Open Lecture

Wind Energy

science, technology, economy, culture & society

Friday, 3rd of November 2017 (holiday), 11:30 - 12:40

Speaker: Prof. em. Dr. Izumi Ushiyama, Founder of Japanese Wind Energy Association (JWEA), Chair of the Board and Professor emeritus, Ashikaga Institute of Technology
Language: English*
Date and time: Friday, 3rd of November (holiday), 11:30 - 12:40.
Place: Science Hall of International Christian University in Mitaka, Room N-220.
Map: Building No. 4 on this campus map: https://www.icu.ac.jp/en/about/campus/index.html
Trafic access: https://www.icu.ac.jp/en/about/access/index.html
Admission: Free of charge.
Reservation: Not needed.
Inquiries: Eckhard Hitzer (hitzer@icu.ac.jp)
*** Notes:** Questions in Japanese are welcome. Everybody is welcome, especially students. Please enter the venue from the 2nd floor.

Contents:

1. **Present status of global environmental issue and renewable energy.**
2. **Wind as a natural phenomenon and energy source.**
3. **Wind culture of European countries.**
4. **History of wind energy utilization; windmills and wind turbines.**
5. **Origin of wind power generation and a riddle of Betz limit.**
6. **Aerodynamics and performance of wind turbines.**
7. **Economics of wind energy and wind energy utilization.**
8. **Future prospect of wind energy utilization.**

Short biography: Izumi Ushiyama is a renewable energy researcher specialized in wind energy. He has graduated from doctoral course of engineering at Sophia University, Tokyo in 1971. He has been working for Ashikaga Institute of Technology since 1971. Promoted to Associate Professor in 1974 and Professor in 1985, and from 2016 to present he is the Chair of The Board and Professor emeritus at AIT. From 2002 to 2006, he was a Chairman of Japan Wind Energy Association. From 2006 to 2008, he was also a Chairman of Japan Solar Energy Society. Published more than 150 papers and more than 20 books and received nine awards including The Pioneer Prize of World Renewable Energy Network and The Honorary Award of World Wind Energy Association 2016.

Image: https://commons.wikimedia.org/wiki/File:Hywind.jpg

ICU 2017 Nov. 3

Wind Energy

～science, technology, economy, culture and society～

Izumi USHIYAMA

Ashikaga Institute of Technology

ushiyama@ashitech.ac.jp

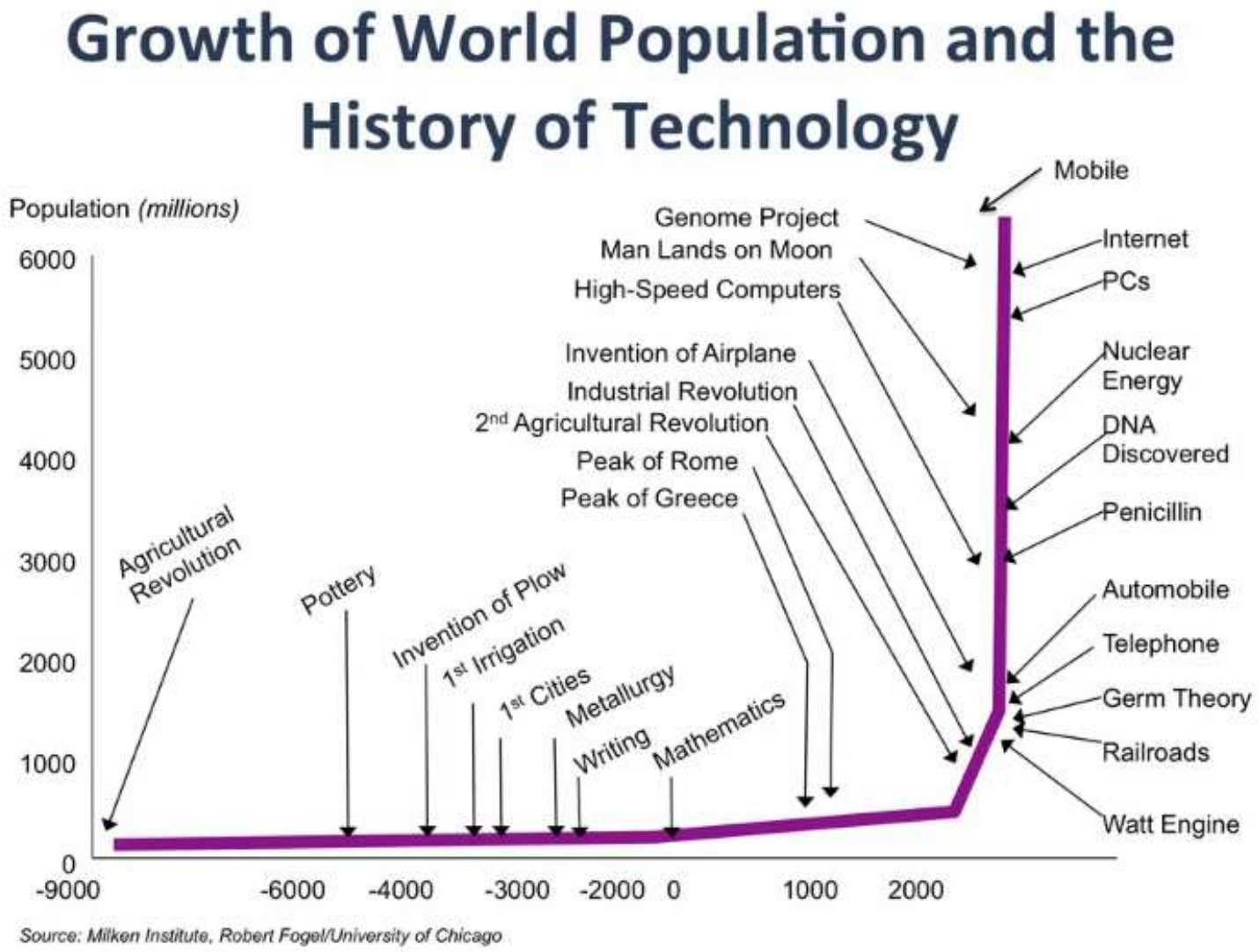
CONTENTS

Big Issues in 21 Century

- ✓ Population
- ✓ Foods
- ✓ Environment
- ✓ Energy
- ✓ Water

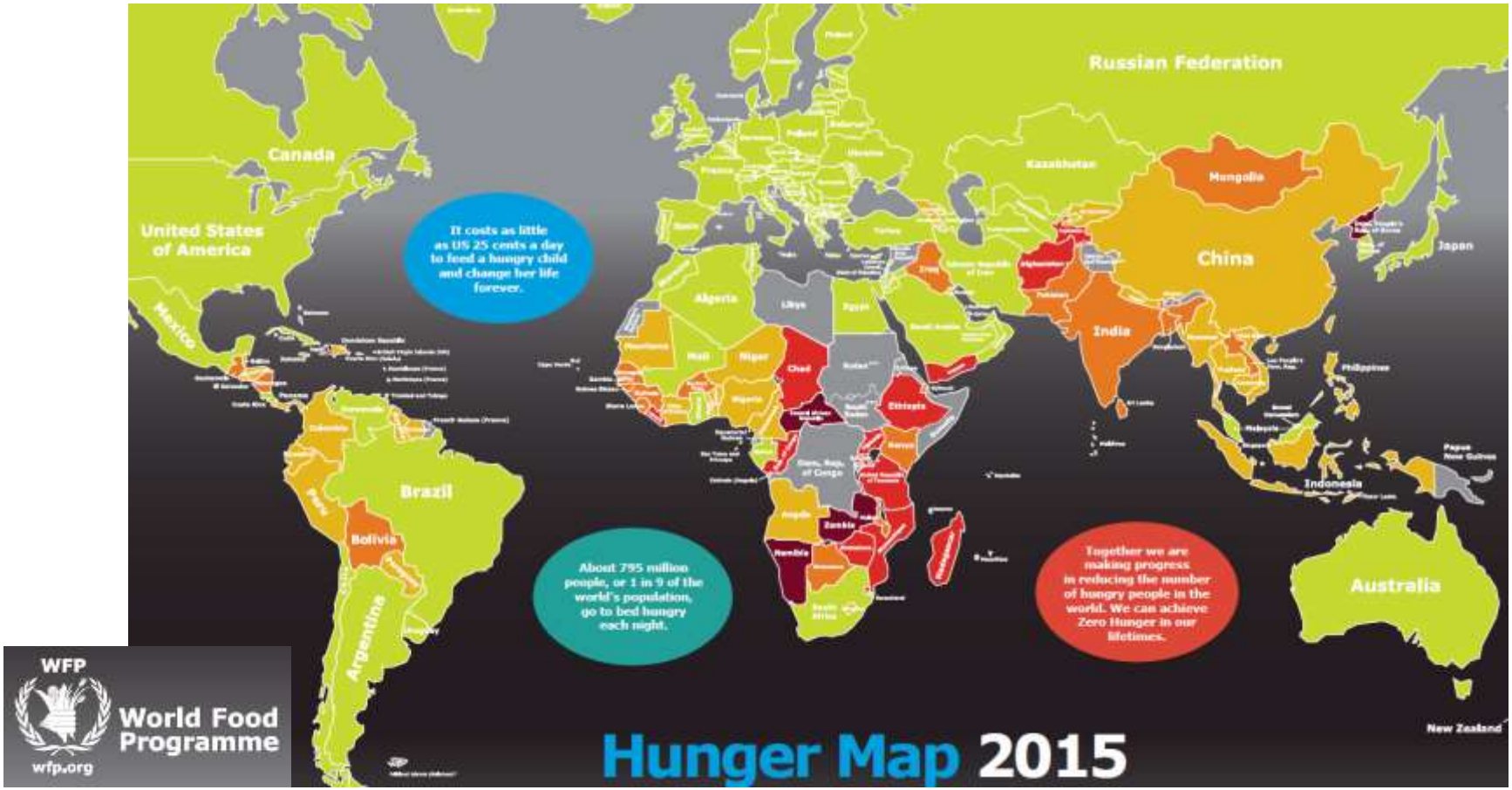
Population Explosion

World population: 7,349 millions @ 2015



http://www.divergingmarkets.com/2013/05/24/chart-of-the-day-world-population-growth-vs-history-of-technology/

World HUNGER MAP 2015



Prevalence of undernourishment in the population (percent) in 2014-16

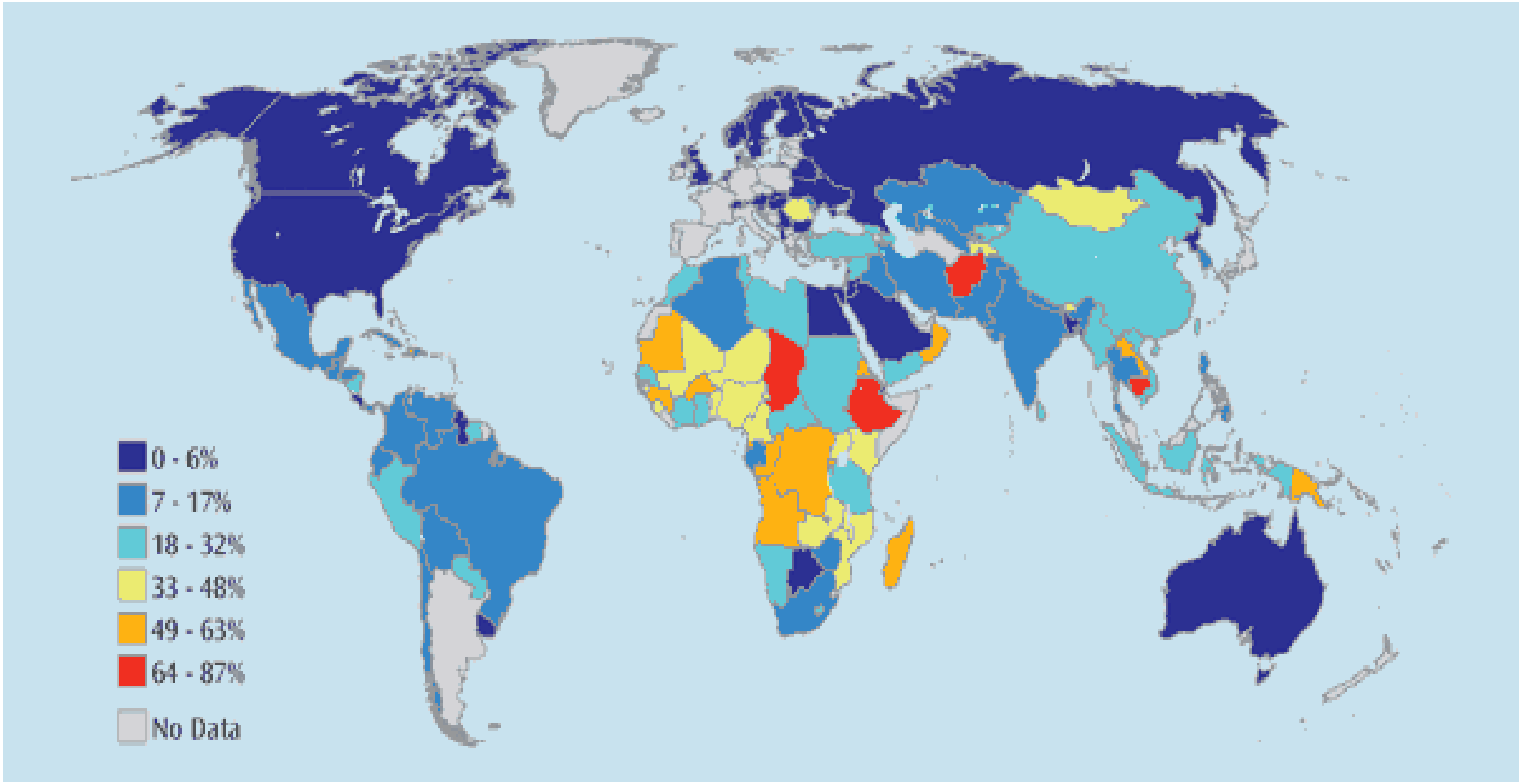
<5%	5-14,9%	15-24,9%	25-34,9%	35% and over	Missing or insufficient data
Very low	Moderately low	Moderately high	High	Very high	

From Africa and Asia to Latin America and the Near East, there are 795 million people (10% of the world population) in the world who do not get enough food to lead a normal, active life.

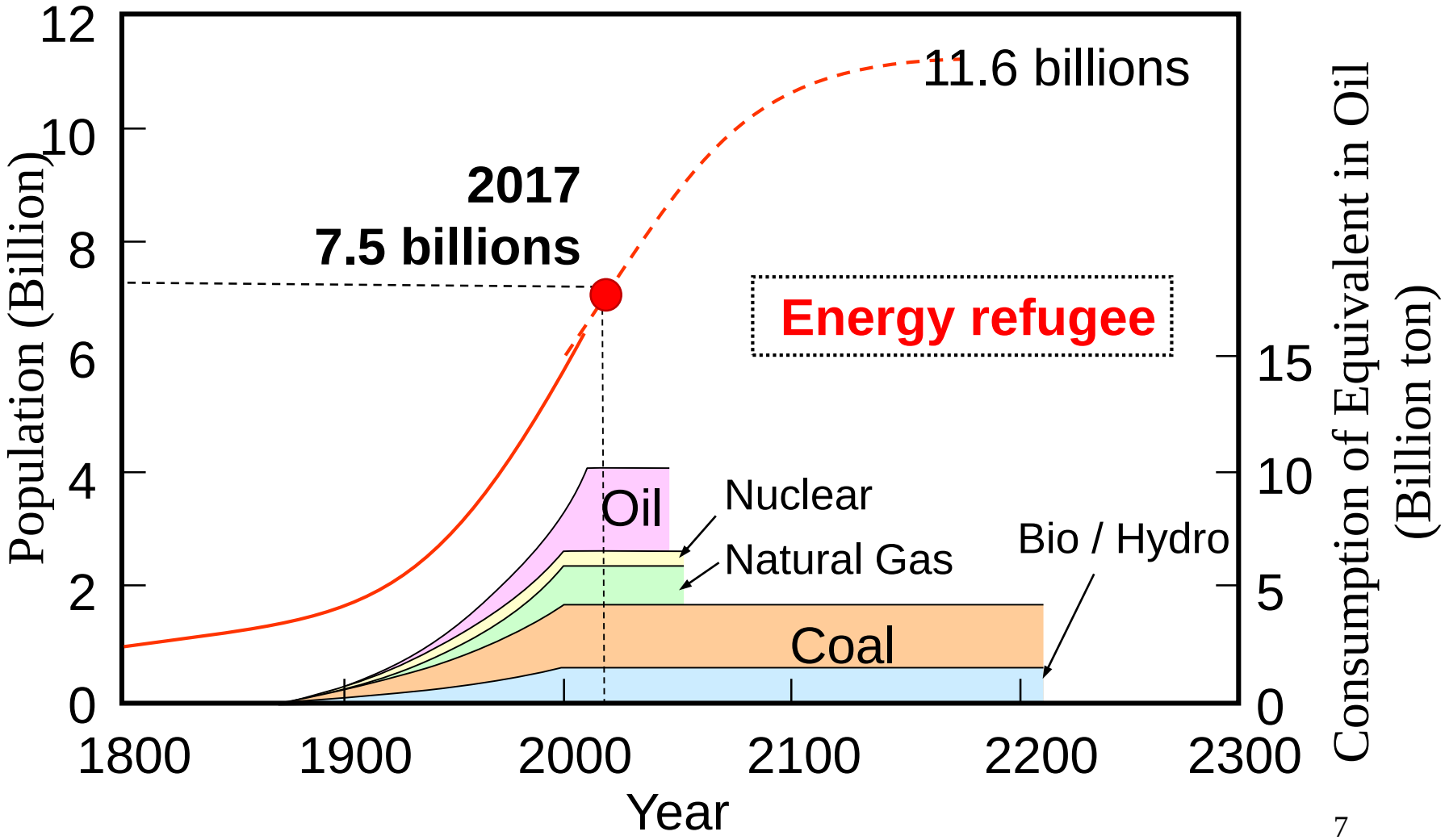
https://www.wfp.org/content/hunger-map-2015

Access to Safe Water

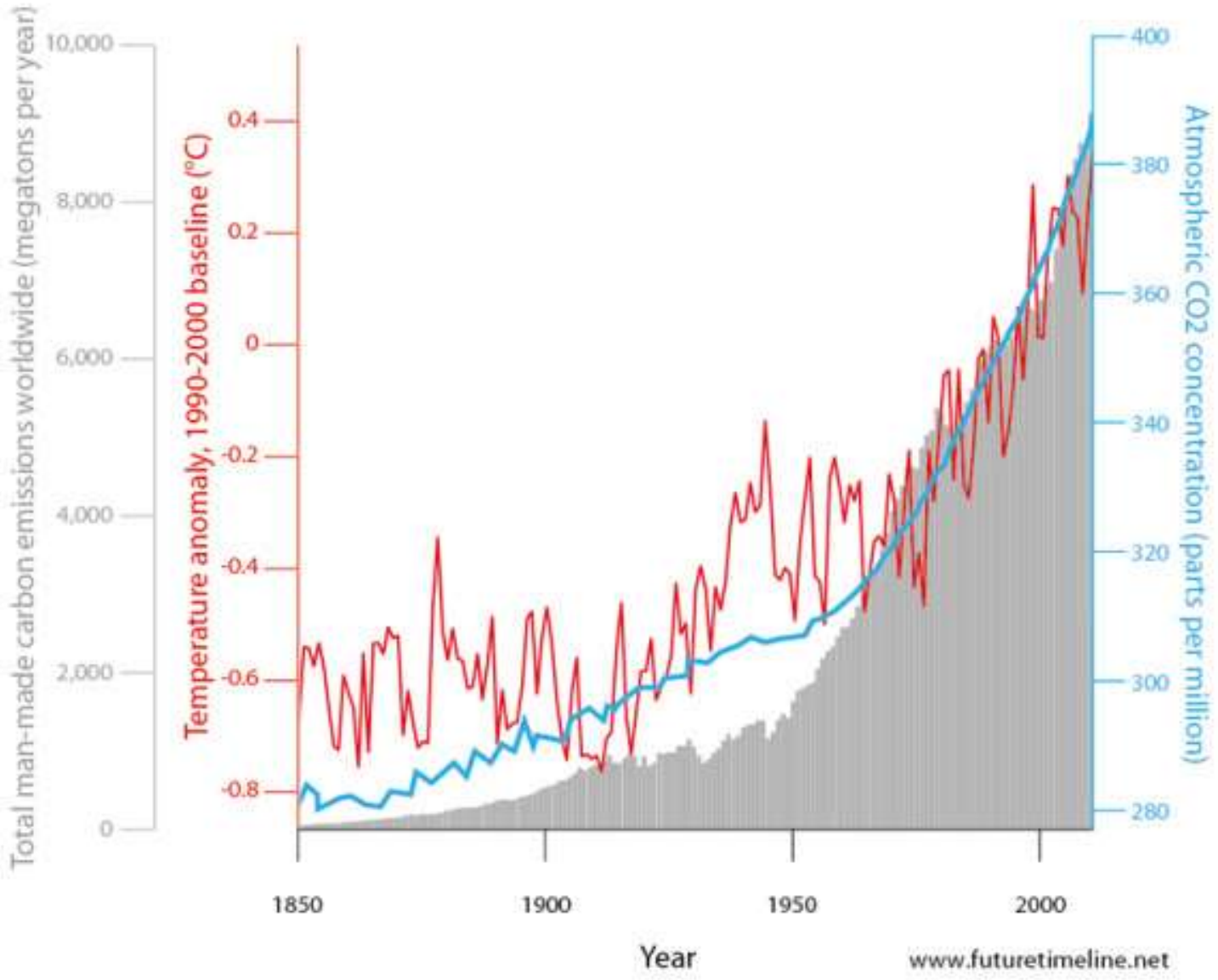
"More than five million people, most of them children, die every year from illnesses caused by drinking poor quality water."



