Scientific and Technological References

Energy Technology Indicators

Area: ELECTRICITY GENERATION

Sector: Wind Energy Technologies

A. State of the art

Advances in Research	**Achieved (facts)**	**Target**	**By (year)**
Largest wind turbine rated power:	4,5 MW	5-7 MW	2003/4
Largest blade: length	52,5 m	60 m	2003/4
Largest blade: weight	20 t	18 tons	2003/4
Blade weight over swept area	1,2 – 1,8 kg/m^2 (2,0kg/m^2)		
Top weight/rotor area	22 - 25 kg/m^2 (50 kg/m^2)		
Efficiency (best reported) (Cp max)	52%		
Load factor (low – high – average)	19 - 43 - 32 %		
Heat recovery or thermal efficiency	n.a.		
Blade heating system and heated components	….		
Specific additional cost for cold climate and mountainous regions (eg. for heating elements)	5% on investment cost (or in €/kW)		

Technology related indicators (for demo and commercially available units)		
Type of wind turbines	> 99% Horizontal axis, < 1% Vertical or others	
Number of blades	3 (2-bladed <1%)	
Blade materials	glass-fibre reinforced plastics, wood-epoxy, carbon fibre reinforced plastics	
Commercial produced size/range	0.03 to 2.5 MW	
Hub Height:	20 – 120 m, 140m in design	
Diameter range:	10 – 90 m, 115 m in design	
Commercially produced blade: length range	5 – 42 m	
Commercially produced blade: weight range	0.5 –16 tons	
Blade weight over swept area	1,2 – 1,8 kg/m^2	
Nacelle: mass range (included blades)	1 – 140 tons	
Top weight/rotor area	7 - 25 kg/m^2 (50 kg/m^2)	
Tower: weight range	10 - 220 t	
Operational temperature	-40° C - +55° C	
Largest wind farm (in operation):	280 MW King Mountain, Texas	
Largest offshore wind farm (in operation):	40 MW	200 MW by 2003

Performance indicators (for demo and commercially available units)		
Efficiency (commonly reported) (electric power)	38 - 48 %	
Overall efficiency (Average Cp over year)	30 - 35 %	
Specific energy production (best performance)	1600 - 2000 kWh/m²/a	(nb: rotor area)
Specific energy production (common performance)	900 - 1400 kWh/m²/a	(nb: rotor area)
Life time operational hours per wind turbine (at production)	120.000 –140.000 h	140.000 h by 2005
Economic life time	10 - 20 years	
Design life time	20 years	
Time needed to compensate for manufacturing energy - at max. power: ~ 1 month, at average power: 3 – 6 m		
Technical availability : best reported	> 99%	
Technical availability : average	96 - 99 % (98% is typical)	
Technical non-availability: average	1 - 4 %	
Capacity factor	20 – 30 %	
Equivalent full load hours	1.800 – 3.400 hours	

