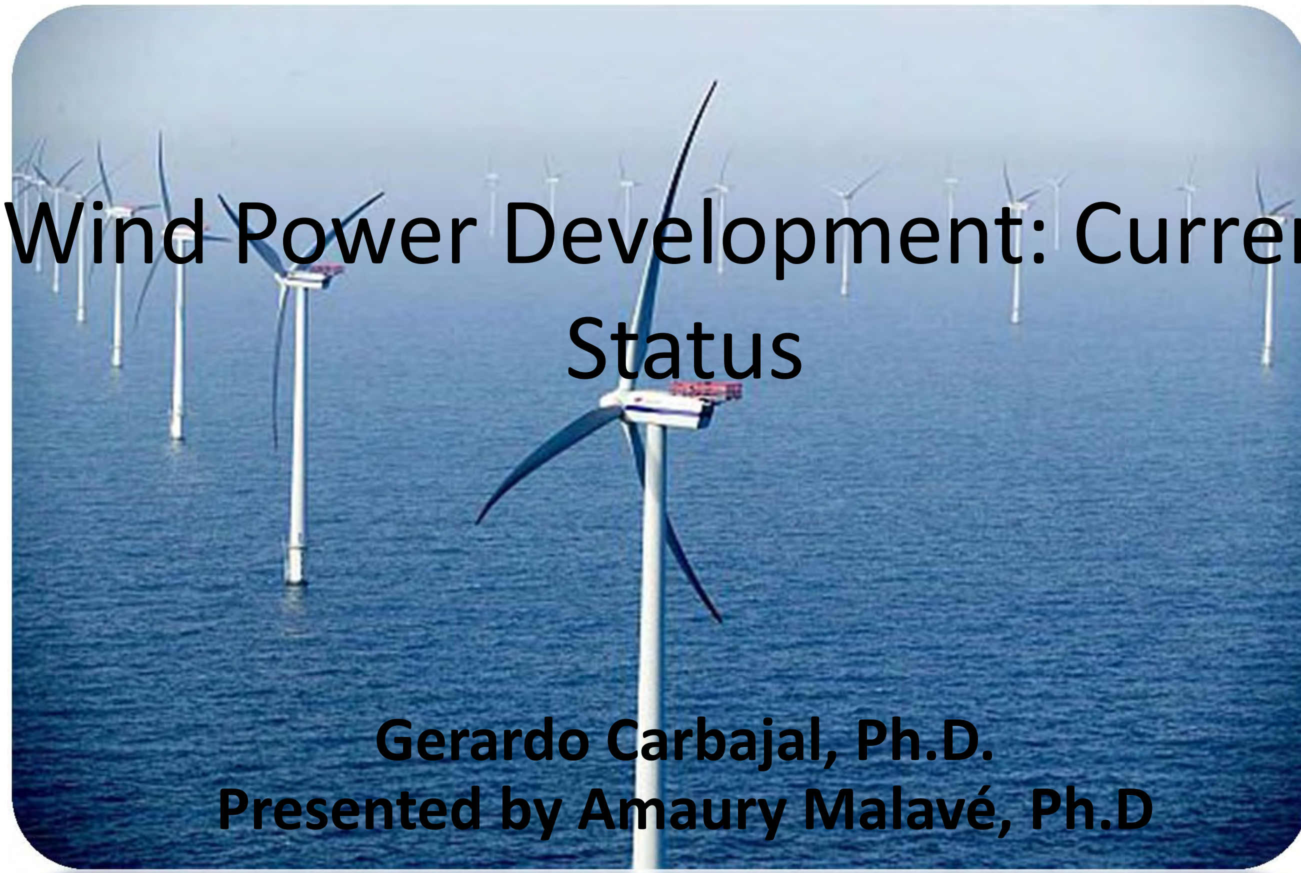
PUERTO RICO ENERGY CENTER

An INTECO project operated by Universidad del Turabo



Wind Power Development: Current Status

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Presentation Outline