Population Growth and Energy Supply of the World



Global Temperature and CO2 Density



Impacts of Global Warming

Double numbers of large scale Hurricanes in last 30 years

Ice shelves are varnishing in Greenland and Antarctic

Sea level rise

Malaria spread in high elevation districts

Heat-waves become more frequent and severer

Glacier drainage in Greenland increases double in last10 years

Droughts and wild fires increase

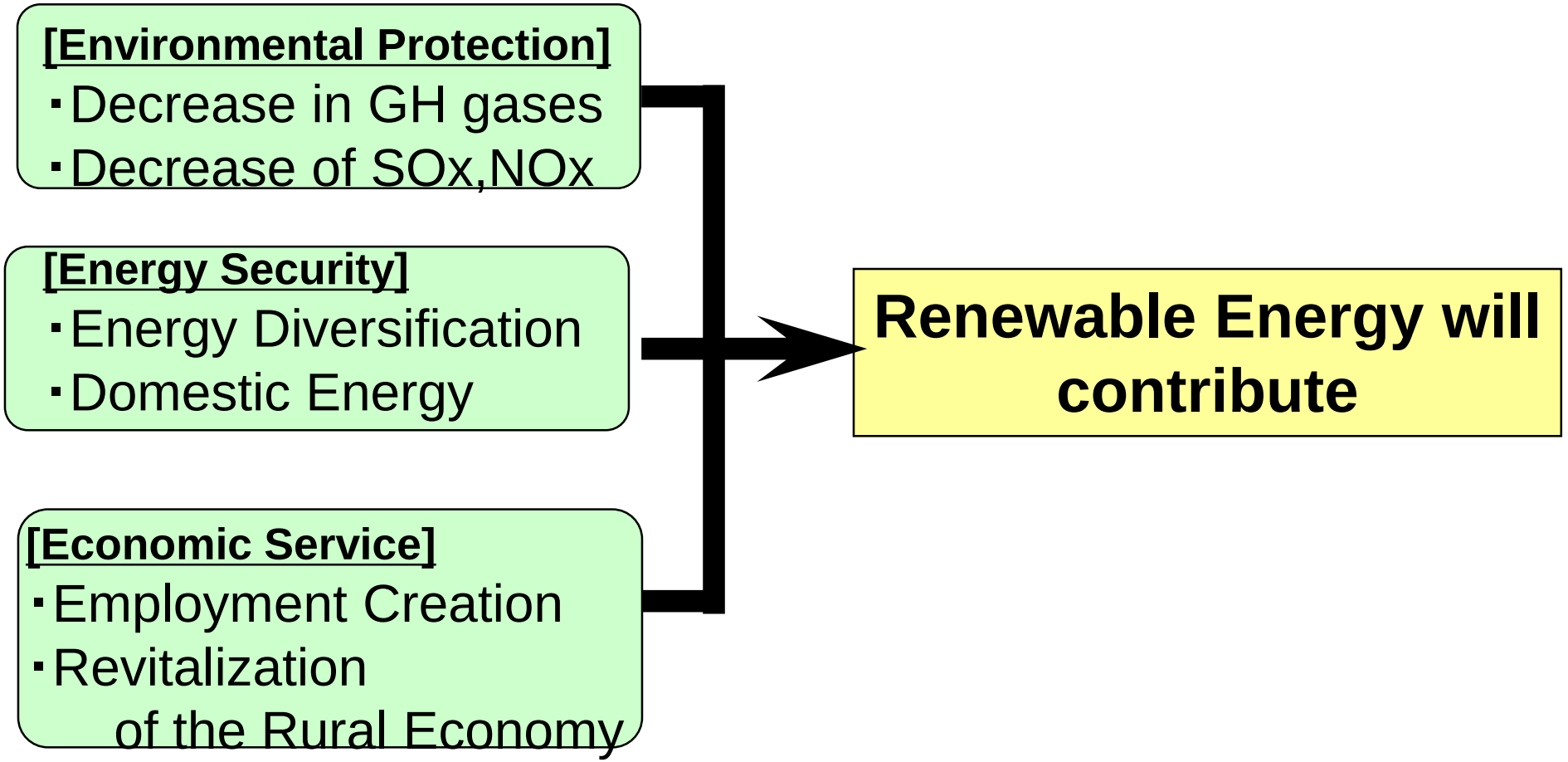
At least 279 species of flora and fauna moved to higher latitude

Ice of Arctic sea in Summer season disappear by 2050

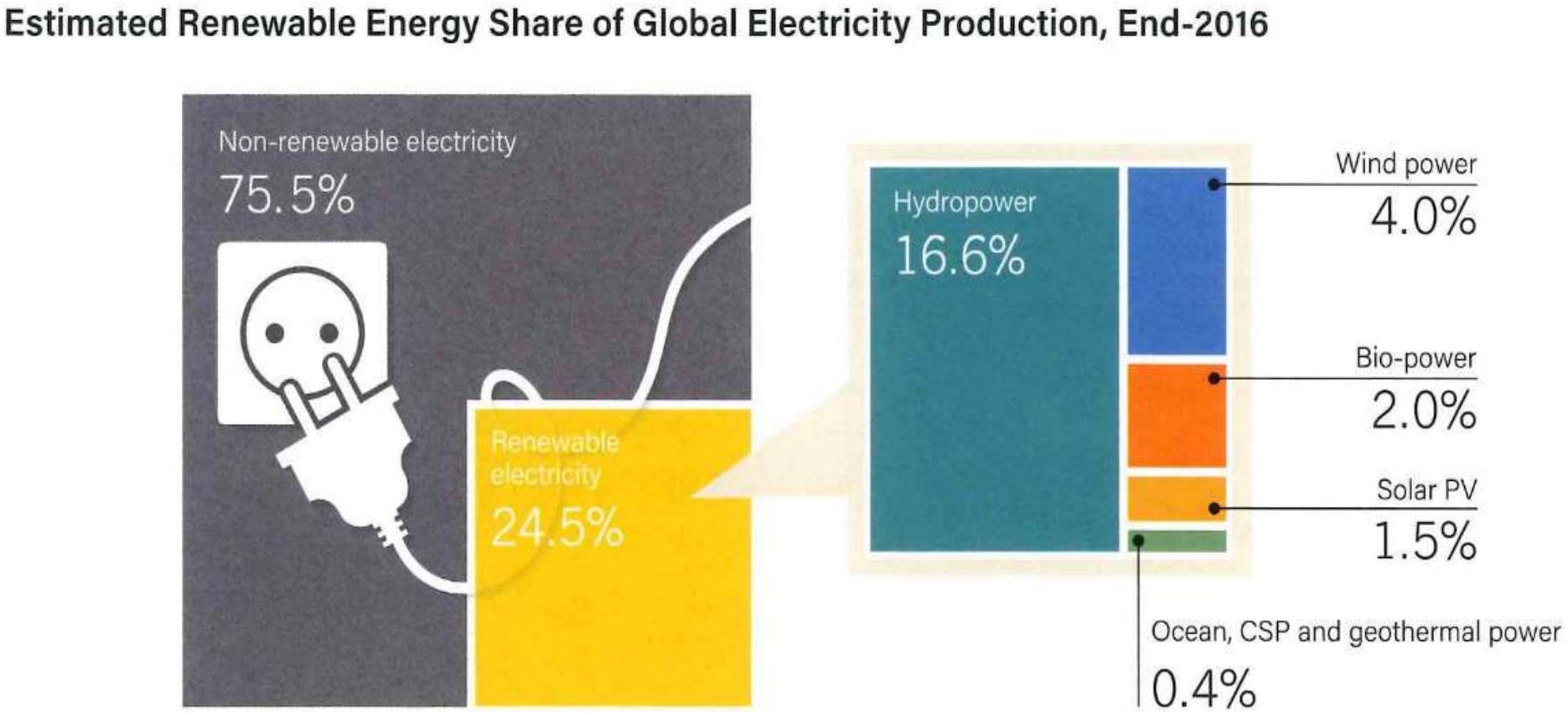
Human Victims by worming are 300,000/year double in this 25 years

Over 1,000,000 species of flora and fauna over the world become extinct

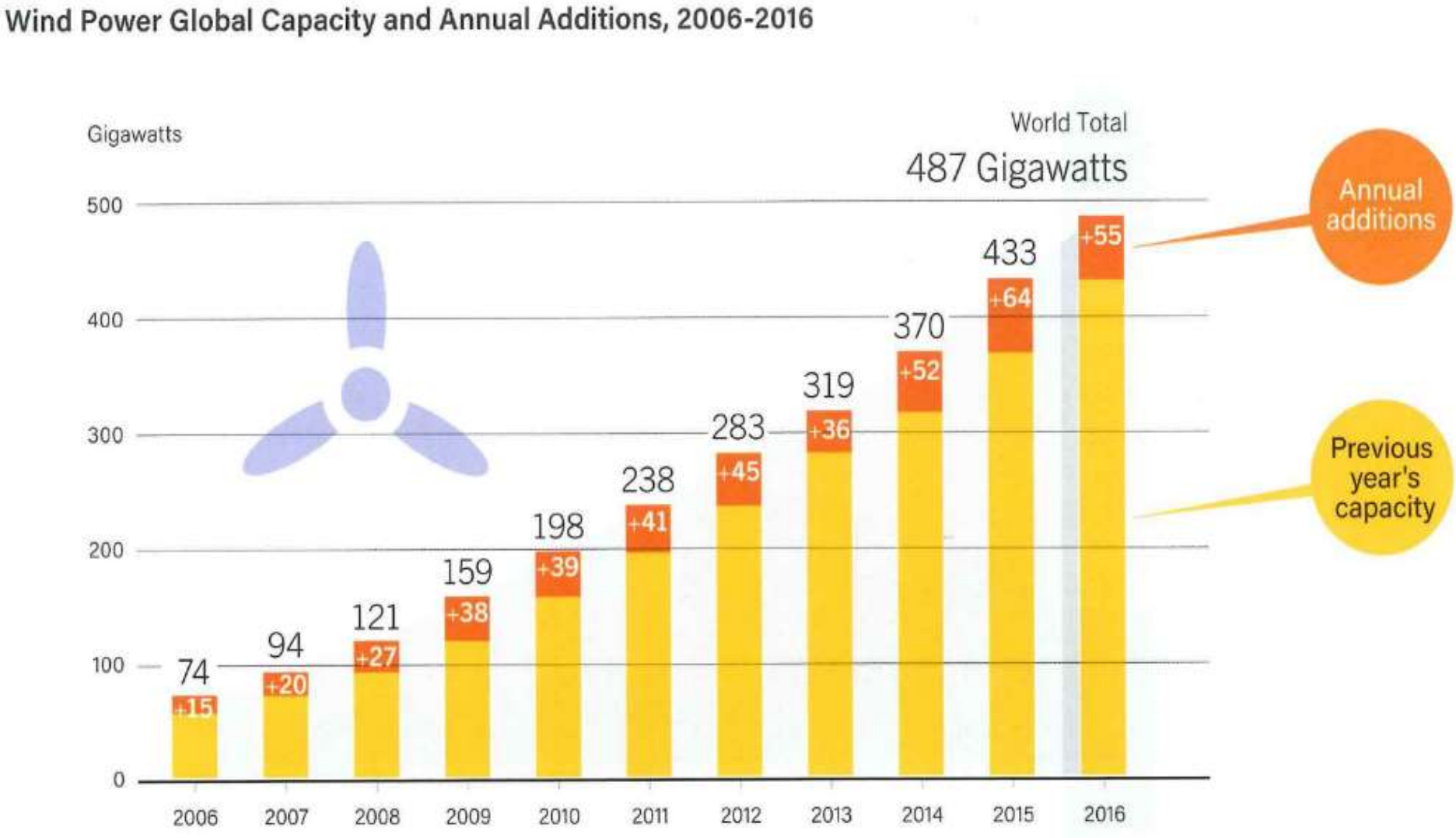
Role of Renewable Energy



Renewable Energy Share of Global Electricity Production, End-2015



Growth of Wind Power Capacity 2006~2016



World Wind Power exceeds 500GW in Oct. 2017

WINDPOWER MONTHLY

Connected global capacity tops 500GW, says WPI

18 October 2017 by Staff , Be the first to comment

WORLDWIDE: Global grid-connected wind capacity has passed the 500GW milestone, according to Windpower Intelligence (WPI), the research and data division of Windpower Monthly.

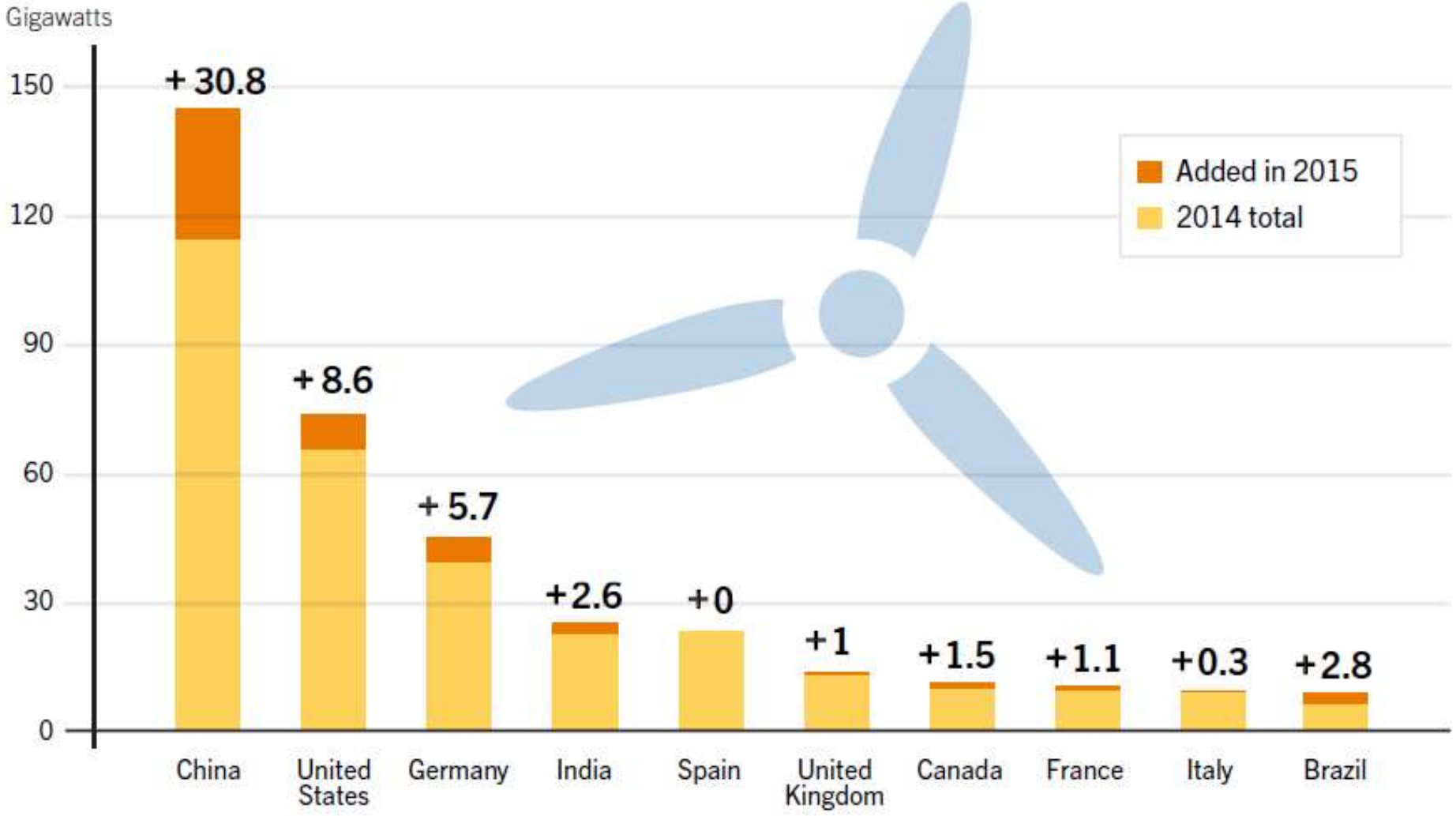
Worldwide grid-connected wind capacity has topped 500GW