Average operational hours/year (at production stage)	6.000 – 7.000 hours/year			
Economic indicators				
a. on land				
Typical turn-key investment costs:	770 - 1000 €/kW	600 - 800 €/kW	2010	
Electricity production at (kWh manufacturing cost):	0,04 – 0,07 €/kWh	< 0,035 €/kWh	2008	
Cost wind turbine including tower, excluding transformer	550 - 880 €/kW			
Typical fuel cost range	n.a.			
Turn-key cost per m^2 of swept area	350 - 400 €/m^2	260 - 300 €/m^2 by 2010		
Typical operating and maintenance[1] (on land)	1,5 – 3,5%			
Typical pay-back time on investment	5 - 10 years (based on 5% for 20 years)			
Decommissioning cost	12 - 100 €/kW			
Typical land requirements (free space)	4 - 5000 m²/unit	(nb: land area)		
Typical land requirements (free space)	30 – 60 m²/kW			
Typical land requirements (foundation - footprint)	200 - 400 m²/unit	(nb: land area)		
Land use factor (using foundation - footprint)	14500-29000 kWh/m^2/a	(nb: land area)		
Typical time frame between order and industrial operation -	without permits: 3 - 12 m (permits available)			
	with permits: 6 – >24 months (when required)			
b. offshore				
Typical turn-key investment costs (10 - 30 km from shore)	1170 - 2000 €/kW	1000 - 1300 €/kW	2010	
Electricity production cost :	0,07 – 0,12 €/kWh	< 0,05 €/kWh	2007-8	
Typical fuel cost range	n.a.			
Typical operating and maintenance[1] (offshore, 30 km from shore):	2 - 3.5%			
Typical pay-back time on investment (offshore)	10 - 15 years (but increased life time)			
Decommissioning cost (offshore)	75 - 125 €/kW (est)			
Typical time frame between order and industrial operation -	without permits: 6 - 24 months (permits available)			
	with permits: 24 - >48 months (when required)			
Typical externalities (based on EXTERNE study)	0,05 – 0,25 c€/kWh			
Market size and industry related indicators				
Total EU installed capacity:	20.461 MW (17.319 MW end 2001)			
Total world-wide installed capacity:	> 27.650 MW corresponding to ~54 TWh/a			
Actual installation rate:	EU: ~ 4.400 MW/a			
	World-wide: ~6.500 MW/a			
Average wind turbine size:	980 kW in 2001	1500 kW by 2010		
(all turbines>0.03 MW included)	900 kW in 2000			
	780 kW in 1999			
	700 kW in 1998			
Manufacturing capacity (approx.)	4100 – 4500 units/a			
Manufacturing capacity (approx.)	6.500 MW/a (7.800 by 2006) 8.300 MW/a by 2010			
Targets 2010: EWEA target 230 GW of which 60 GW offshore producing ~564 TWh/a				
IEA estimation : 80 GW				
Targets 2020: EWEA target 1260 GW of which 150 GW offshore producing ~3093 TWh/a				
IEA estimation : 200 GW				
Social indicators				
Manufacturing direct employment	17 jobs/a/unit (expected to fall to ~ 13 by 2010)			
Total employment	22 jobs/MW installed (17 in manufacturing;			
	5 in installation jobs/a/unit)			
Probability of event (accident) based on LCA	…..			
Severity of consequences of event	…..			
Human risk (probability of event x severity of event)	…..			
Environmental and other specific indicators				
Source noise levels	95 - 105 dB(A)			
System's overall recyclability	65 - 70 %			
Cost of system's recyclability	…. €/kW			

[1] ie the percentage of the average O&M annual expenses – including provisions for big repairs – and excluding fuel costs of the initial investment cost

Manufacture process:	
Waste produced	~ 10 %
Recyclability of waste	0 %
Manufacture related toxicity involved	polystyrene, epoxy
Cost of recyclability	…. €/kW
Operation process :	
recyclability of wastes produced	~80% (incl. replac. parts with lifespan <20 years)
involved toxicity of wastes	….
Cost of recyclability	…. €/kW

Kyoto: wind energy alone is expected to lead to 3,2% less CO_2 by 2010.

B. Headline indicators

Technical or scientific bottlenecks or impediments

- electricity production cost reduction through design optimisation (to increase competitiveness)
- size and availability increase for offshore applications (to increase rentability of standard costs)
- sound power level reduction (to reduce distance from close-by habitats and increase public acceptability)
- size, aerodynamics and aeroelasticity of blades (to capture more wind)
- overall nacelle weight reduction (to reduce mass and increase efficiency)
- increase of the degree of system's overall recyclability
- develop reliable output prediction tools and reduce uncertainties
- there is not a fully quantified value system of wind electricity

Headline indicators	**actual**	**target**	**limited by**	**by**
Largest wind turbine rated power onshore	4.5 MW	5 MW	components' development	2003/4
Wind turbine rated power offshore	2 MW	5-7 MW	development, authorisations	2005-7
Blade length	52,5 m	80 m	lack of experience for very large composite structures	2010
Overall nacelle weight/rotor area	22-25 kg/m^2	< 18 kg/m^2	components, loads	2010
Sound power level	95-105 dB(A)	<90 dB(A) for >2MW (on shore)		2010
Turn-key cost per kW installed (onshore)	770-1000 €/kW	600-800 €/kW		2010
(offshore)	1170-2000 €/kW	1000-1300 €/kW		2010
Cost per m² of swept area (FOB price)	350-400 €/m^2	260-300 €/m^2		2010
Electricity cost (kWh manufacturing):	0,04 – 0,07 €/kWh	< 0,027 €/kWh (2010), < 0,018 €/kWh		2020