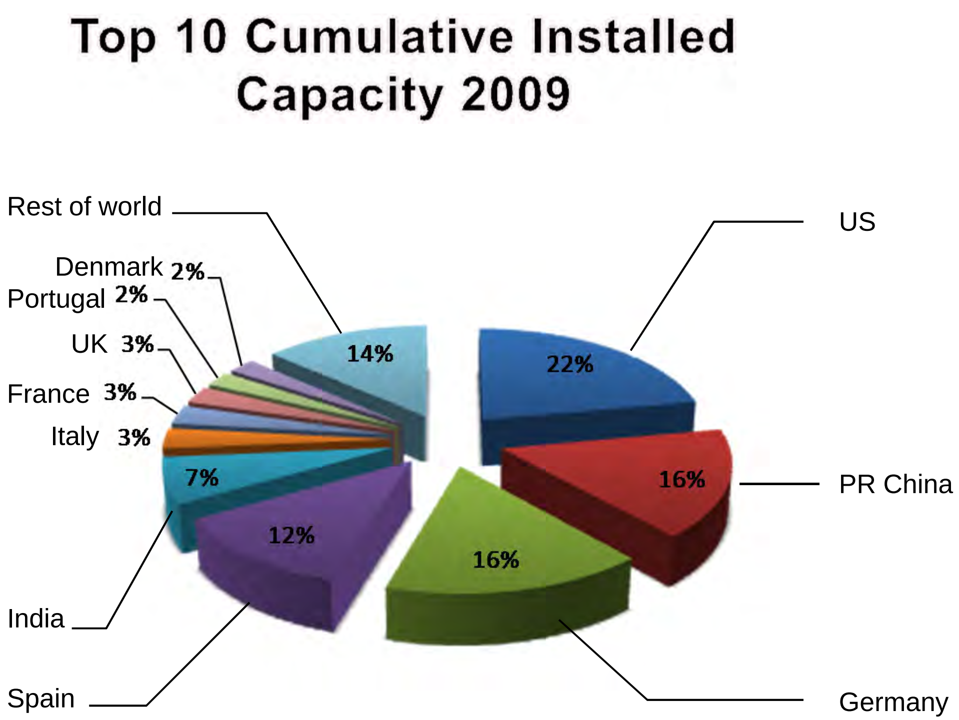
- Introduction
- Wind Energy- Global Context
- Renewable Energy Targets
- Renewable Predictions-US
- Wind Energy- US, PR
- Wind Energy Challenges: Onshore, Offshore
- Wind Power – Universidad del Turabo