MORE ON THIS TOPIC

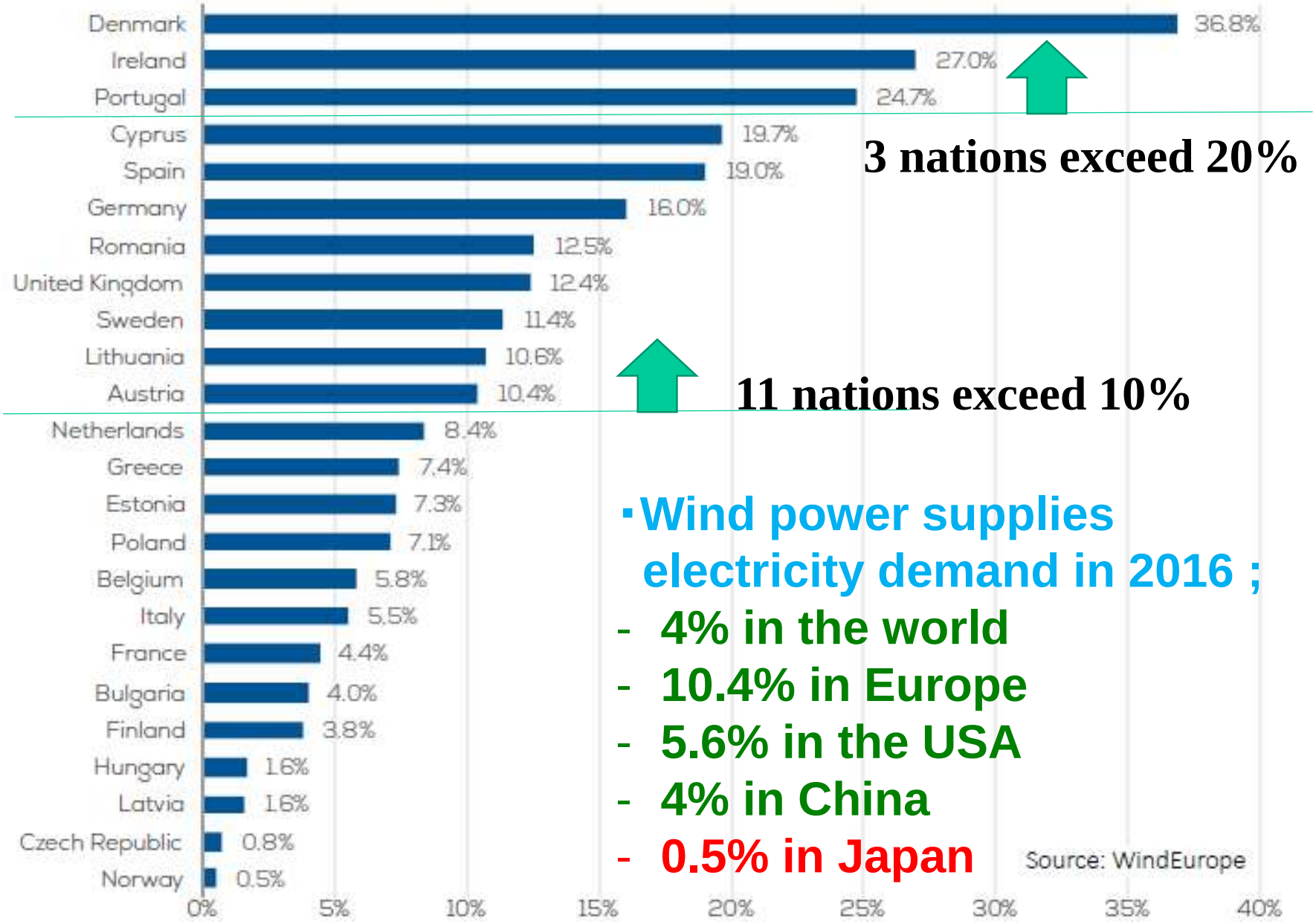
Oklahoma 2GW

Wind Power Top 10

Wind Power Capacity and Additions, Top 10 Countries, 2015



Wind Power Penetration rate



3 nations exceed 20%

11 nations exceed 10%

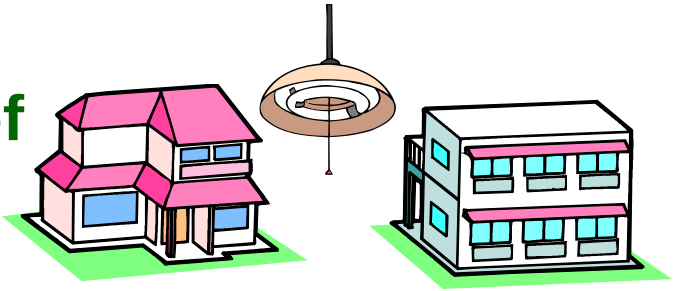
- **Wind power supplies electricity demand in 2016 ;**
  - **4% in the world**
  - **10.4% in Europe**
  - **5.6% in the USA**
  - **4% in China**
  - **0.5% in Japan**

Source: WindEurope

Environmental Contribution by 2MW class Wind Turbine

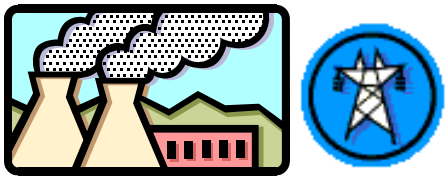
- 2MW Wind Turbine generates 700 mill.kWh/year

Equivalent to the power demand of 1400 ordinary family.



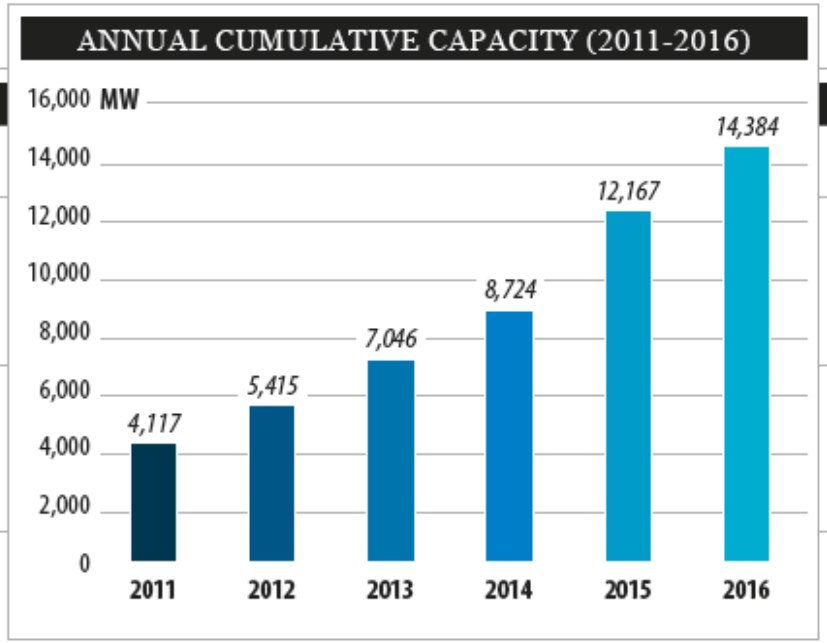
Equivalent to 17000kl(8600drums) of oil by thermal power plant

CO_2 reduction of 5,000tons



Absorb the CO_2 correspond to 360 thousand of cedar forest.

GLOBAL CUMULATIVE OFFSHORE WIND CAPACITY in 2016



	UK	Germany	PR China	Denmark	Netherlands	Belgium	Sweden	Japan	S Korea	Finland	US	Ireland	Spain	Norway	Portugal	Total
Total 2015	5,100	3,295	1,035	1,271	427	712	202	53	5	32	0.02	25	5	2	2	**12,167**
New 2016	56	813	592	0	691	0	0	7	30	0	30	0	0	0	-2	**2,219**
Total 2016	5,156	4,108	1,627	1,271	1,118	712	202	60	35	32	30	25	5	2	0	**14,384**

Source: GWEC


Off-Shore Wind Farm in Denmark

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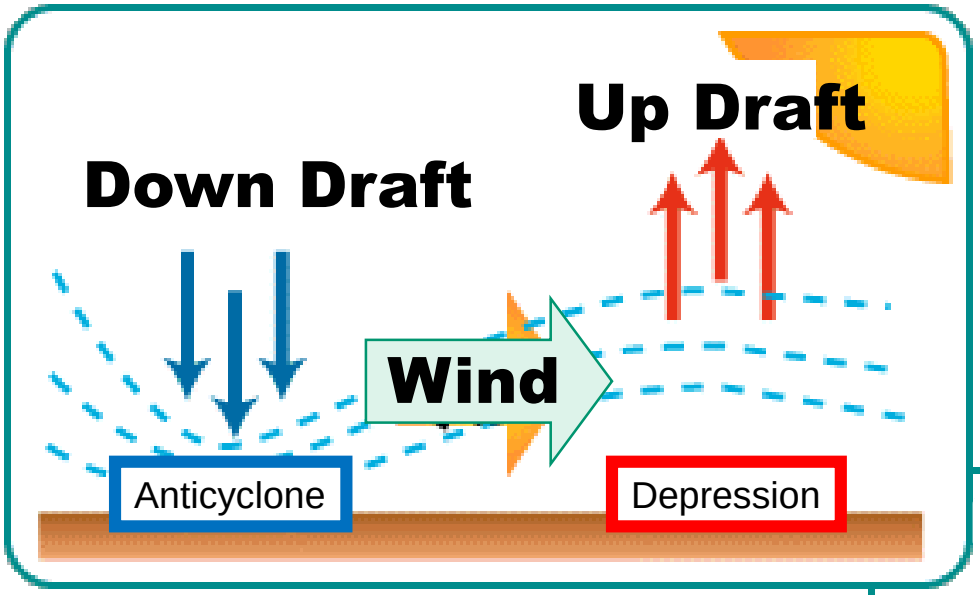
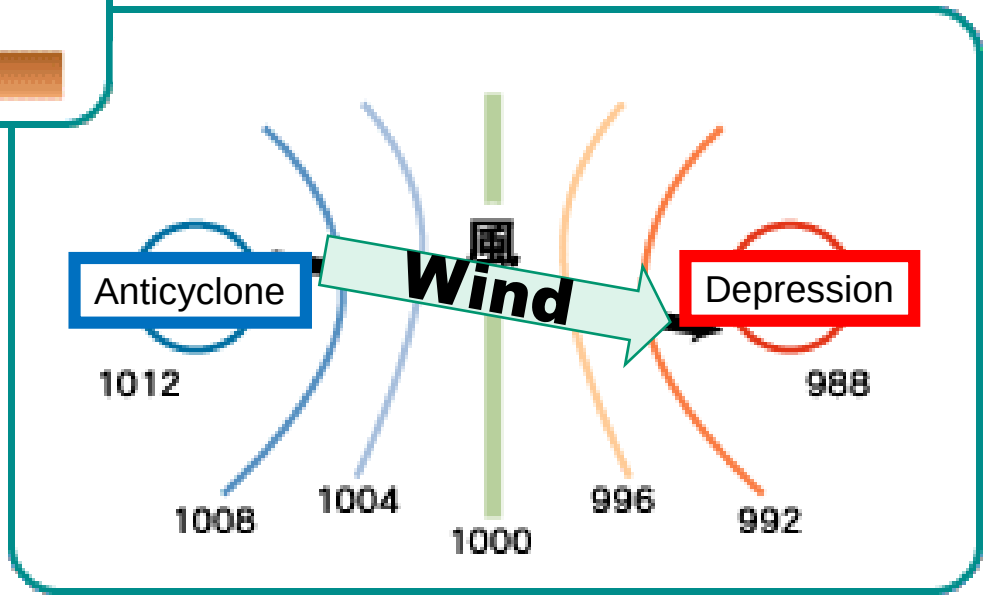
Windy area in Kenya

How wind is Created?

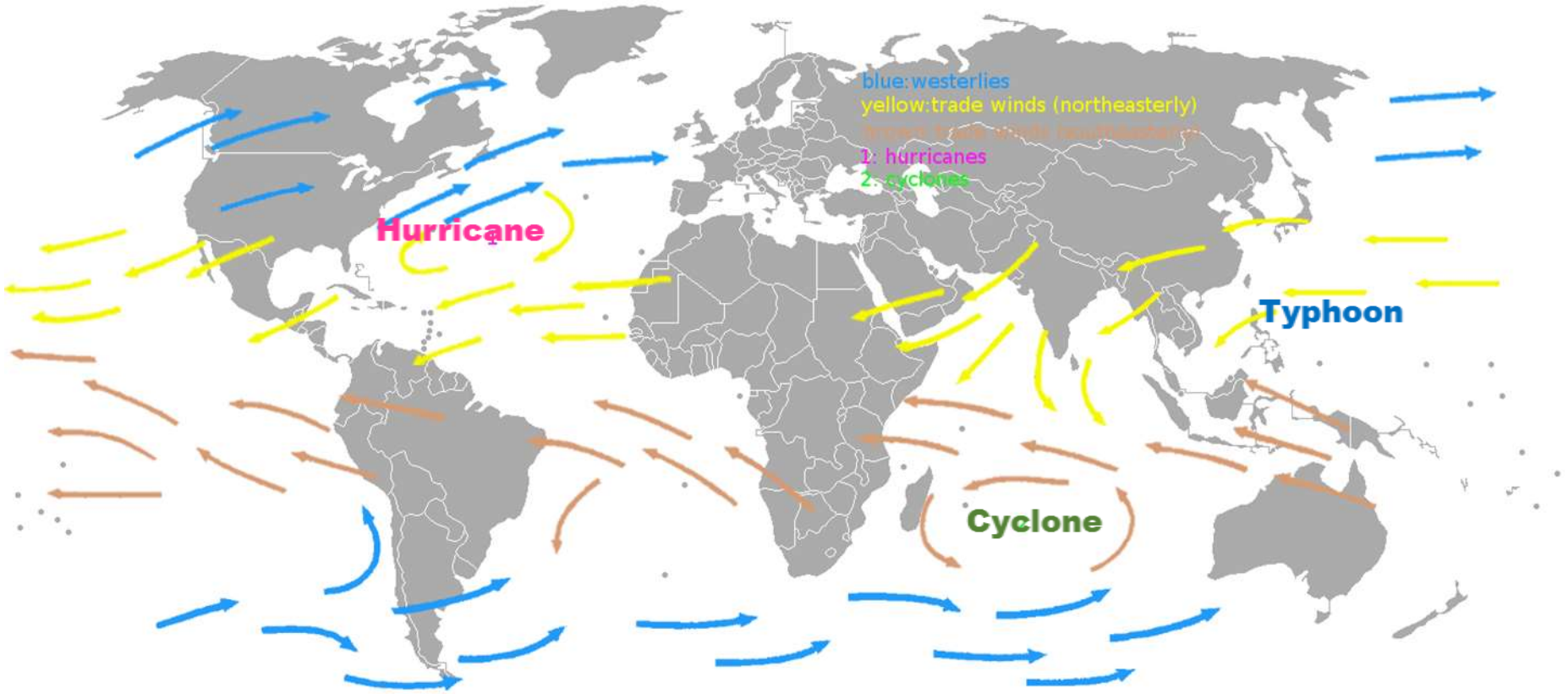


Warm air climb upward then create Low pressure



Window blows from High (Anticyclone) to Low (Depression)

Global wind flow



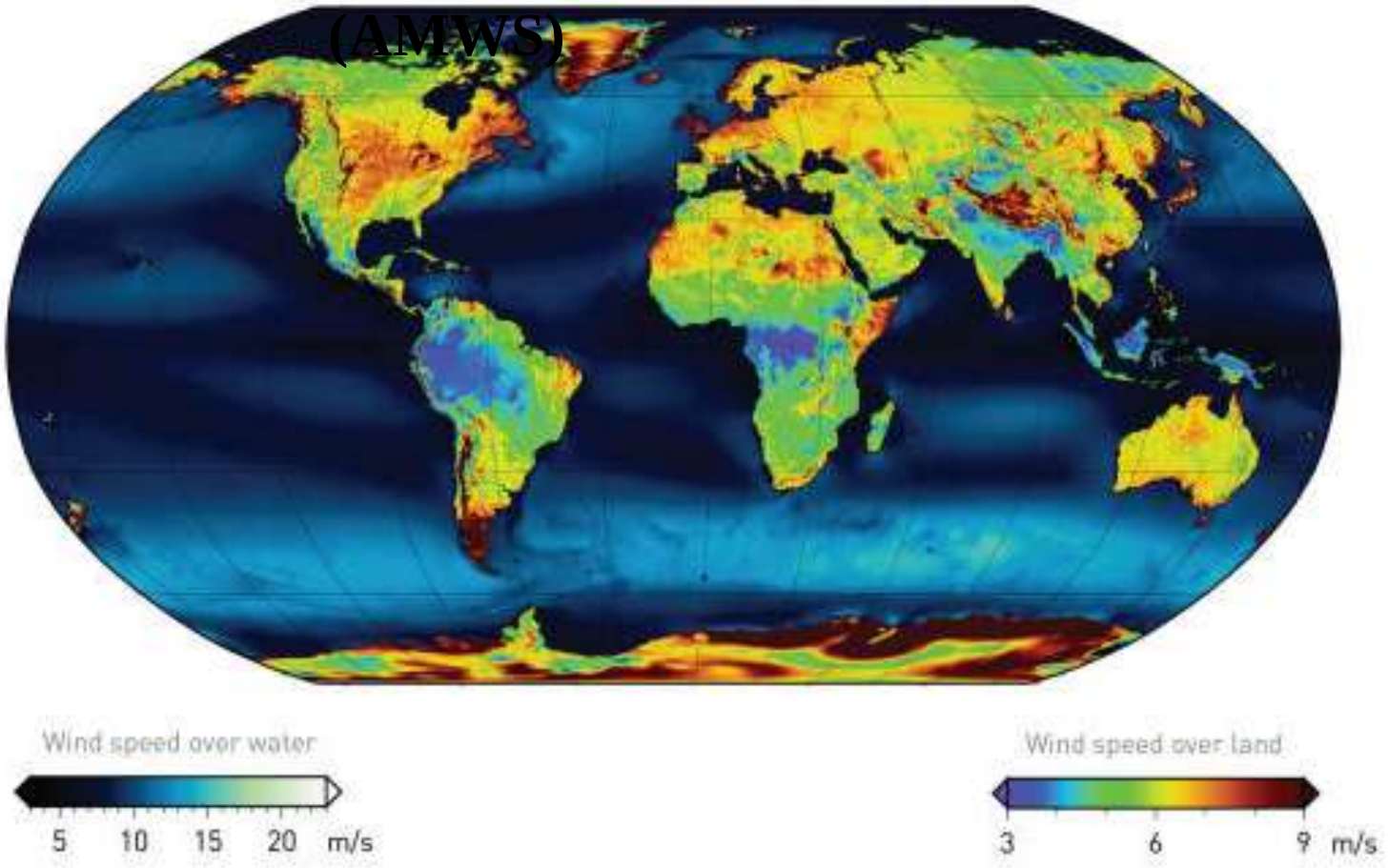
classification		maximum sustained surface wind speed
International	Japan	
Tropical Depression	熱帯低気圧	<17m/s(34kt)
Tropical Storm	台　風	17 - 25m/s (34-48kt)
Severe Tropical Storm		25 - 33m/s (48-64kt)
Typhoon / Hurricane / Cyclone		≧33m/s(64kt)

http://www.jma.go.jp/jma/kishou/know/yougo_hp/haichi.html
http://www.aoml.noaa.gov/hrd/tcfaq/A1.html

Wind resources

Wind atlas / map

Annual Mean Wind Speed (AMWS)



A map showing the extent of Canada's wind farms as of 2011. (Oracle Education Foundation. Comparing Alternative Energy Forms: Wind Geography. March 23, 2012. http://library.thinkquest.org/17658/wind/windgeoht.html).