C. Further R&D work focus (national and/or FP6)

Technology Development:

- from classical drive trains to direct driver
- introduction of power electronics
- market share of variable speed increases quickly
- from fixed blade pitch angle to variable pitch angle
- offshore:
  - grid integration
  - dedicated wind turbines to reduce costs
  - transport
  - installation methods
  - load conditions
  - reliability
  - forecasting extreme wind, wave and icing conditions
- sound power level reduction
- blade heating and heating elements
- geometric and aero-elastic stability for large rotors
- short term power output predictions
- new blade materials
- condition monitoring (especially offshore)
- validation of standards
- storage techniques
- better models for aerodynamics/aeroelasticity
- new intelligent structures/materials/recycling
- mechanical design

- electrical design
- wind farm integration
- update of wind resource including implementation constraints
- standards related R&D wind conditions
- optimised statistics & logistics (transport O&M etc)
- materials; lack of standards
- heated ice free components (wind gauges, tip brakes, brakes etc)
- better models (of turbines) for cold climate operation

D. Monitoring

Non-technology related bottlenecks/Actions that could facilitate market penetration:

- noise reduction and related legislation
- NIMBY syndrome
- visual impact, sea collision risk
- impact studies on Flora and Fauna
- conflicts of interest
- planning issues and authorisations
- good demonstration of successful operation of wind turbines under heavy icing conditions

Other issues

- Overall wind energy share in EU : 1,1 to 1,2% of EU electricity consumption (data of 2001)
  0.5 – 0.6 % of EU electricity consumption (data of 1999)

- **Wind Installed capacity**

	Autumn 2002		**by 2010**
D	10.650		25.000 MW (offshore)
ES	4.079		8.900 MW
DK	2.515		by 2030:5.500MW (offshore 4000 MW)
I	755		
NL	622		
UK	613	(10/2002)	… MW of which 500 MW Scottish Power
S	318	(10/2002)	
GR	290	(10/2002)	
P	171	(10/2002)	
FR	131	(10/2002)	1.500 MW (offshore) 5-10.000 MW
IRL	129	(10/2002)	
AU	100		
SF	39		
B	34		
L	15	(10/2002)	
Total (a)	**20.461**	**MW**	
N	97		
PL	29		
TK	19		
CZ	12		
CH	5		
RO	1		
Total (b)	**163**	**MW**	**(end of 2001: 78 MW)**

- **increase <u>on annual basis</u>: > 35% between end 2000 and end of 2001(17.319 MW)**
- **current increase on annual basis : > 35 % between 2001 and 2002**

USA	4.245	MW		
INDIA	1.456	MW		
CHINA	406	MW		
JAPAN	357	MW		
CANADA	214	MW	10.000 MW (CanWEA target) by	2010
AUSTRALIA	71	MW		
EGYPT	69	MW		
MOROCCO	54	MW		

NEW ZEALAND	35	MW		target 5.000 MW by 2010
ISRAEL	8	MW		
Other countries	117	MW		
Total (c)	**7.032**	**MW**	**(end 2001)**	

Total current world-wide (a+b+c) : >27.656 MW (end of 2001: 24.927 MW)

EWEA Targets: Windforce-12 : 12% of world's electricity from wind power by 2020
i.e. 100 GW in Europe by 2010
230 GW world-wide by 2010
1.260 GW world-wide by 2020 worth € 133 billion

