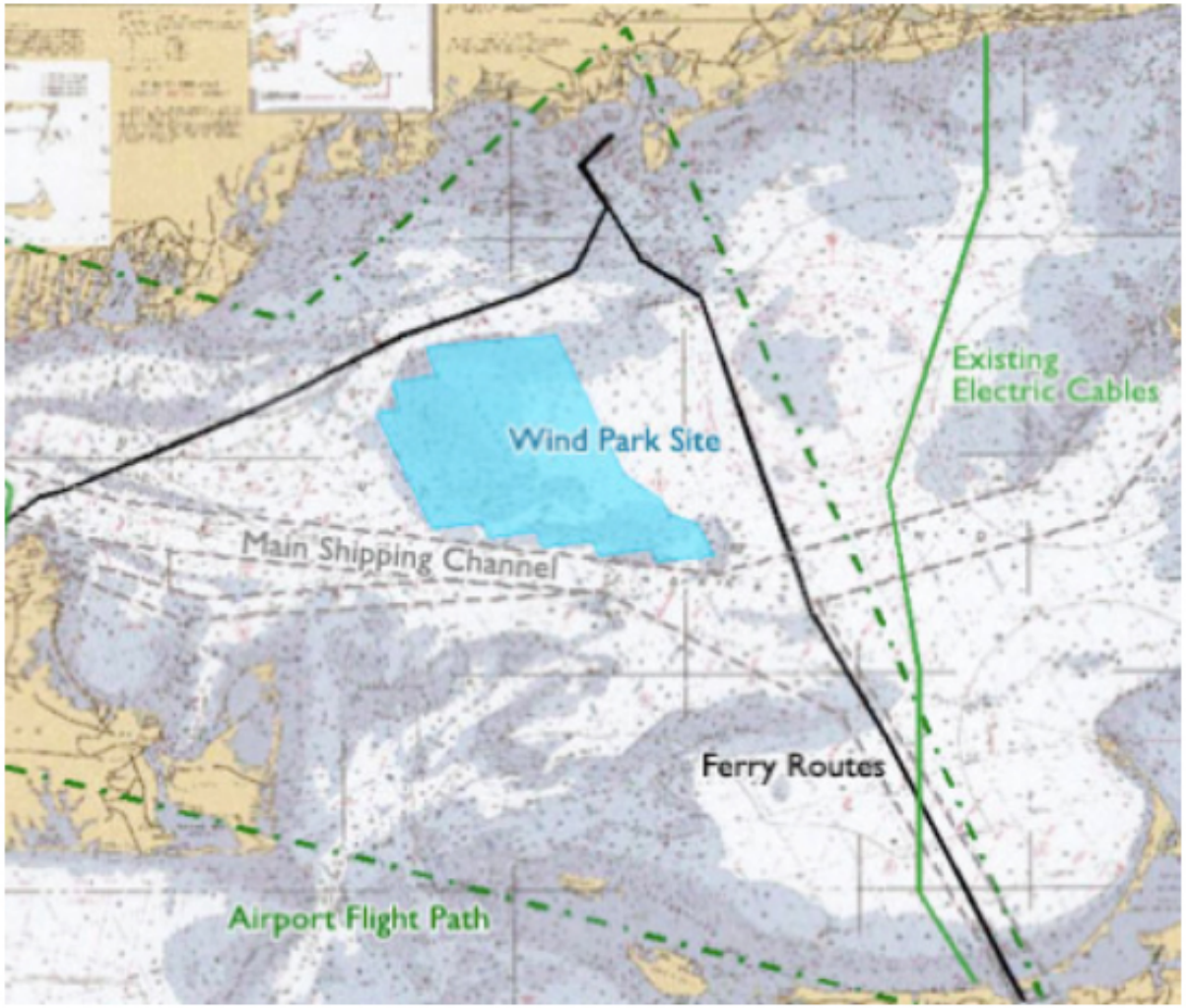
Twenty-six of the 28 coastal states have enough offshore wind resource to meet at least 20% of their electricity needs with wind energy.

Cape Wind Simulated View, Nantucket Sound, 6.5 miles Distant

- 130 Turbines, 468 MW
- Power approx 200,000 homes
- Cost: 2.62 billion
- CO_2 benefit – equivalent to taking 175,000 cars off the road.