http://www.energybc.ca/profiles/wind/windspeedworld.html

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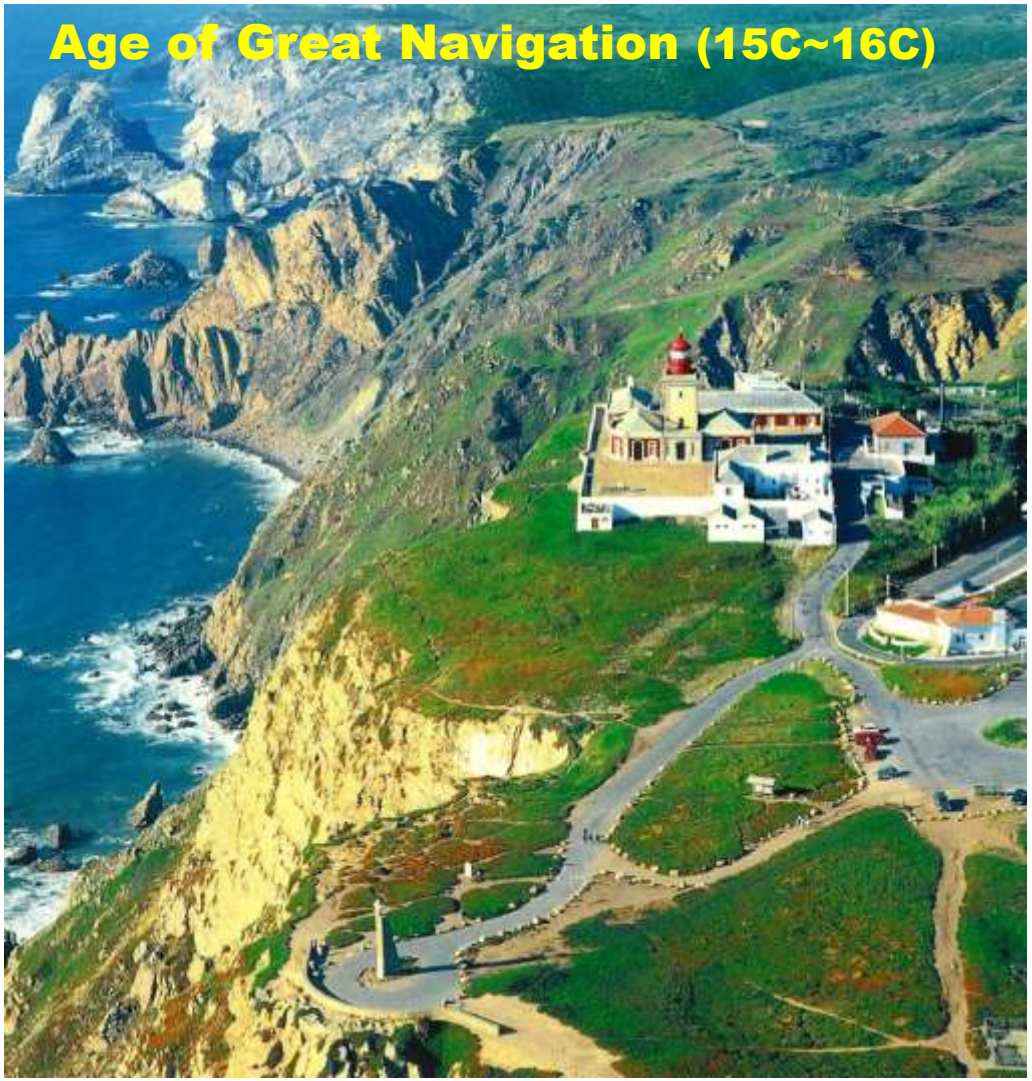
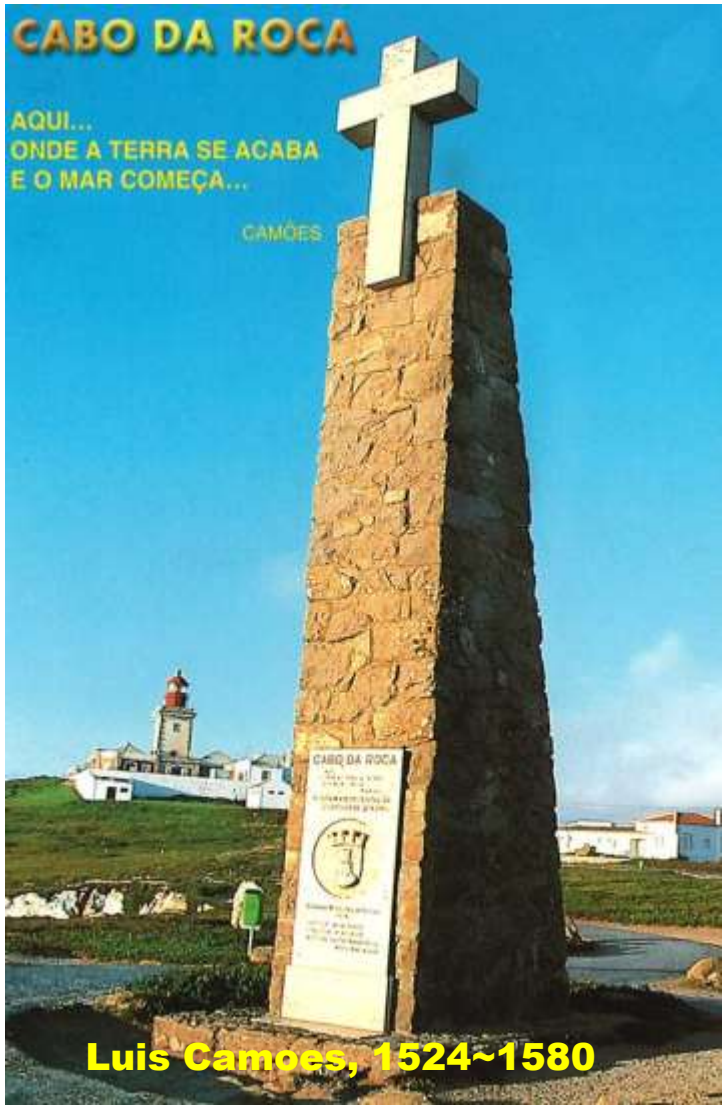
Cabo da Roca; West end of Portugal





Vasco da Gama; 1497, Indian Route

Mayflower and Puritans

1620 at Plymouth

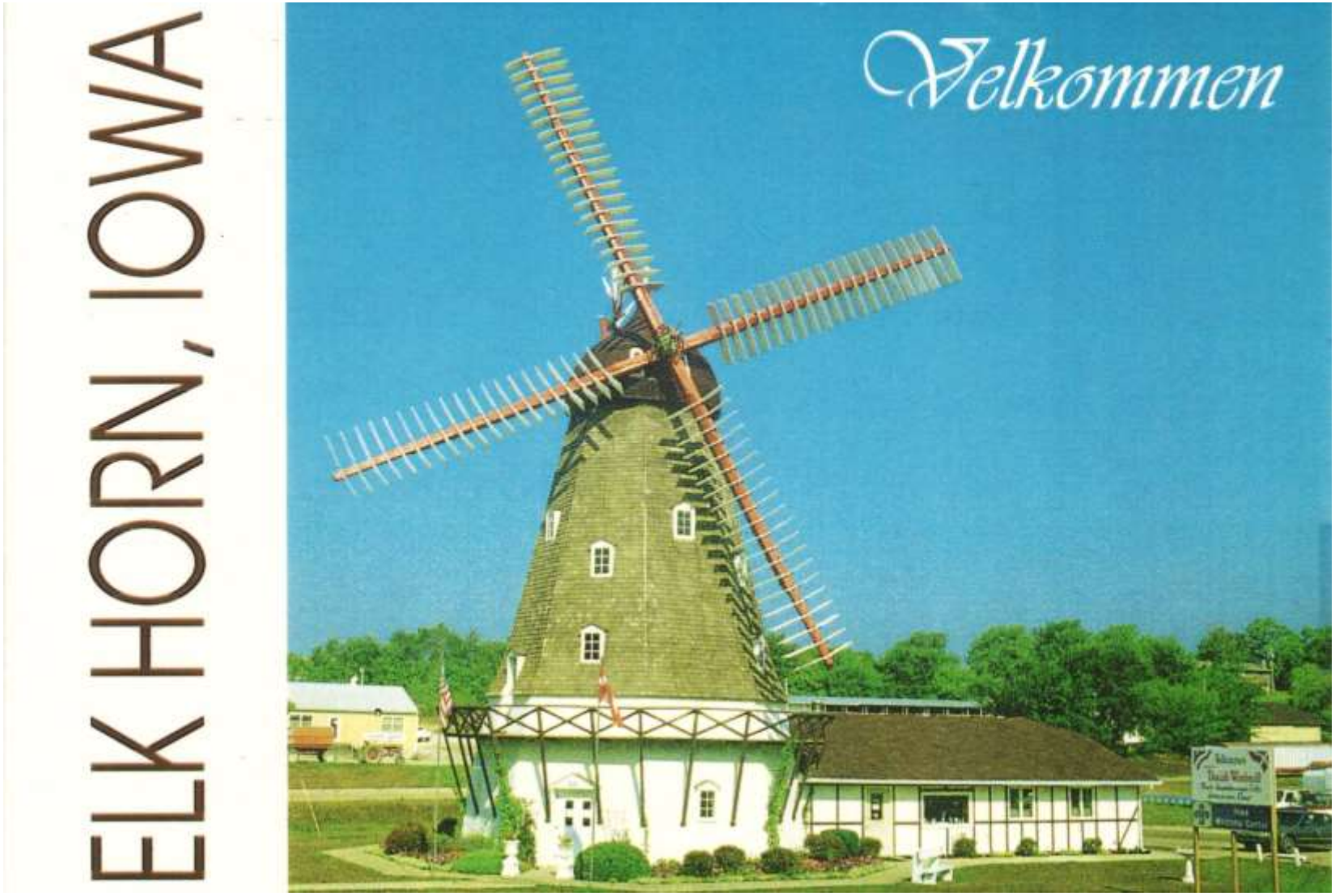
(By Jennie A. Brownscombe)

Model Windmills of gardening shop in Denmark

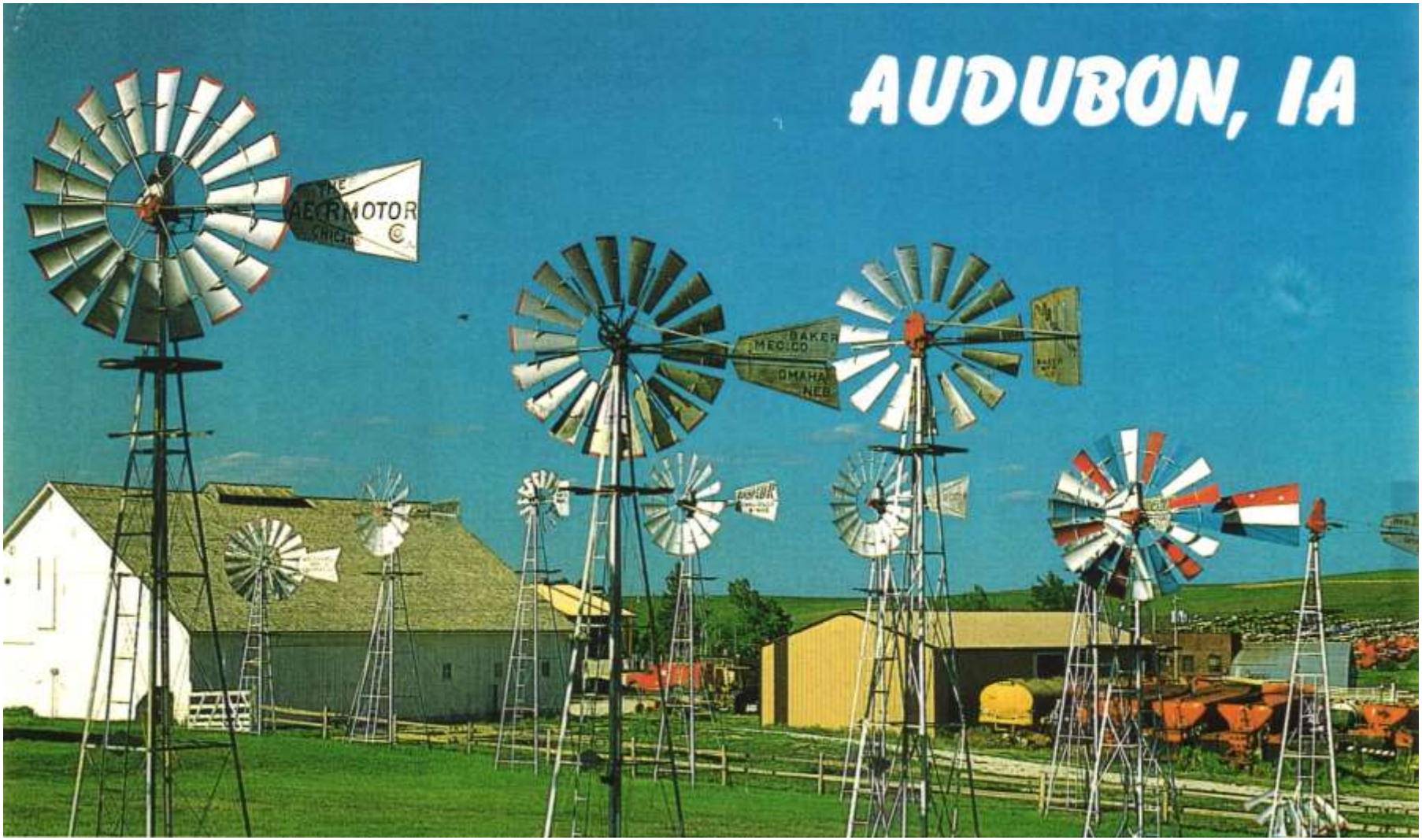
French restaurant particular about windmill in Lille

Water pumping windmill in Pennsylvania

Symbol windmill of immigrants from Denmark

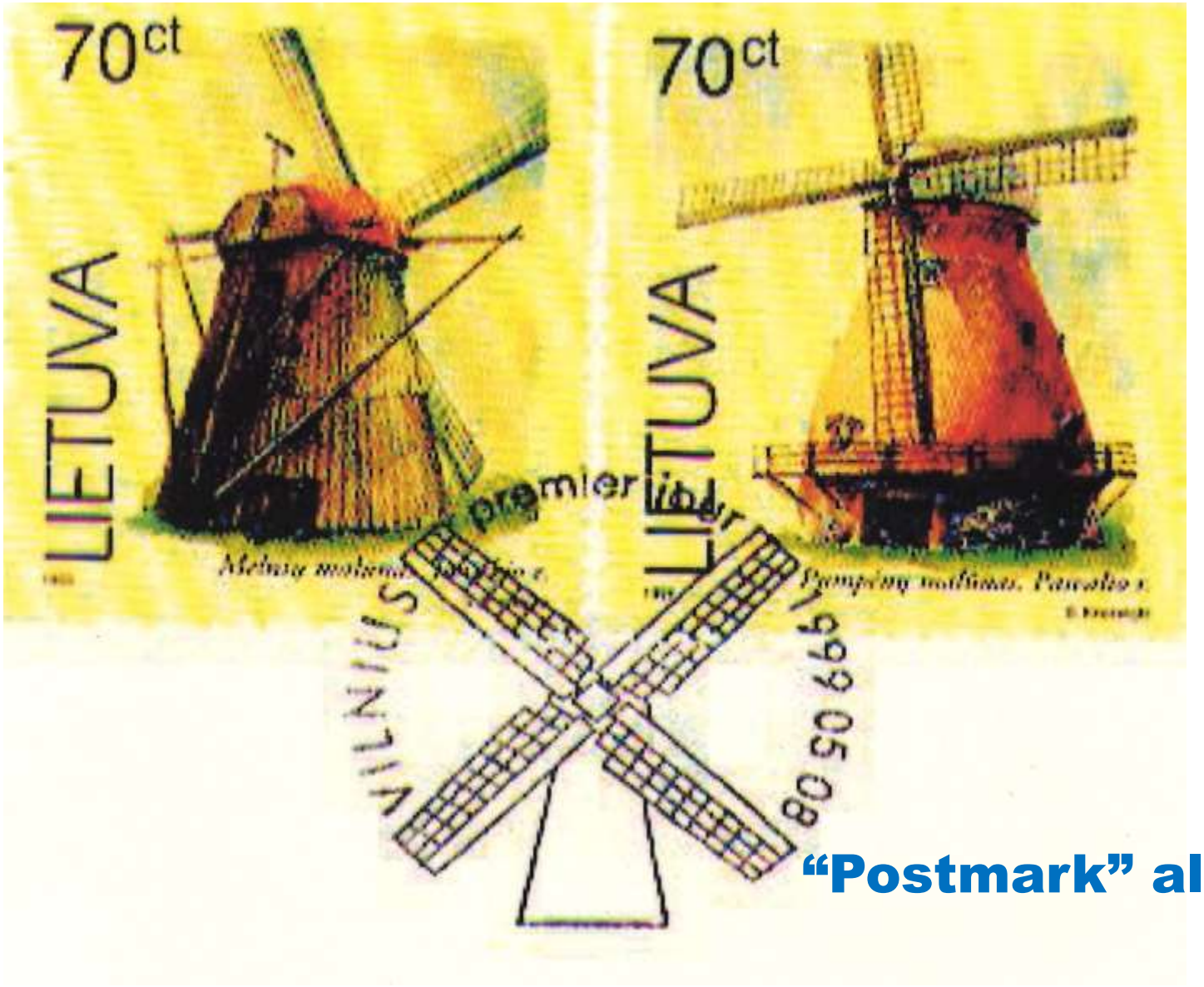


Windmill Museum in Audubon, Iowa



Windmill Museum of Wimbledon in suburbs of London

“Quixotic windmill” in Spain



"Postmark" also

Postage stump in Lithuania

A commemorative stamp of Daudet's windmill in France

“Moulin Rouge”

A famous sightseeing spot in Paris

“Toy museum”
and
wind-powered
musical box
in Munich

Wind turbine is "Cool" in the world.

Wind turbine made a spectacular debut at "the Paris Collection" at 2013.

"Chanel" Spring Summer 2013 Paris Full Show by Fashion Channel

http://www.youtube.com/notify-BlockCodeC_1?aHR0cDovL3d3dy55b3V0dWJlLmNvbS93YXRjaD92PWFoanliczk5SS1F

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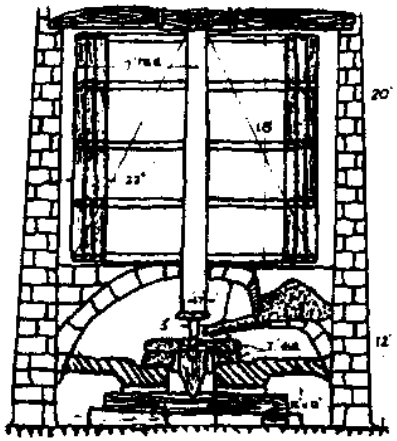
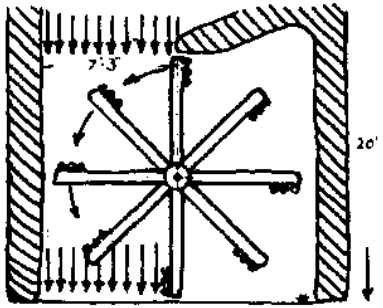
Windmill since ancient time to today





Persian vertical axis windmill

http://historicaliran.blogspot.jp/2012/03/nashtifan-windmills.html

http://www.history.alberta.ca/energyheritage/energy/wind-power/wind-power-in-early-times.aspx

European Wind mills

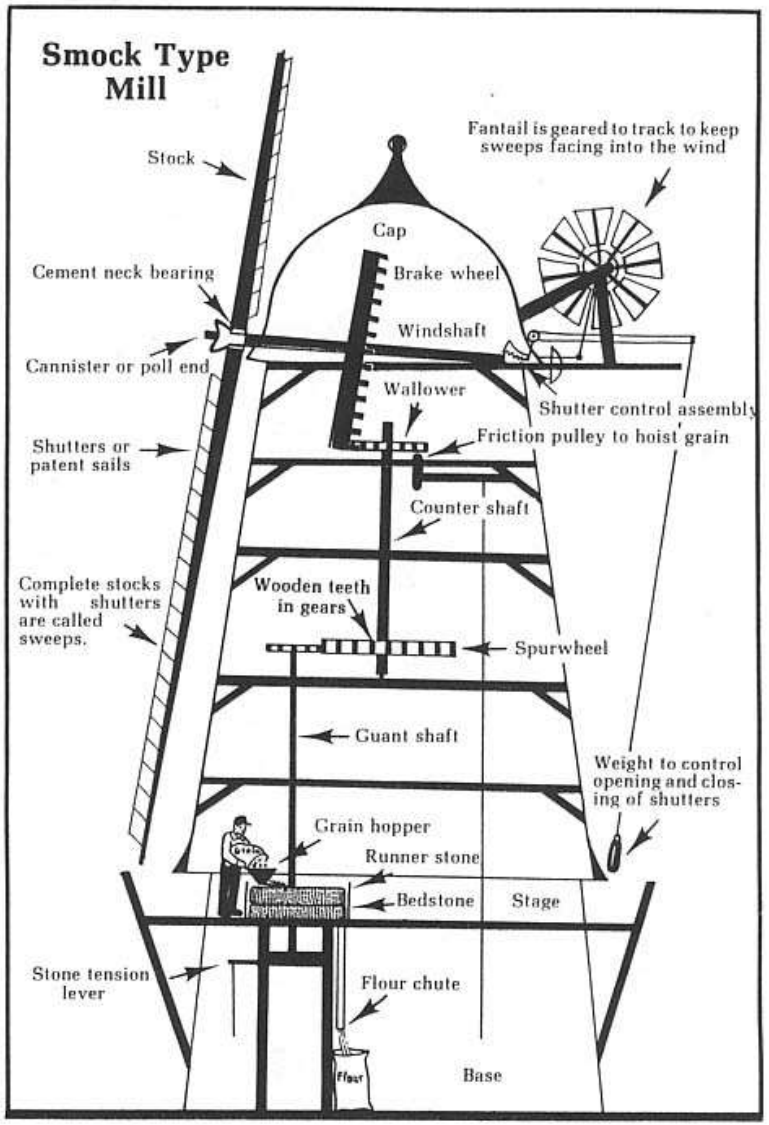
- From 2500 years ago, wind machines have been used for grain threshing and water drawing.
- Transferred from Middle East to Europe by Christian Crusade.
- In The Netherlands, 9,000 wind machines were operated at 19th century.