- At present about 80% of all installed power (= 27.650 MW) is installed in 5 countries: D, USA, DK, E and India
- 74% of the total wind capacity by the end of 2001 was installed in Europe
- Over 80% of the global wind turbine market is supplied by European companies
- Wind energy now counts for 4% of national electricity consumption in D and 18 % in DK (2002 data).
- DK: 6.525 wind turbines of total 2.456 MW produce about 17% of DK electricity consumption (end of 2001) ; actual annual growth rate 44%: target by 2005: to reach 30% of DK electricity consumption.
- Leading countries : D, E, DK > USA > India >> JPN
- There are over 55.000 wind turbines installed world-wide:
  - Wind power already meet the electricity needs of around 14 million households, more than 35 million people.
  - Wind farms across America now generate about 10 billion-kilowatt hours annually, enough to power one million households.
- Market penetration rate at EU 4.400 MW/a and World-wide at 6.500 MW/a (2001)
- During the last 5 years the annual growth rate was above 30%.
- In the year 2000 the average new turbine installed in Germany rose above 1.000 kW for the first time.
- Rates and Trends from 1985 to 2000.
  - The average hub-height rose from 28m to 55m.
  - The average installed capacity from < 150kW to 980kW.
  - The installed swept area per kW from 1,7 m^2/kW to 2,5 m^2/kW.
- Job creation**:** 30.000 jobs within last 10 year.
  - Globally, the industry employs around 70.000 people, is worth more than € 4,5 billion and is growing at a rate of almost 40% per year.
  - A total of 1.475 million jobs will have been created around the world by 2020 in manufacture, installation and other work associated with the industry.
- Annual CO_2 reductions rising from 32,7 million tonnes CO_2 in 2001.
- On the assumption that the average value for CO_2 saved by switching to wind power is 600 t/GWh, the annual saving will be 1.856 million t of CO_2 by 2020 and 4.800 million tonnes by 2040. The cumulative savings would be 11.768 million tonnes of CO_2 by 2020 and 86.469 million tonnes by 2040.
- Price wind electricity 0.025 – 0.05 €/kWh (targets 2005)
  - By 2020 it is expected to have reduced to 1,89 € cents/kWh, with an installation cost of 402,3 €/kW by 2020 – a substantial reduction of 41% compared with today.
- The variability of the wind has produced far fewer problems for electricity grid management than sceptics had anticipated. On windy winter nights, the wind sometimes exceeds 100% of power generation in the northern part of Germany and in the western part of Denmark, for example, but the grid operators have managed it successfully.
- The world's wind resources are estimated to be 53.000 TWh/year, whilst the world's electricity consumption is predicted to rise to 25.818 TWh/year by 2020. The total available global wind resource that is technically recoverable is therefore more than twice as large as the projection for the world's entire electricity demand.

- By the year 2020, based on Wind Force 12 the wind industry can deliver :
  - 12% of global electricity demand, assuming that global demand doubles by 2020
  - installed capacity of 1,261 GW, generating 3,093 TWh equivalent to the current electricity use of all Europe
  - cumulative CO_2 savings of 11,768 million tons

- The annual investment required to achieve the deployment of wind energy outlined starts at € 4,68 billion in 2001 and increases to a peak of € 60,3 billion by 2020. The total investment needed to reach a level of 1.200 GW by 2020 is estimated at € 565,74 billion over the whole period. This is a very large figure, but it can be compared with the annual investment in the power sector during the 1990s of € 153 – 180 billion. The future investment required globally has also been broken down on a regional basis.

- The goal of the German government is to see up to 25.000 MW of wind parks in the sea by 2025. This would satisfy roughly 15% of the country's electricity demand.

- Beyond 2020, development continues with an annual installation rate of 150.000 MW. Market penetration is expected to follow a typical S-curve, with a "saturation" point reached in some 30-40 years, when a global level of roughly 3.000 GW of wind energy will be maintained. Over time, an increasing share of new capacity is used for replacement of old wind power plant. This assumes a 20 year average lifetime for a wind turbine, requiring replacement of 5% of capacity each year.

- Standards on Wind : IEC, CENELEC, GAP and EU-national standards

- Recommended practices on Wind: World bank, IEA, EU and EU- nationally funded projects

- Regulations for Wind technology: ….

LITERATURE

(in addition to the September 2002 version)

EWEA *briefing and press release*, 13 November 2002.

ISET, *Wind energy report Germany 2002, Annual evaluation of WMEP*. Kassel, October 2002