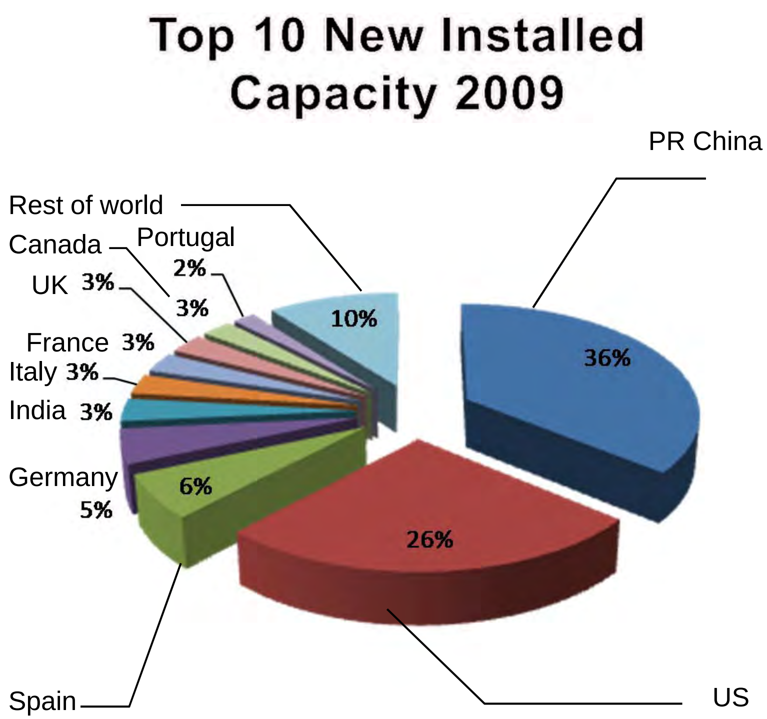
Introduction

- The unpredictable oil prices, geopolitical and military tensions rising over oil reserves, and growing concerns about climate change, make the alternate sources of energy to becoming more attractive.
- More than 99% of the total electricity in Puerto Rico was generated from fossil fuels (coal, oil, natural gas) resulting in a significant emission of the man-made carbon dioxide.
- Nearly two-third of the total electricity in the US was similarly generated from fossil fuels.
- Puerto Rico can generate energy from vast renewable energy sources.

Wind Energy Global Context

Since 2003 wind power installed capacity has increased significantly around the world. For example, the global market of wind energy increased by 41% in 2009 [1].



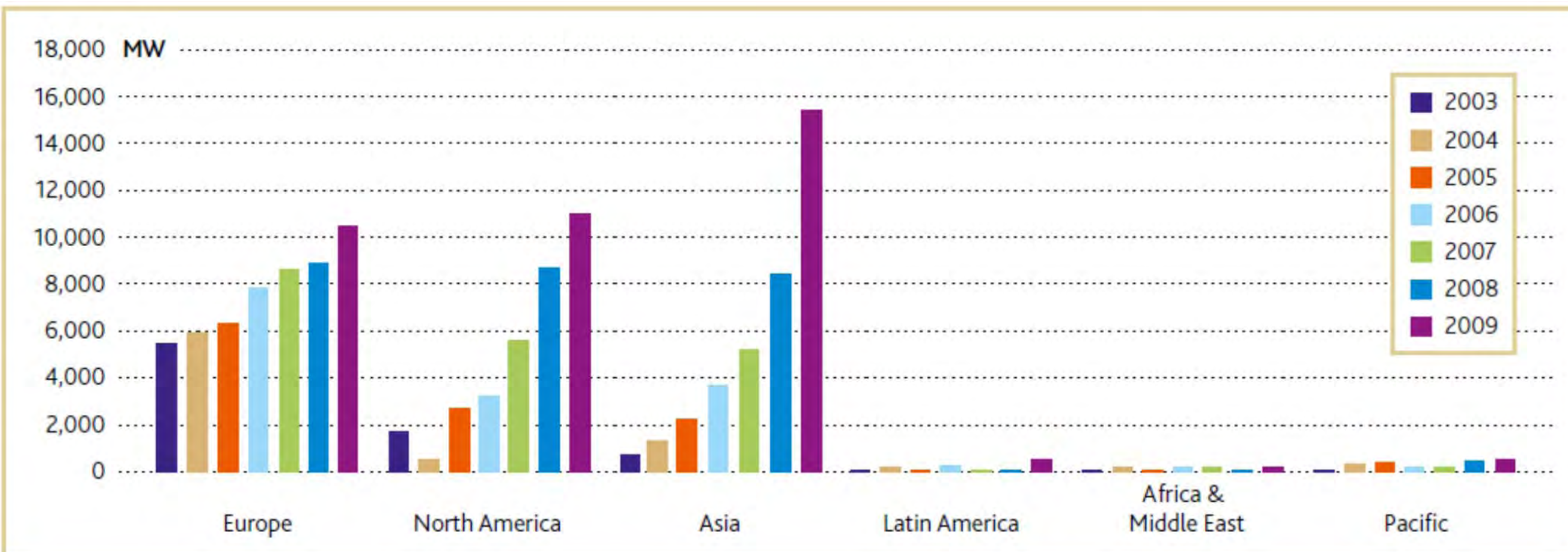


[1]Global Wind Energy Council, Global Wind 2009 Report

Wind Energy Global Context

The United Stated is presently the world leader in installed wind capacity. In 2009 alone the US wind energy market installed nearly 10 GW, representing an increase of 39 % of the total installed grid-connected capacity to 35 GW. Asia was the world's fastest market of installed wind capacity during 2009, driven primarily by China

Annual Installed Wind Capacity by Region for the period between 2003-2009 [(1)]



[(1)]Global Wind Energy Council, Global Wind 2009 Report

Renewable Energy Targets

Renewable Energy Targets from different countries around the world [1].