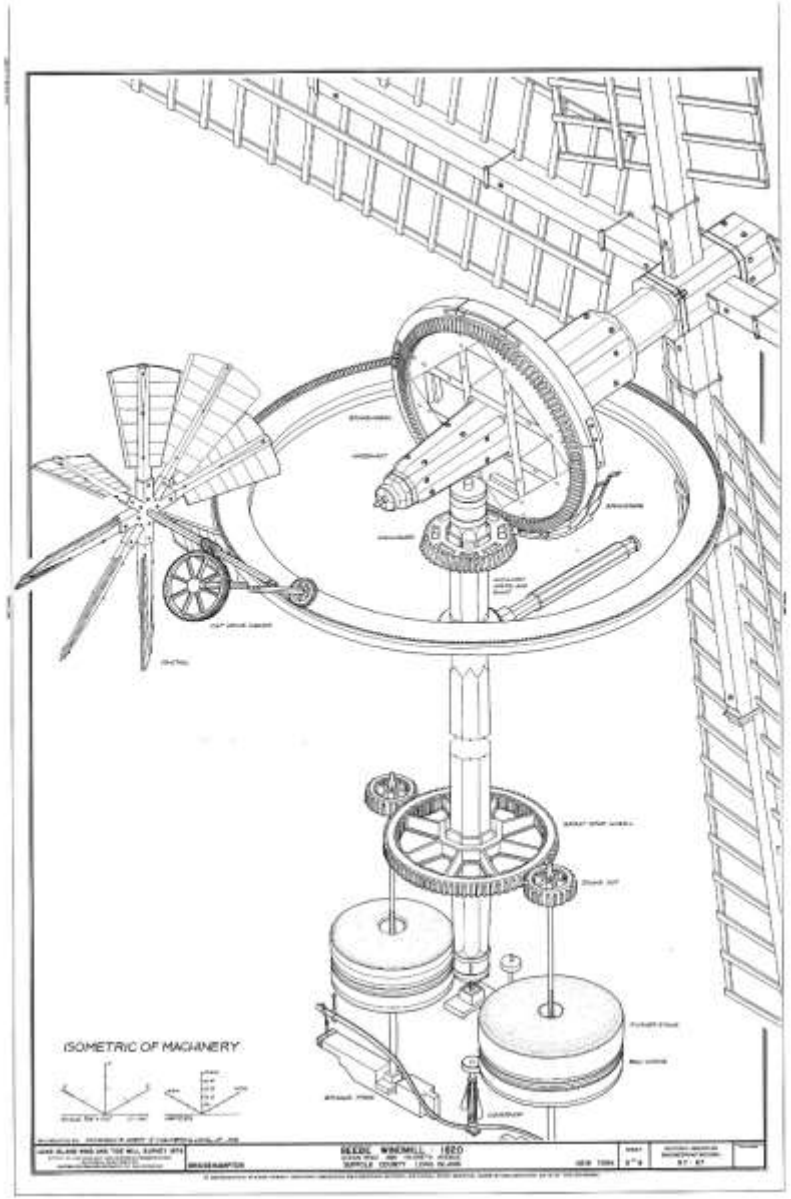
English Post mill (17 C)

Dutch type wind mill

Danish type wind mill

Basic mechanism of windmills





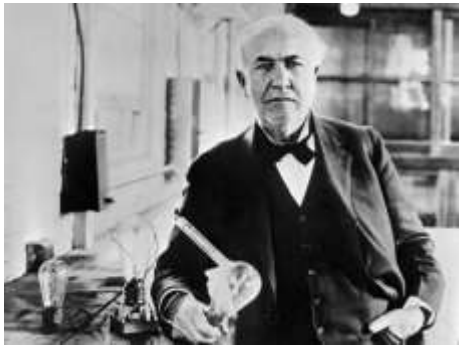
http://www.lowtechmagazine.com/2009/10/history-of-industrial-windmills.html

From Windmill to Wind power generation

◎ **Maturity of windmills as social applications**

◎ **Introduction of practical use of electricity**
Electrical lamp, Motor, Generator

◎ **Progress of aviation**



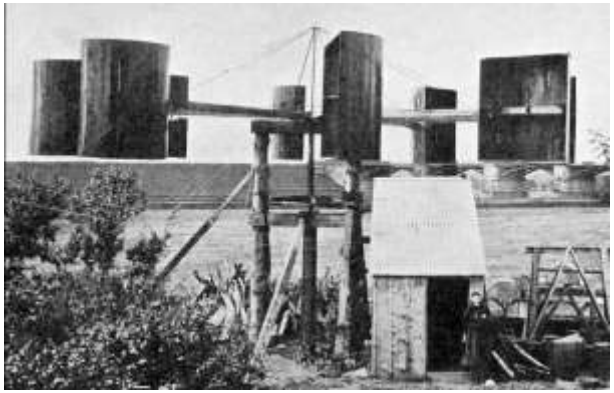
Thomas Alva Edison
(1847-1931)

Otto Lilienthal : May 29, 1895

Wright Brothers : December 17, 1903

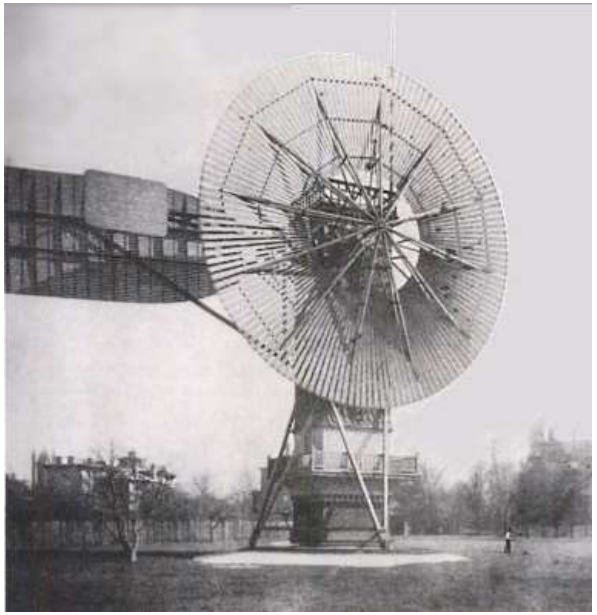
Pioneers of Wind Turbine Generator

(U.S.A, UK, DK)



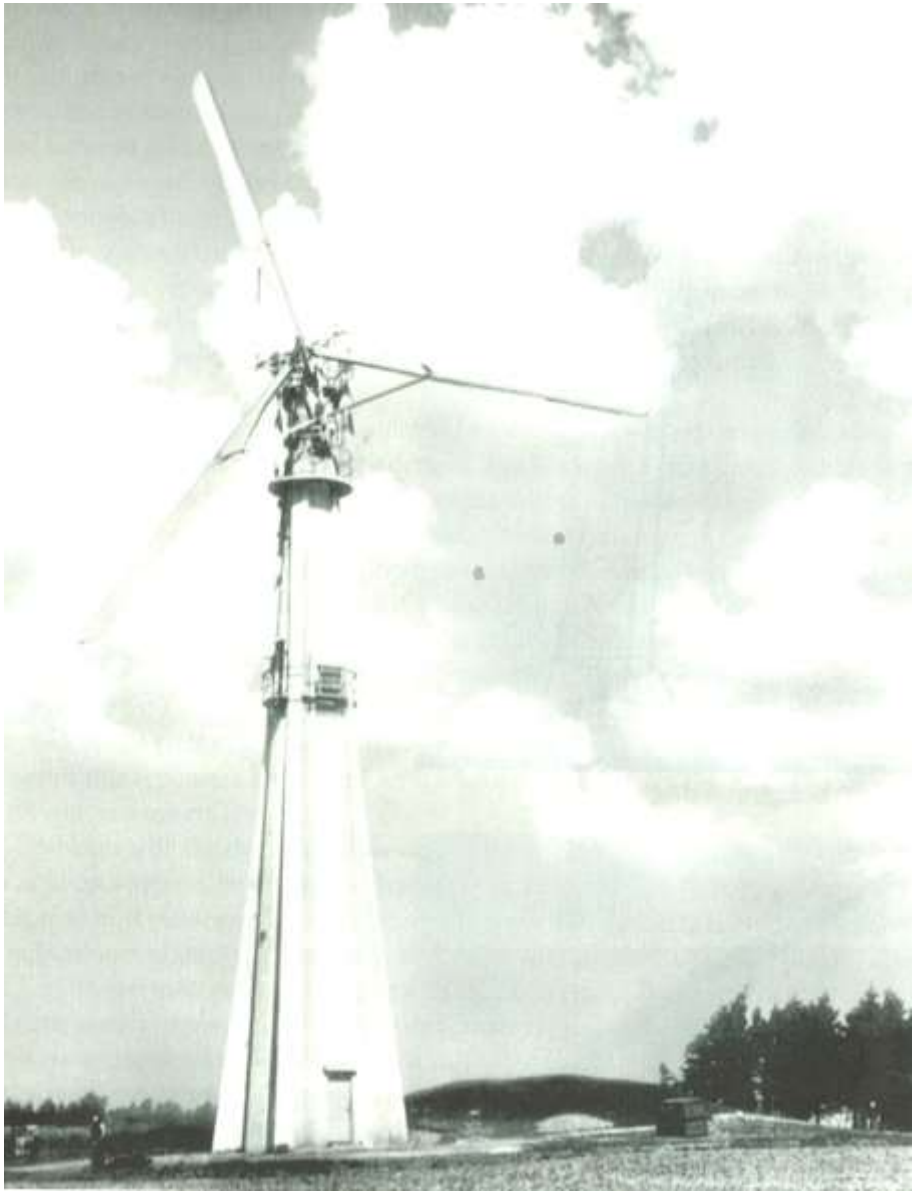
1887
James
Blyth (UK)

1891 Paul la Cour (DK)



1887
Charles
Brush (USA)

F.L. Smidth, Aeromotor in DK
(1942~1943, Dia. 24m, 70kW)



During WWII

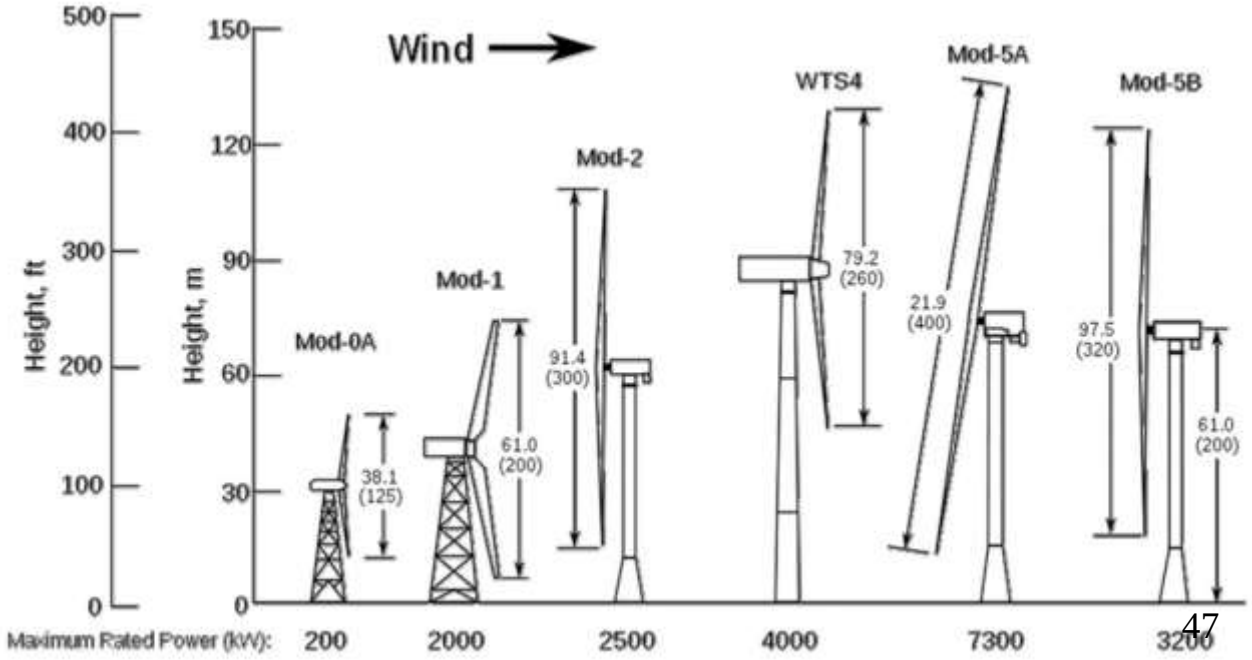
Vestas turbines (at Sky River, Tehachapi) led the California wind rush

Giant machines

1941 USA Smith-Putnam
1.25MW d=53m

1985 Canada Darrieus
4MW, h=107m, d= 64m

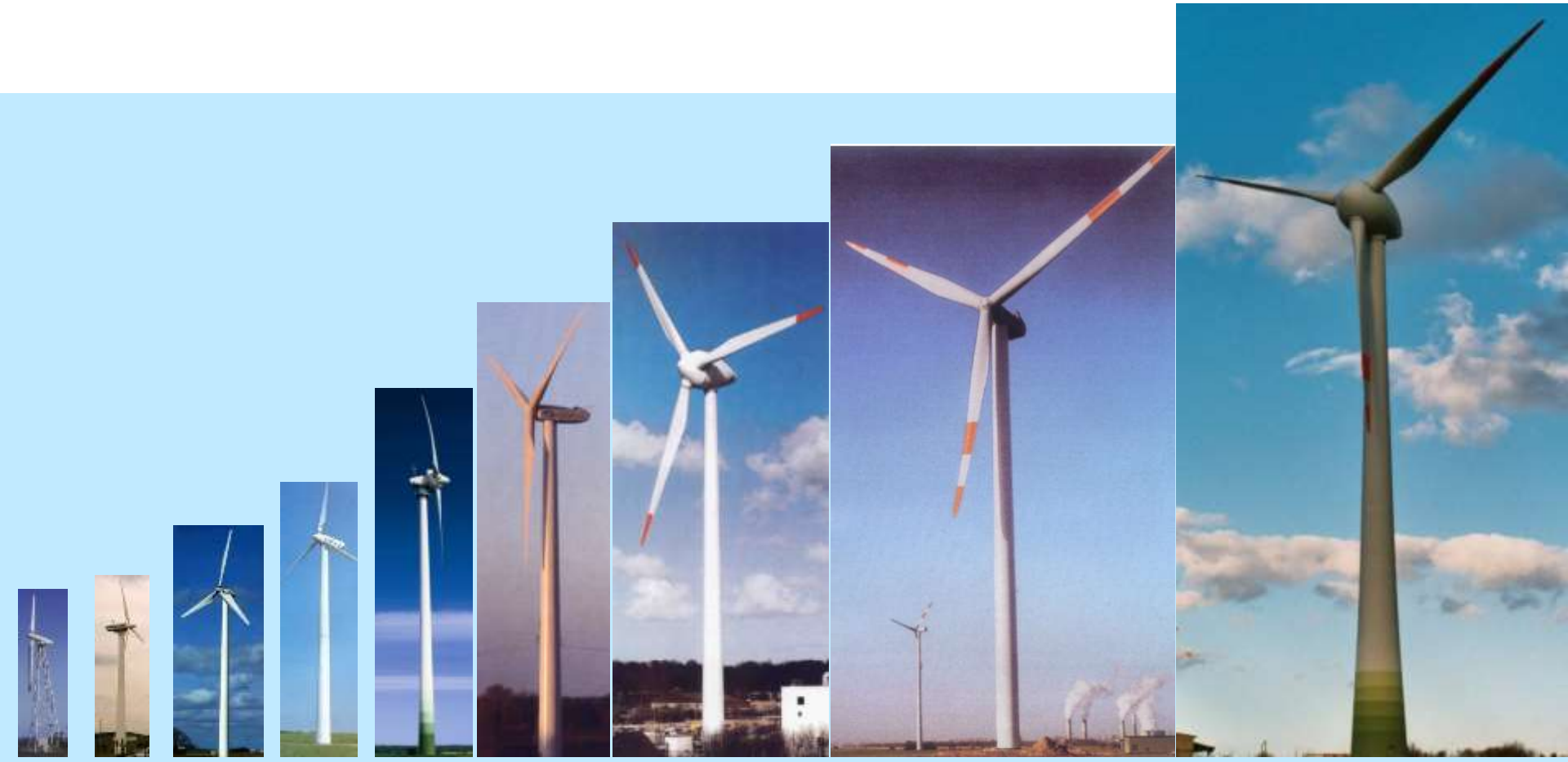
1983 Germany, Growian
3MW, d=100.4m



Giant Wind Turbines developed by DOE USA

20 Years Development of Wind Turbine Tech.

(From 20kW to 4.5MW)



1982	1984	1986	1988	1992	1994	1996	2000	2002
Aeroman 20kW Ø 11,5m	Vestas 55kW Ø 17m	Nordtank 150kW Ø 25m	Micon 250kW Ø 30m	Enercon E40 500kW Ø 40m	Nordex N54 1000kW Ø 54m	Enercon E66 1500kW Ø 66m	Nordex N80 2500kW Ø 80m	Enercon E112 4500kW Ø 112,8m

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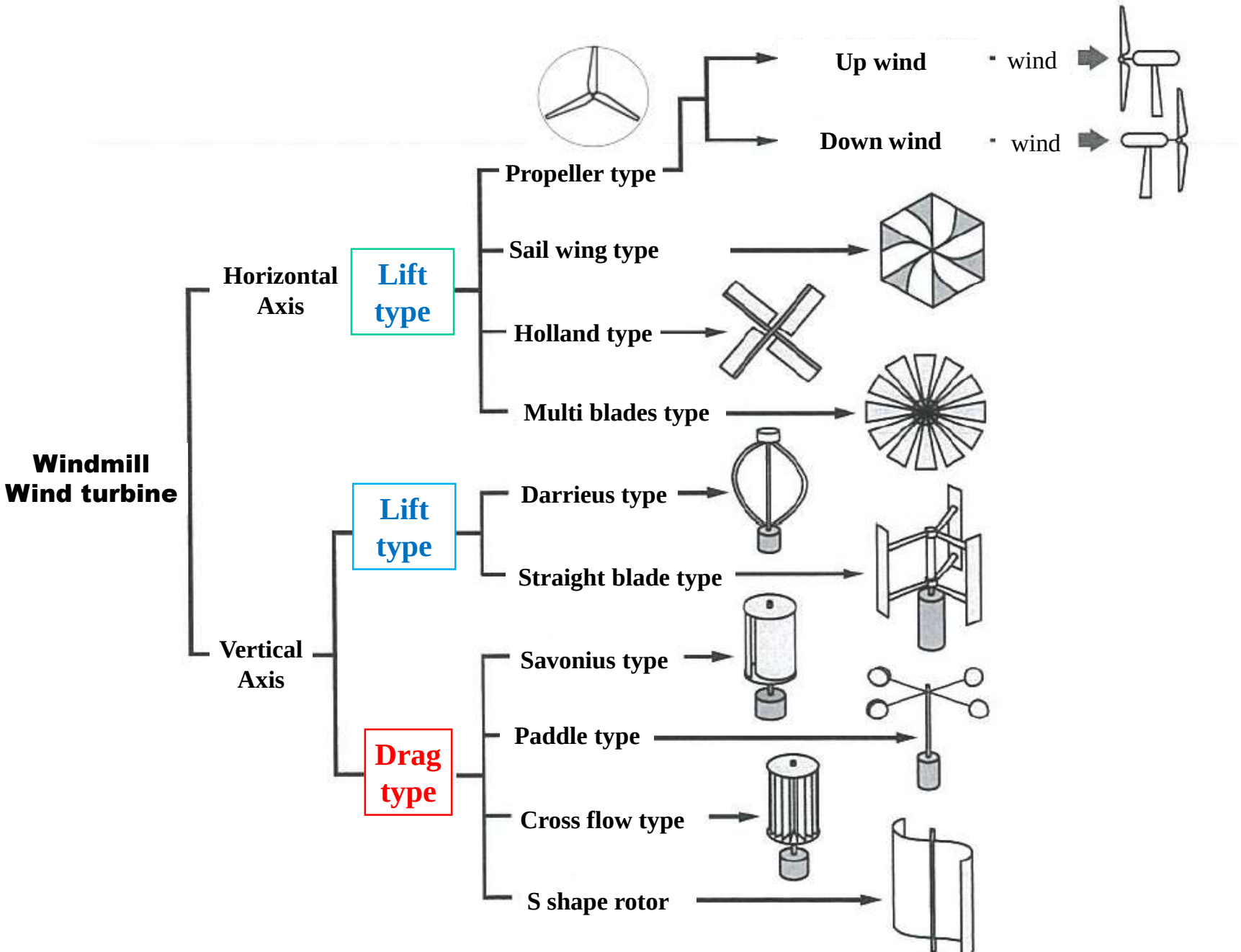
Category of Windmill / Wind turbine