Source: www.capewind.org

Capewind Site Map

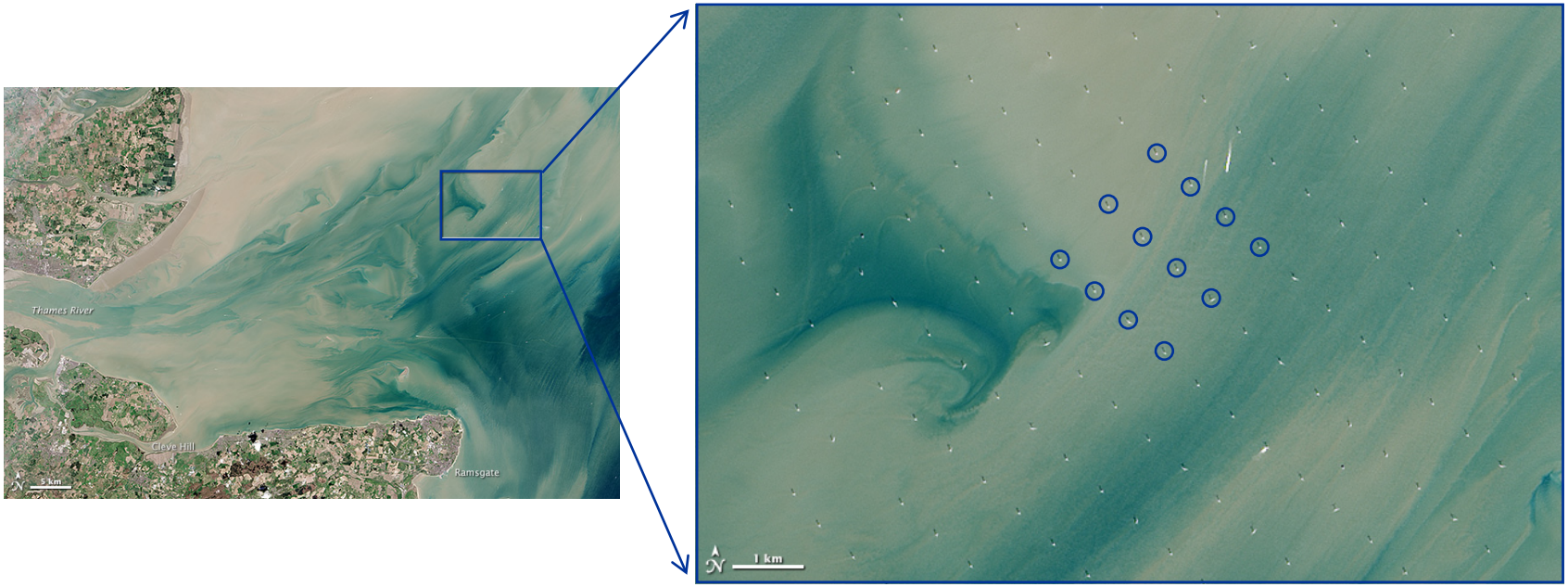


Lessons Learned from the CapeWind Project

- Engage stakeholders early
  - Coastal communities
- Involve utilities in the discussion from the beginning
  - Guarantee a market for the electricity
  - Integrated Resource Planning (IRP)
- Be up front about the costs (financial and environmental) and benefits
- Build on the positive experiences of European proejcts (ex: London Array Offshore Wind Farm)

London Array

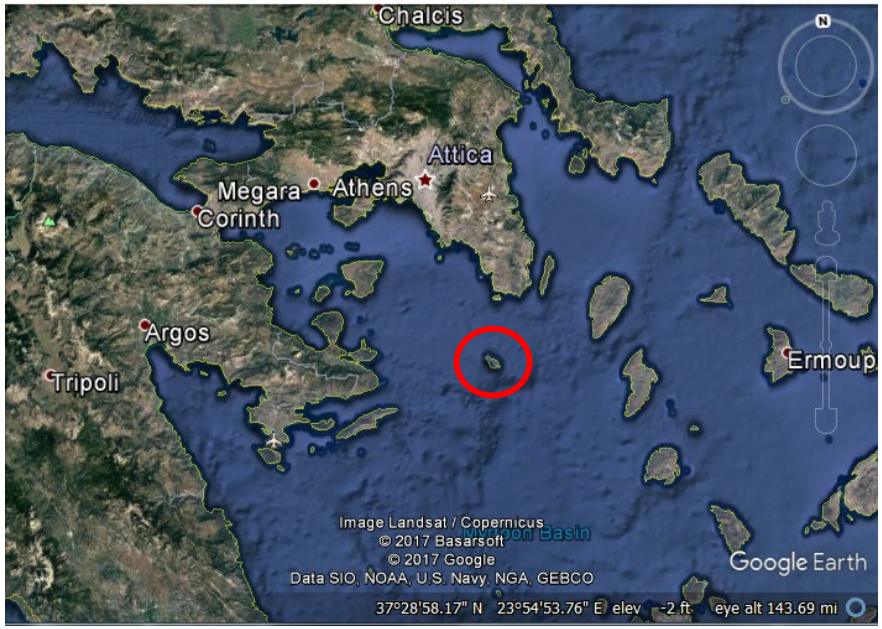
- 175 Siemens SWT3,6 = 630MW
- 120m dia, hub height = 147m
- Spacing 650m x 1200m
- Water depth up to 25m
- Average wind speed 9.8 m/s



http://earthobservatory.nasa.gov/IOTD/view.php?id=82844

Agios Georgios

- Uninhabited 4.3 km^2 island in the Aegean sea
- On-shore wind farm with off-shore wind characteristics
- 73.2 MW: 9 Vestas V90-3MW, 14 V112-3.3MW
- 40 km submarine cable, grid connected Aug 2016



37°28’26”N, 23°55’34”E

https://globalwindday.org/photocompetition/winners/