THEORETICAL POWER IN THE WIND

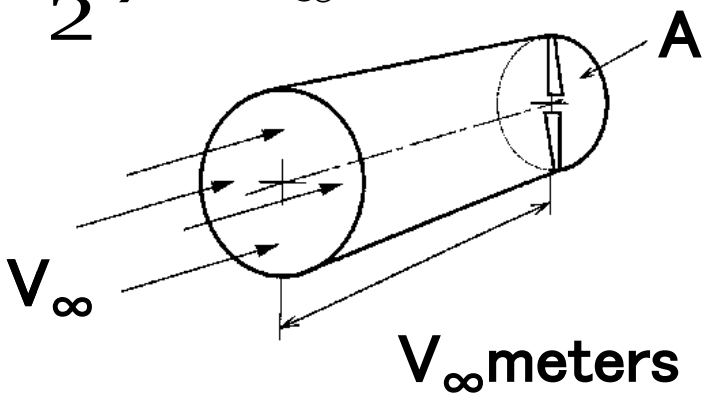
Kinetic energy : $E = \frac{1}{2} m V^2$

Kinetic energy per volume of air :

$$E_{air} = \frac{1}{2} \rho V_\infty^2$$

Theoretical power P_{th} in the wind :

$$P_{th} = \left(\frac{1}{2} \rho V_\infty^2 \right) A V_\infty = \frac{1}{2} \rho A V_\infty^3$$



Area A and Volume Flow per Second

The general expression for extractable power from the Wind

$$P_e = C_p \frac{1}{2} \rho A V_\infty^3$$

where , C_p : power coefficient

Maximum value of C_P : 0.593 (Betz limit)

Propeller Type

C_P = 0.3～0.4

Savonius Type

$C_P \fallingdotseq 0.15$

Multi-bladed Type

$C_P \fallingdotseq 0.25$

Cross Flow Type

$C_P \fallingdotseq 0.10$

The Extractable Power from the Wind

$$P_e = \rho A\left(\frac{V_\infty + V_e}{2}\right)^2 (V_\infty - V_e)$$

$$= \rho \frac{AV_\infty^3}{4}(1+\alpha)(1-\alpha^2)$$

where, $\alpha = V_e / V_\infty$

By differentiate Pe from α

$$\frac{dP_e}{d\alpha} = 0 \Rightarrow \alpha = -1 \text{ or } \alpha = \frac{1}{3}$$

$\alpha = -1$: **Physically impossible**

Substitute $\alpha = \frac{1}{3}$ **into** P_e

$$P_e = \rho A V_\infty^3 \frac{8}{27} = 0.593\left(\frac{1}{2}\rho A V_\infty^3\right)$$

$$= \underline{0.593 P_{th}}$$

Betz limit : 0.593

Who is the first ?
Max. Power Coefficient.

N.E. Joukowsky

1920

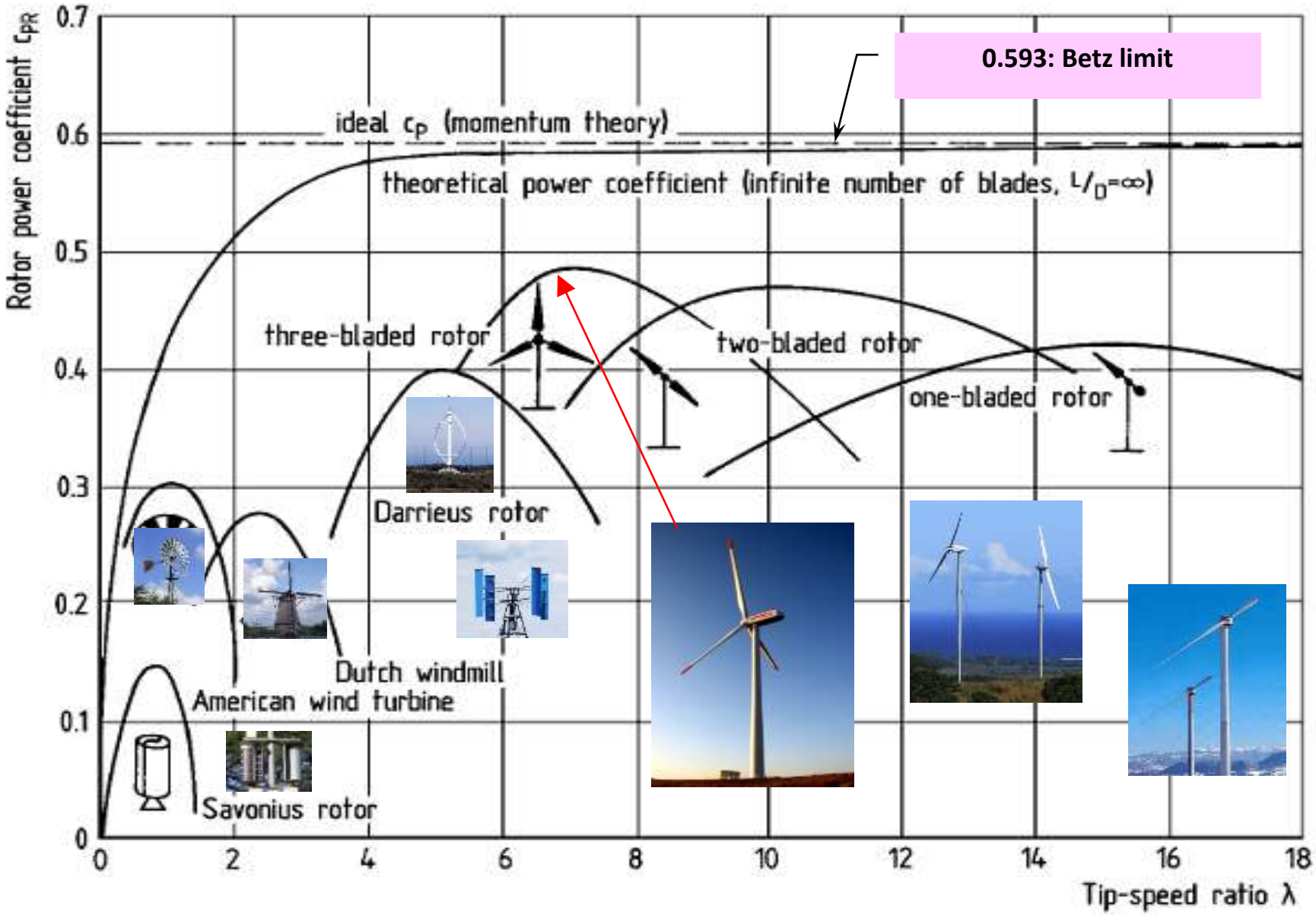
A. Betz

1920

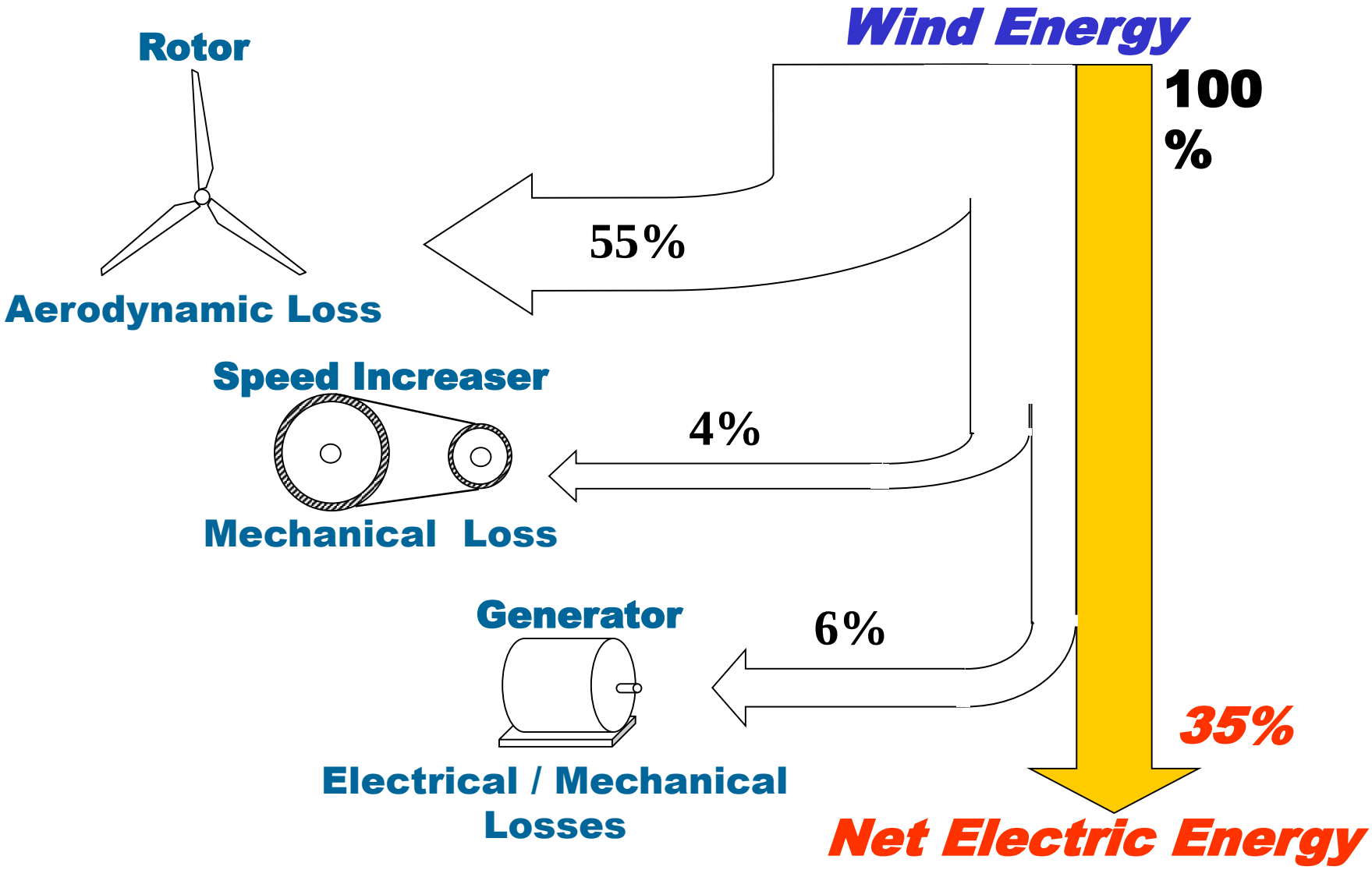
F.W. Lanchester

1915

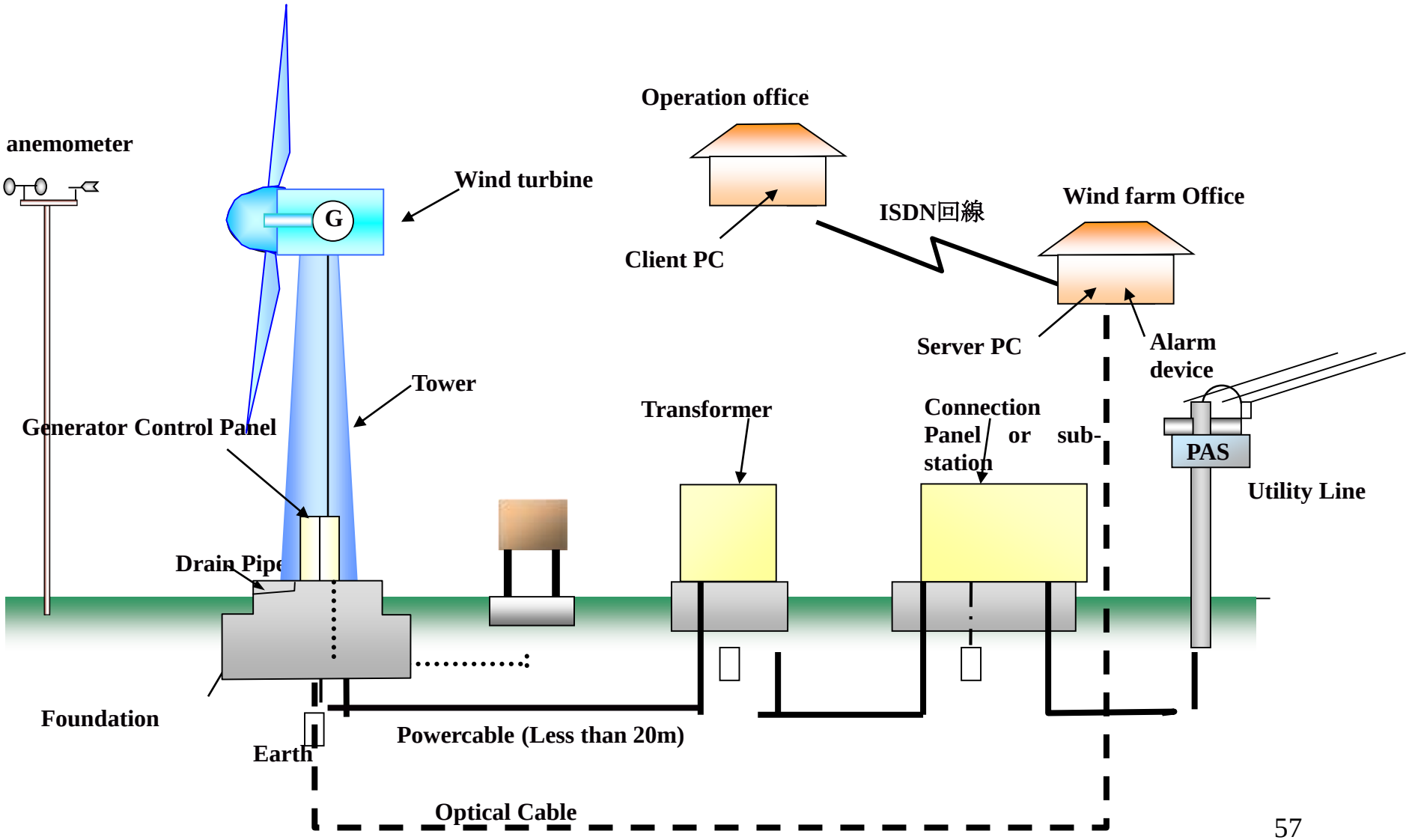
Performance of wind turbine rotor



Efficiencies of Components of Wind Power Generator



Wind turbine generation system



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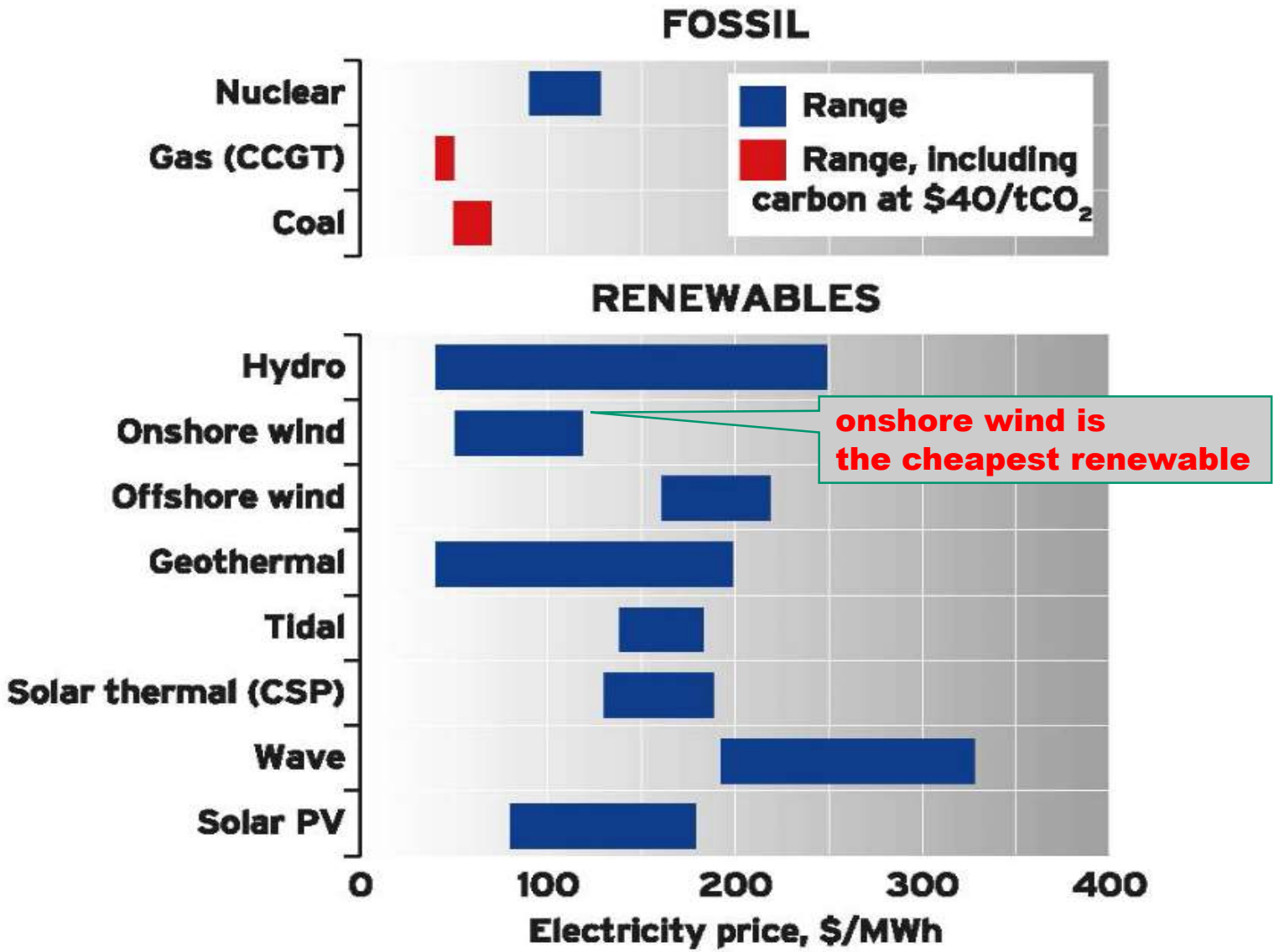
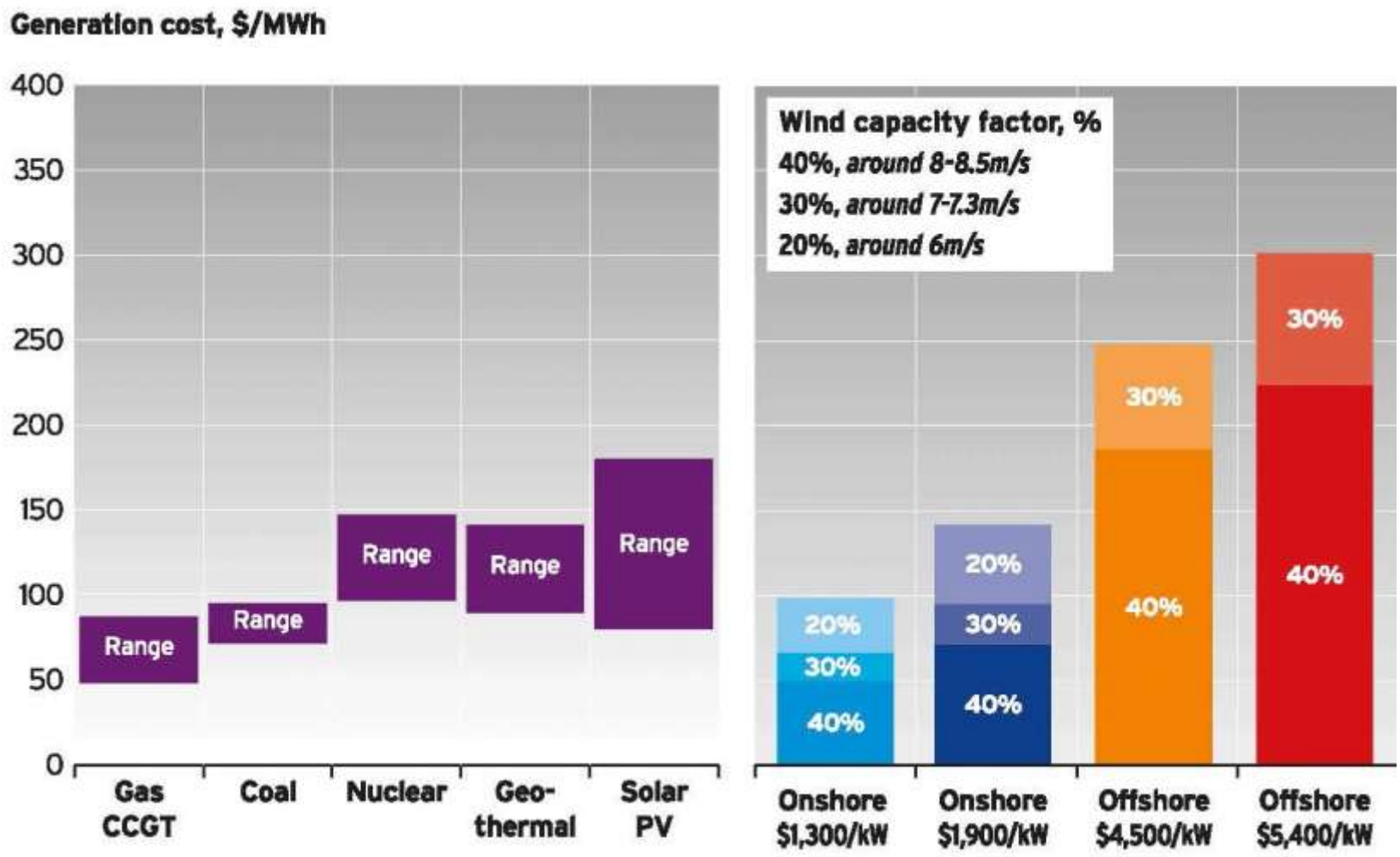
Price comparison of various energies

Generation cost projected 2020



Sources: International Energy Agency 2014; Decc UK Generation Costs Update 2013; EPRI 2013 Costs and Performance of Generation Technologies

Cost comparison with various capacity factors



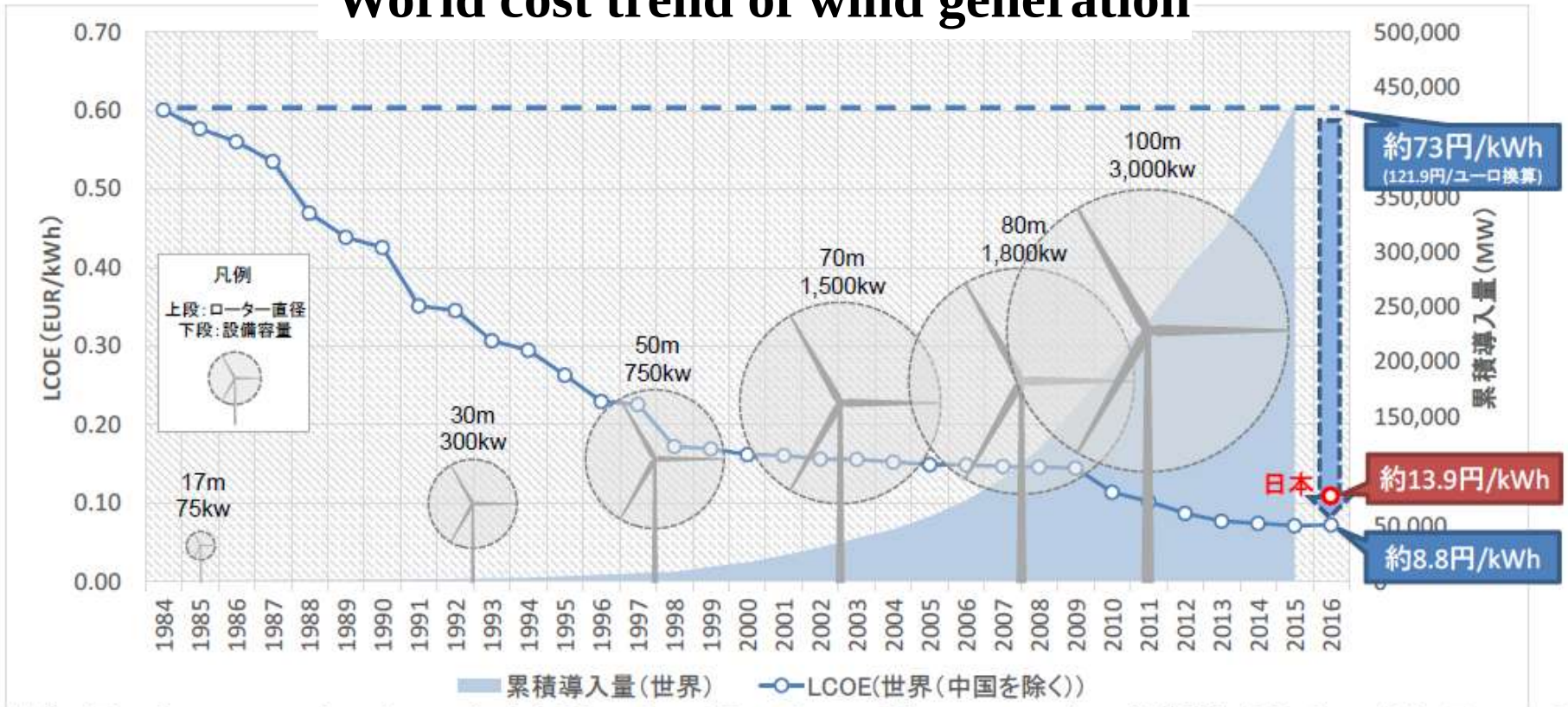
GAP NARROWS CHEAPEST ONSHORE BELOW $50/MWH WHILE OFFSHORE EXCEEDS PRODUCTIVITY GOALS

http://www.windpowermonthly.com/article/1330525/onshore-wind-competitive-ever

Trend of price down of wind energy

- On shore : 2-3 ¢ / kWh (USA)
- Off shore : 7.2 € ¢ / kWh (8.1円/kWh）;Netherland, June 2016
  : 6.0 € ¢ / kWh (6.9円/kWh）;Denmark, Sept. 2016 (+2 € ¢ / kWh (with submarine cable)

World cost trend of wind generation

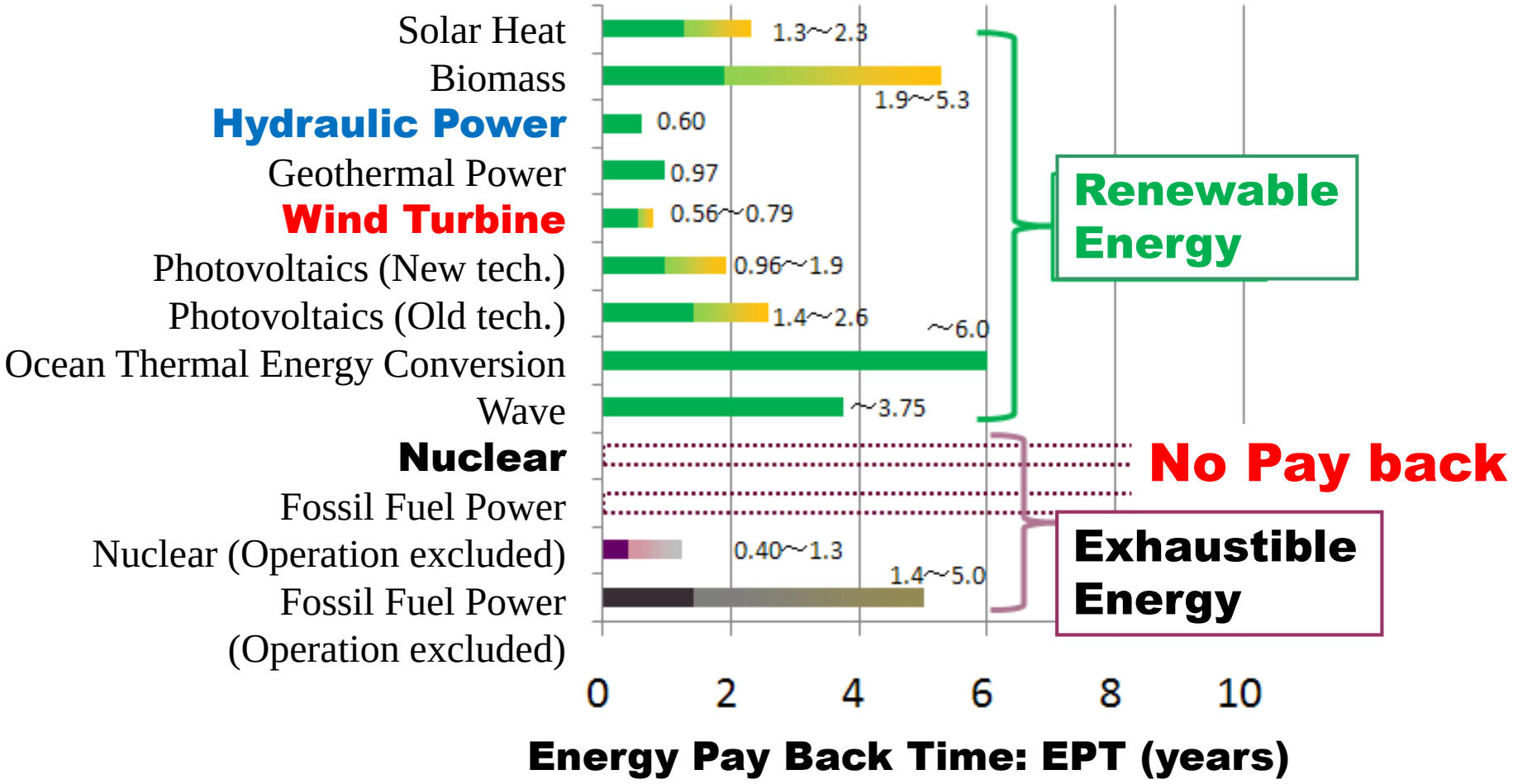


出典：The future cost of onshore wind （ Bloomberg New Energy Finance, 2015)、 IEA Wind Task 26 "The Past and Future Cost of Wind Energy(IEA, 2012)を基に NEDO 技術戦略研究センター作成

※LCOE：均等化発電原価。ライフタイムに要するコストの総計を現在価値に割引き、年間発電量に基づいて均等化して算出したコスト

出典：風力発電競争力強化研究会について -報告書 2016年10月17日 経済産業省
http://www.meti.go.jp/committee/kenkyukai/energy_environment/furyoku/report_01.html

Energy Pay Back Time by Each Power Plant



Wind Turbines Manufacturers of Japan

MITSUBISHI HEAVY INDUSTRIES
2.5 MW
(7MW)

JAPAN STEEL WORKS
2.7 MW
(3MW)

KOMAIHALTEC
300 kW

HITACHI
2.0 MW
(5MW)

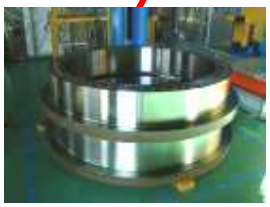
( ) under development

Wind turbine sub-components

Wind turbines are consisted by about 10,000 of Mechanical/Electrical components/parts.



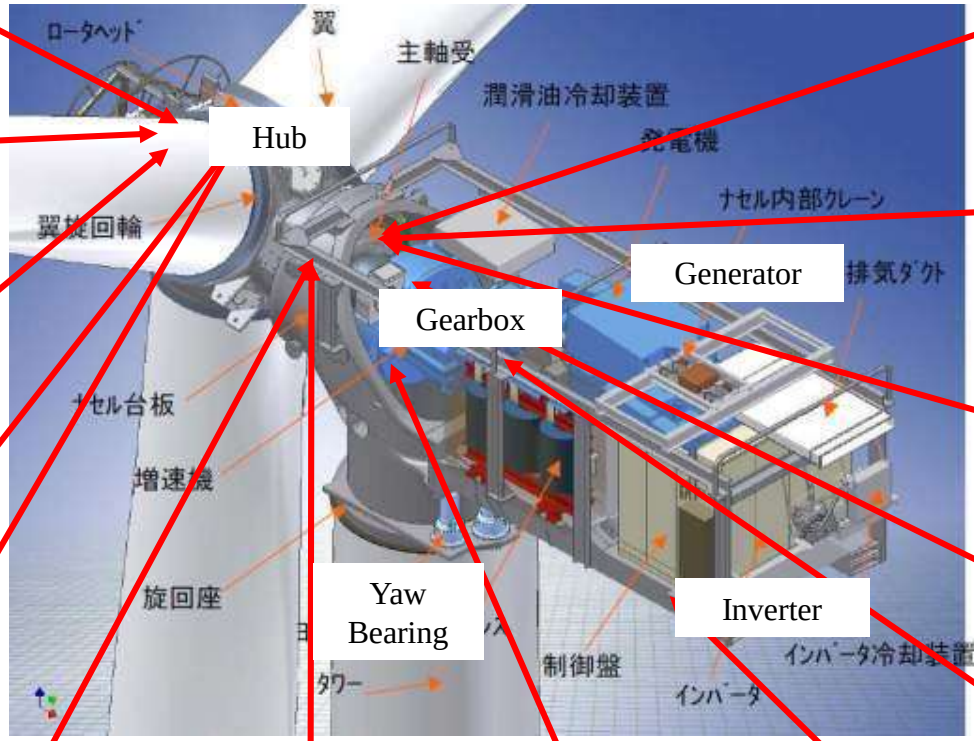


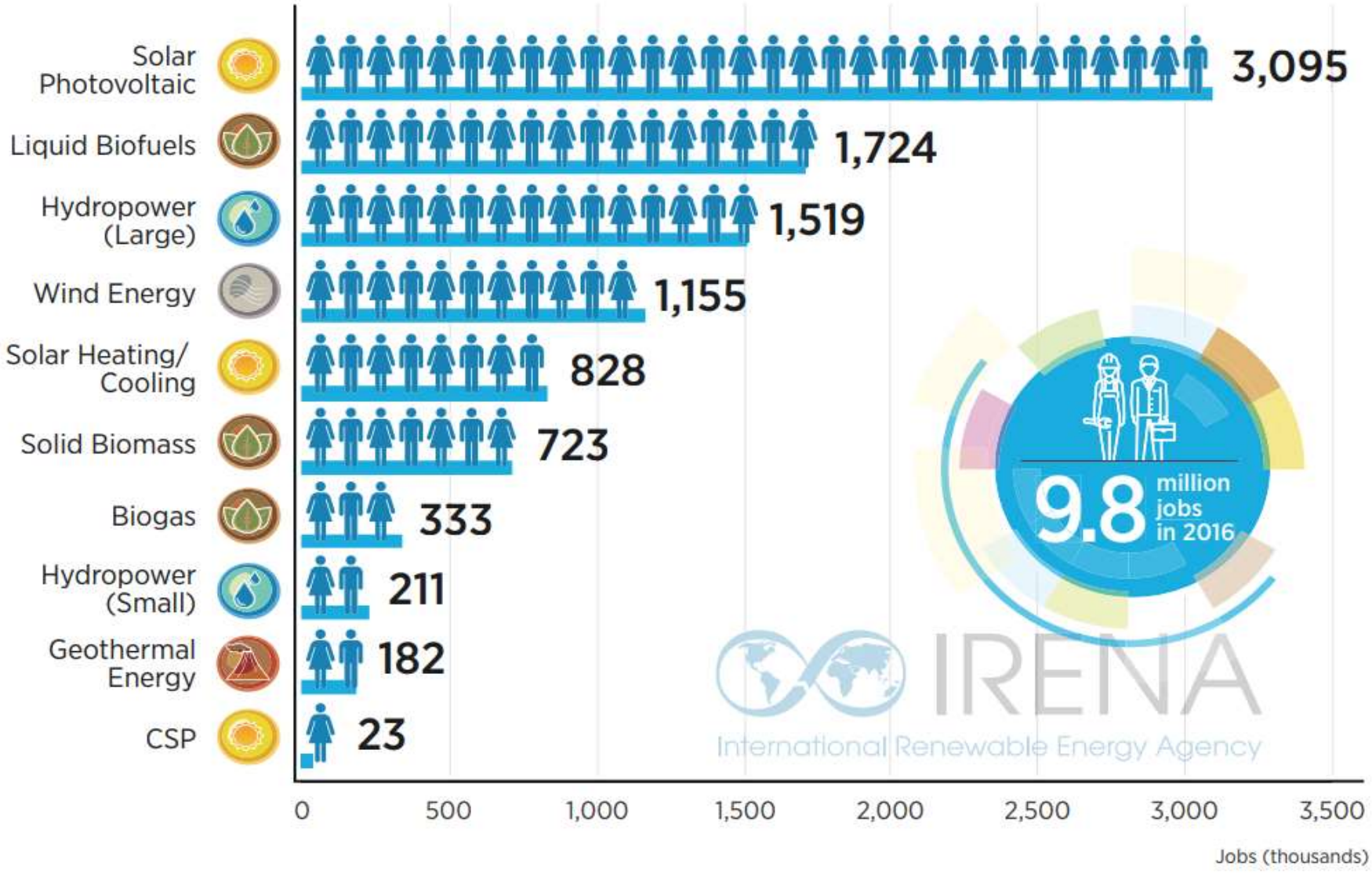






Renewable energy employment (Job creation)



Renewable Energy and Jobs, Annual Review 2017 IRENA

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“Fukushima”changed Germany: to denuclearization

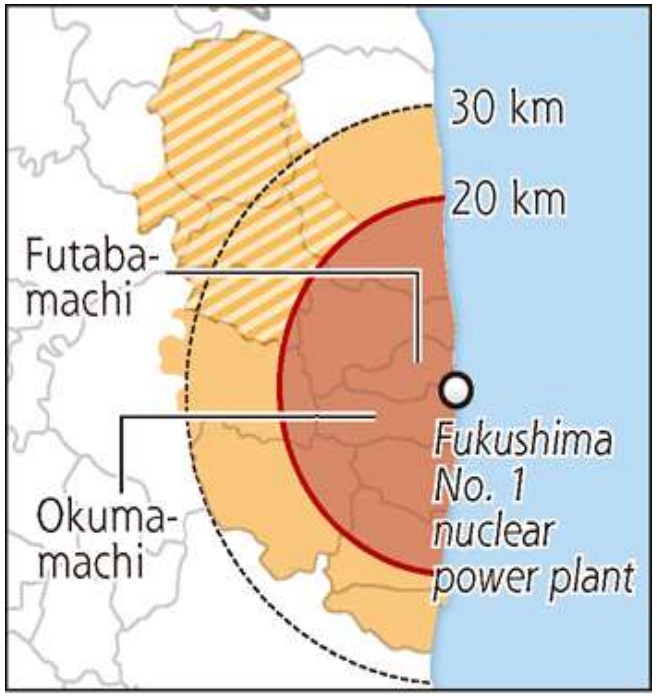
“Prime minister Merkel wake up as an approver of nuclear power in the morning of march 11, 2011, and went to bed as an opponent of nuclear power on the same night.”（from “Der Spiegel”）

Merkel loves wind energy

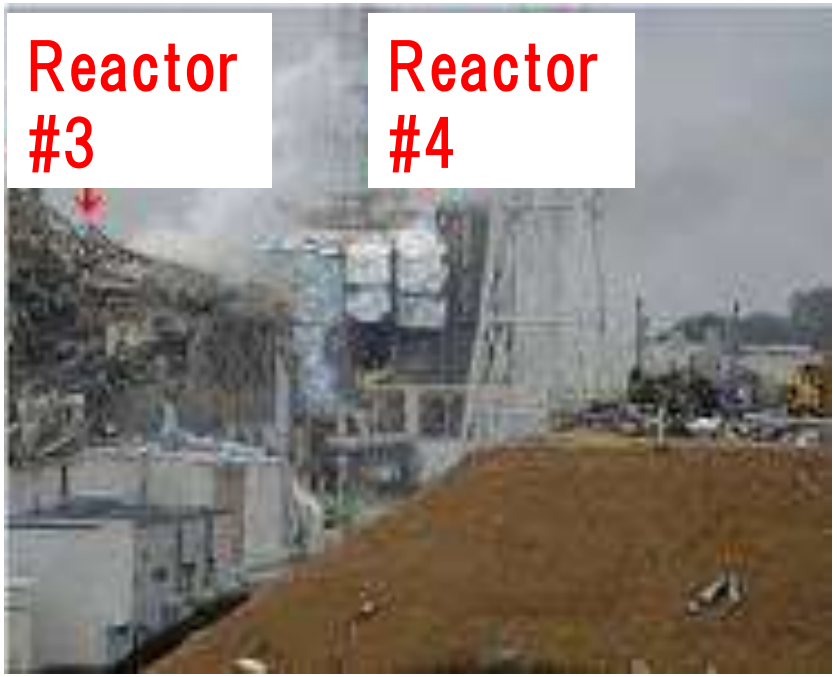
because of God's breathing.

Public Opinion has changed in Japan

Impact of Fukushima No.1 nuclear incident in 2011 was broad and long-lasting, thus public opinion dramatically changed from "accepting-nuclear" stance to "anti-nuclear and pro-renewables"



Source: Daily Yomiuri

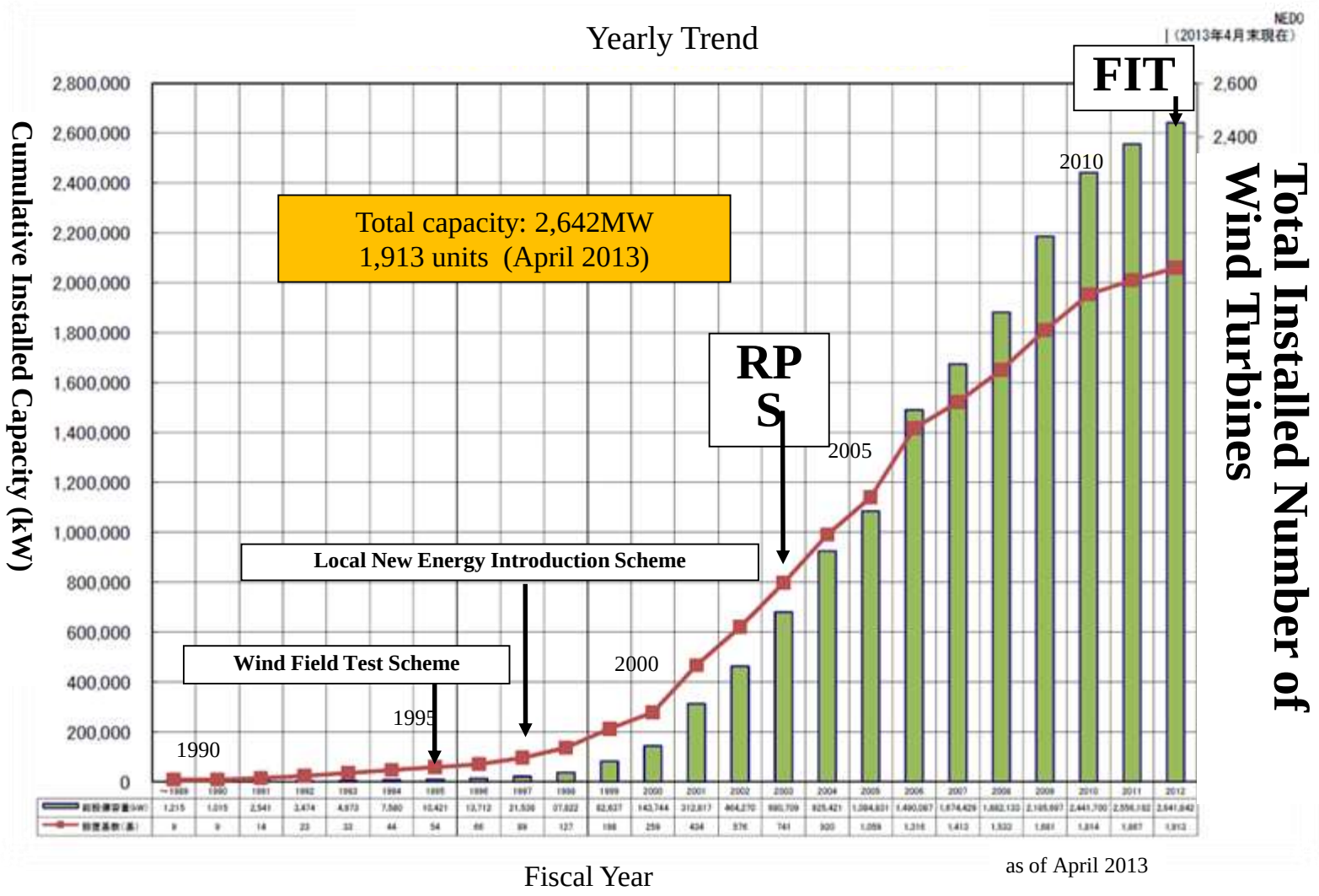


Source: Jiji Press

Typical Wind Farm in Japan;

Hakodate in Hokkaido

Wind Energy Growth of Japan

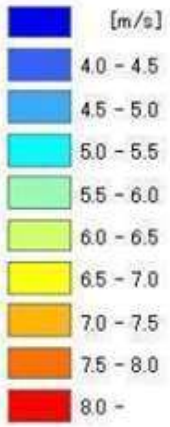


Ongoing National Offshore Wind Projects

Goto
2012 FHI 100kW
2013 Hitachi 2MW
（Floating）

Hibikinada
2013
JSW 2MW

Fukushima
2013 Hitachi 2MW, Floating Power Station
2014 MHI 7MW
2015 MHI 7MW
（Floating）



Choshi
2013
MHI 2.4MW

Floating Type Offshore WT

HITACHI 5MW

Rotor Dia.126m at Fukushima

This machine got “Good Design Award” in 2017

World Biggest 7MW WTG on 3 Column Floater in Fukushima 2015

World First Wind Thermal Generation

Heat Generator：Rotating power is changed to heat by IH.

Gear less

50～100m

Circulation of liquefied salt.

Steam turbine

Steam generator

Heat recerver

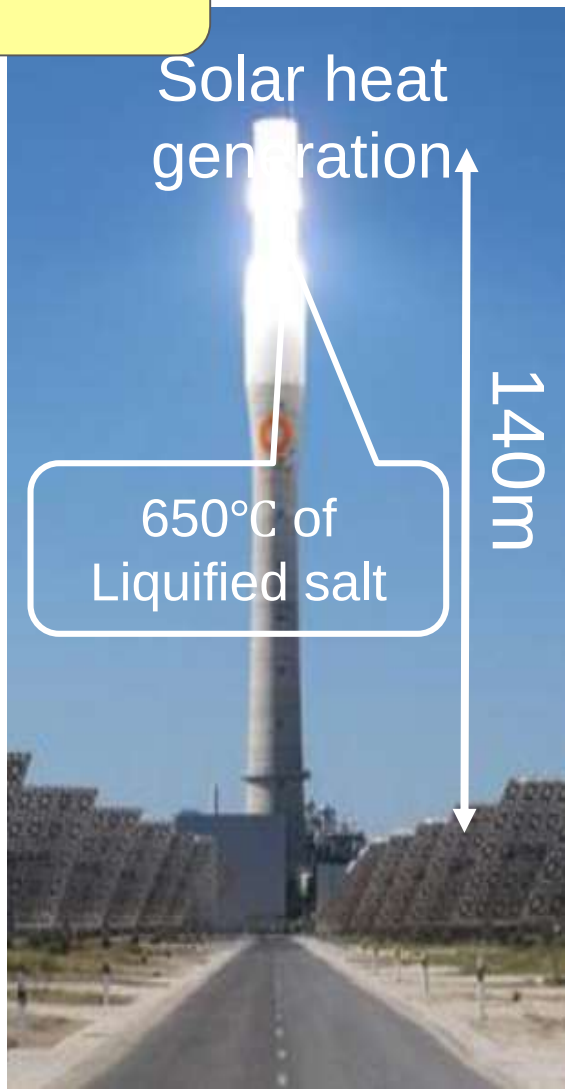
Gene

Condenser

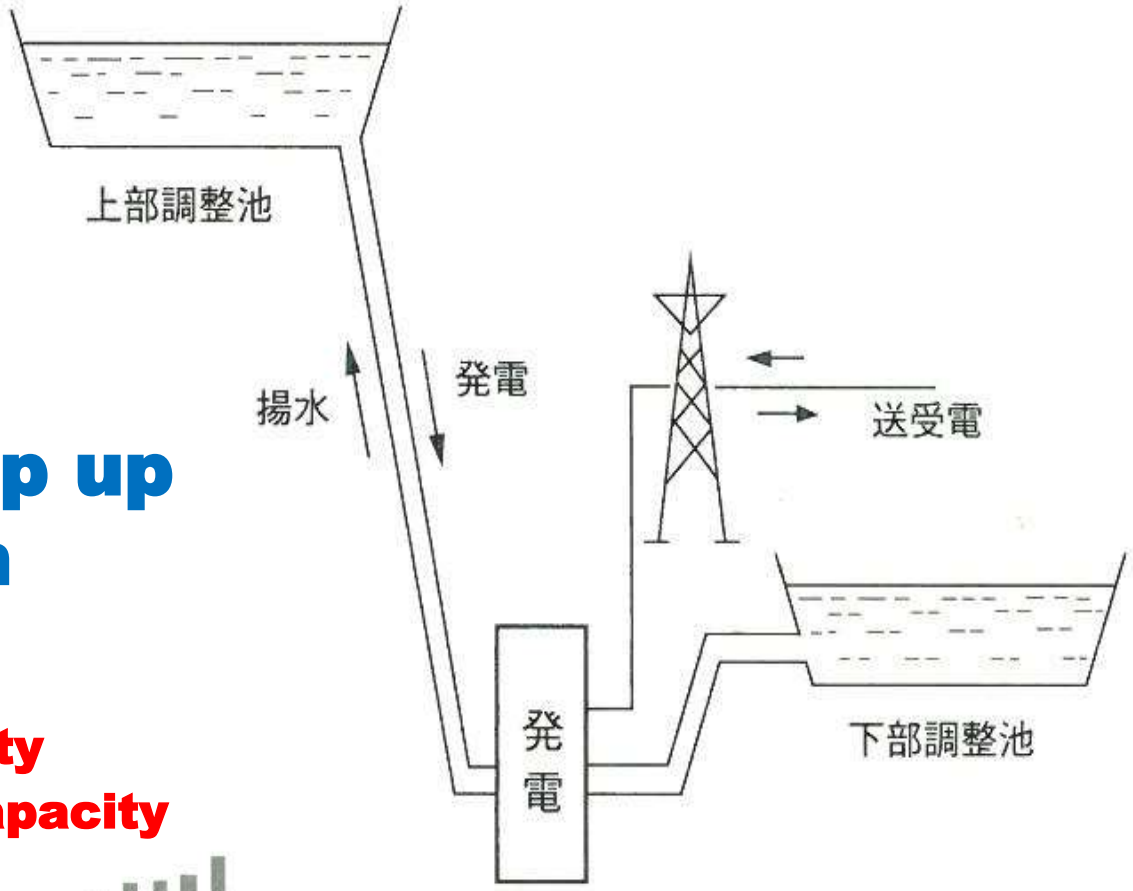
To another tower

Same as Steam turbine

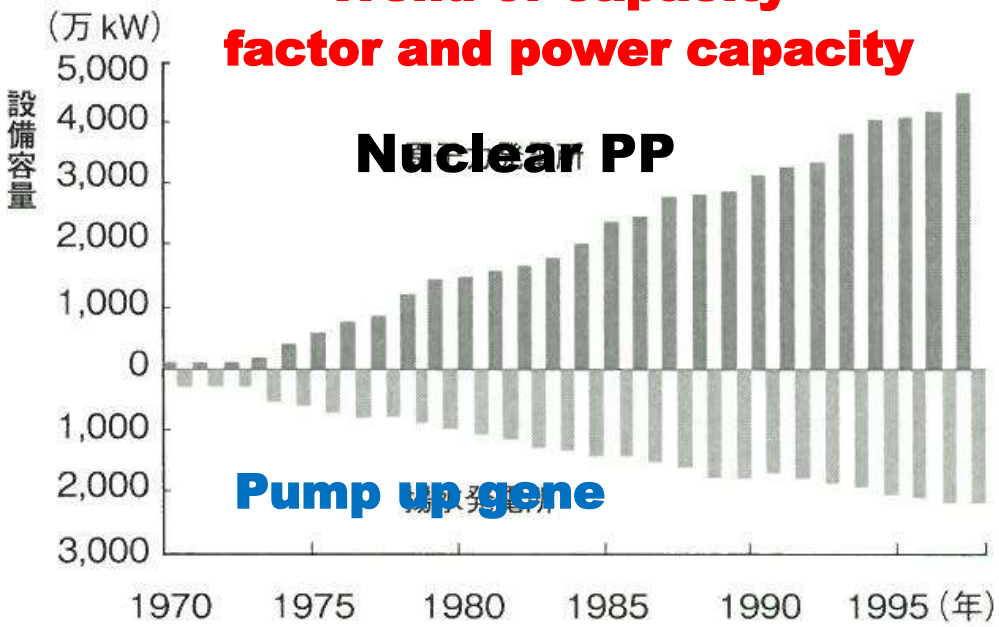
Same as solar heat generation



Nuclear PP & Pump up generation system



Trend of capacity factor and power capacity



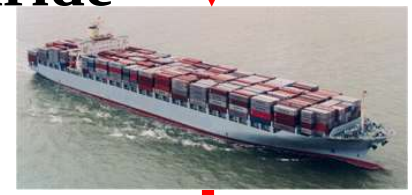
Pump up water system

Wind Energy to Hydrogen in every strong wind area

Liquefied Equipment

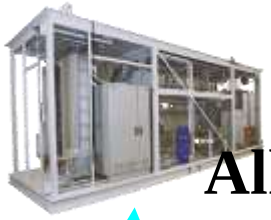
LH Carrier

Organic Hydride



Oxygen

Hydrogen



Alkalizer

In country distribution system

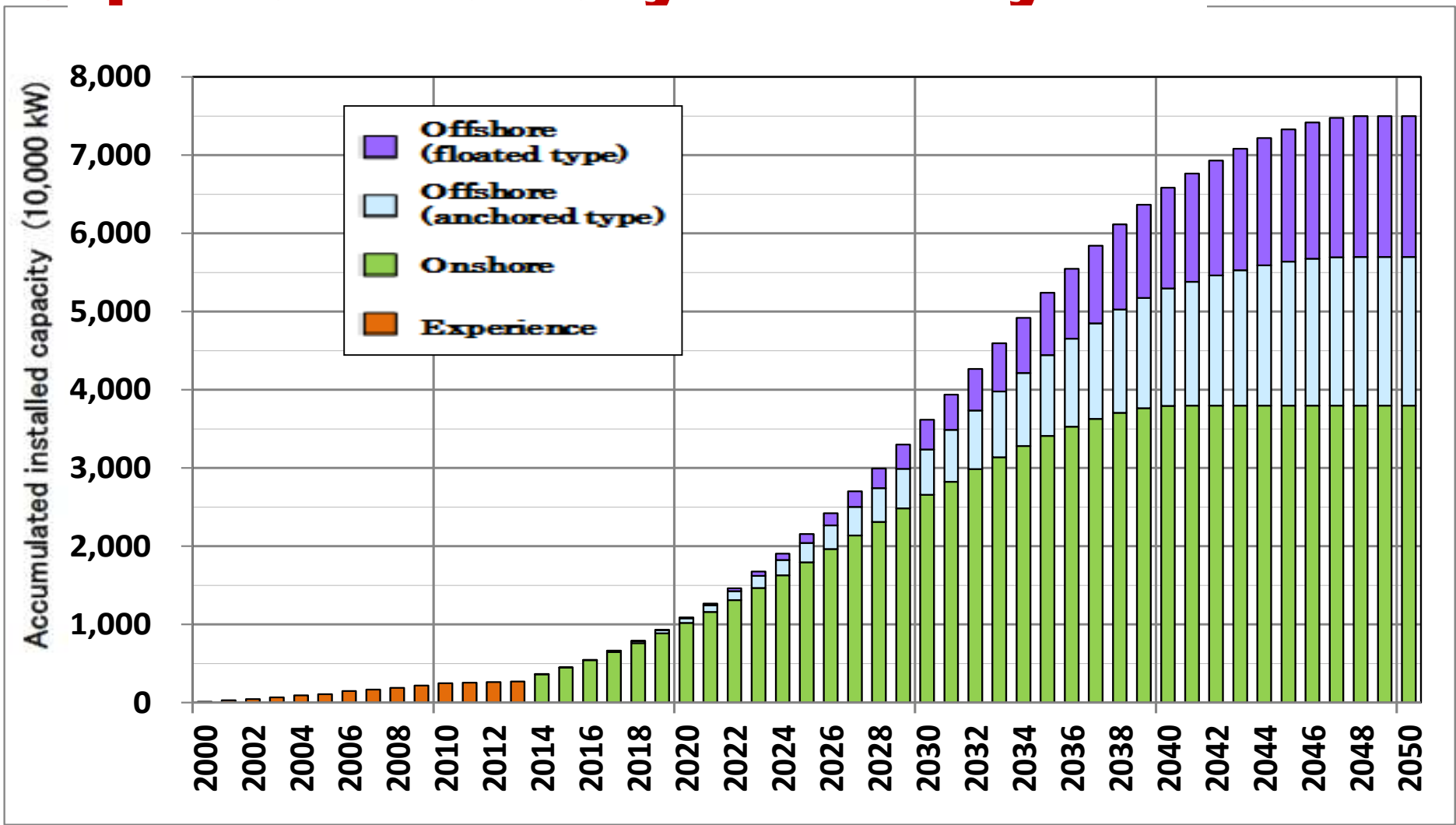
Pipeline - Vehicle - Train - Ship

Water

- LH2 Turbine Power station
  Fuel Cell Power station
  Fuel cell Vehicle
- For House
  For Commercial use
  For Office use
- Industrial Application
  - Synthesas Gas
  - Annmonia Plant
  - Fertilizer Plant etc

Roadmap for the introduction of wind power estimated by JWPA

Wind power supplies more than 20% of Japanese electricity demand by FY 2050.



CONCLUSION

Energy Hunting Civilization
by **Fossil Fuel**

Transition period
(Natural Gas / Nuclear)

Energy Cultivating Civilization
by **Renewable Energy**

Sustainable Society