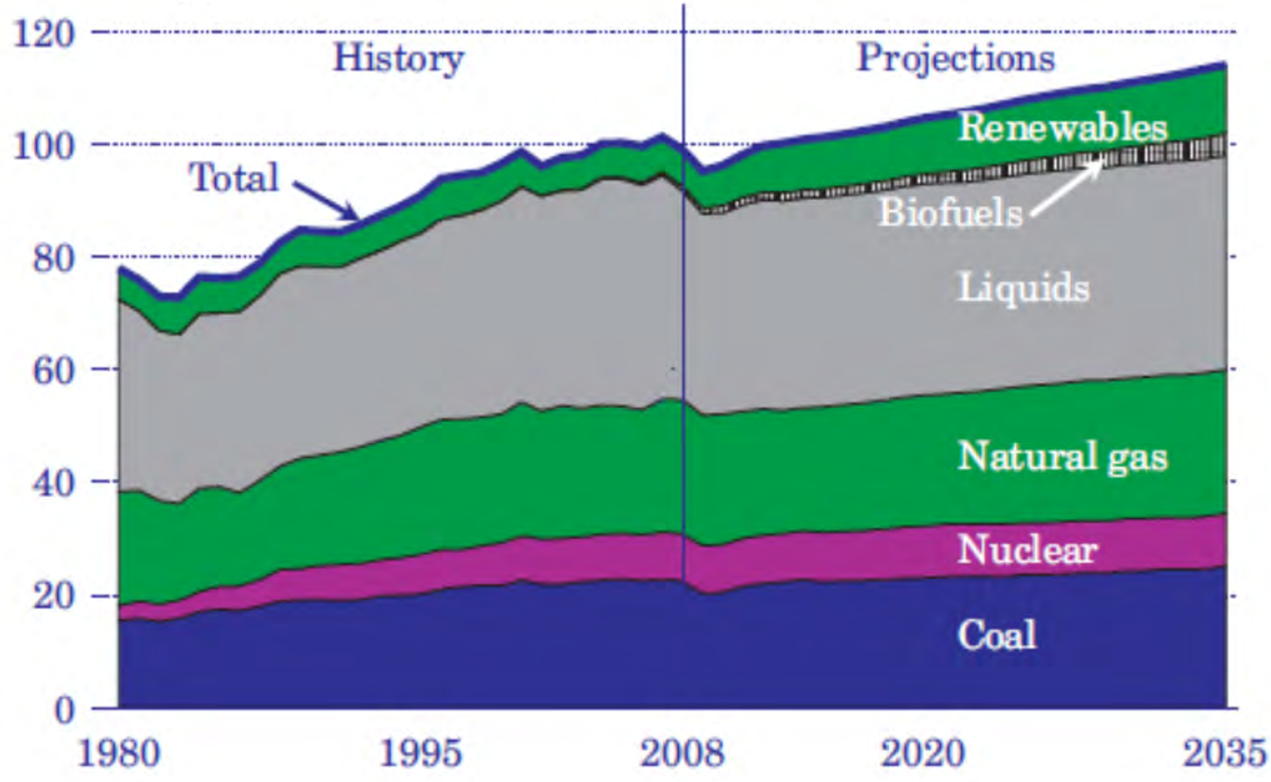
Country	Year of Target	Total Energy by Renewable (%)
Australia	2020	20
Denmark	2025	50[a]
Europe Union	2020	20
France	2020	23
Germany	2020	18
United Kingdom	2020	15
United States	2025	25

[a] wind energy

[1] Global Wind Energy Council, Global Wind 2009 Report

Renewable Energy Predictions -US

The Annual Energy Outlook 2010 report [(2)] projections of US energy consumption (in quadrillion BTU) through 2035 indicates that renewable energy will keep on the rise.

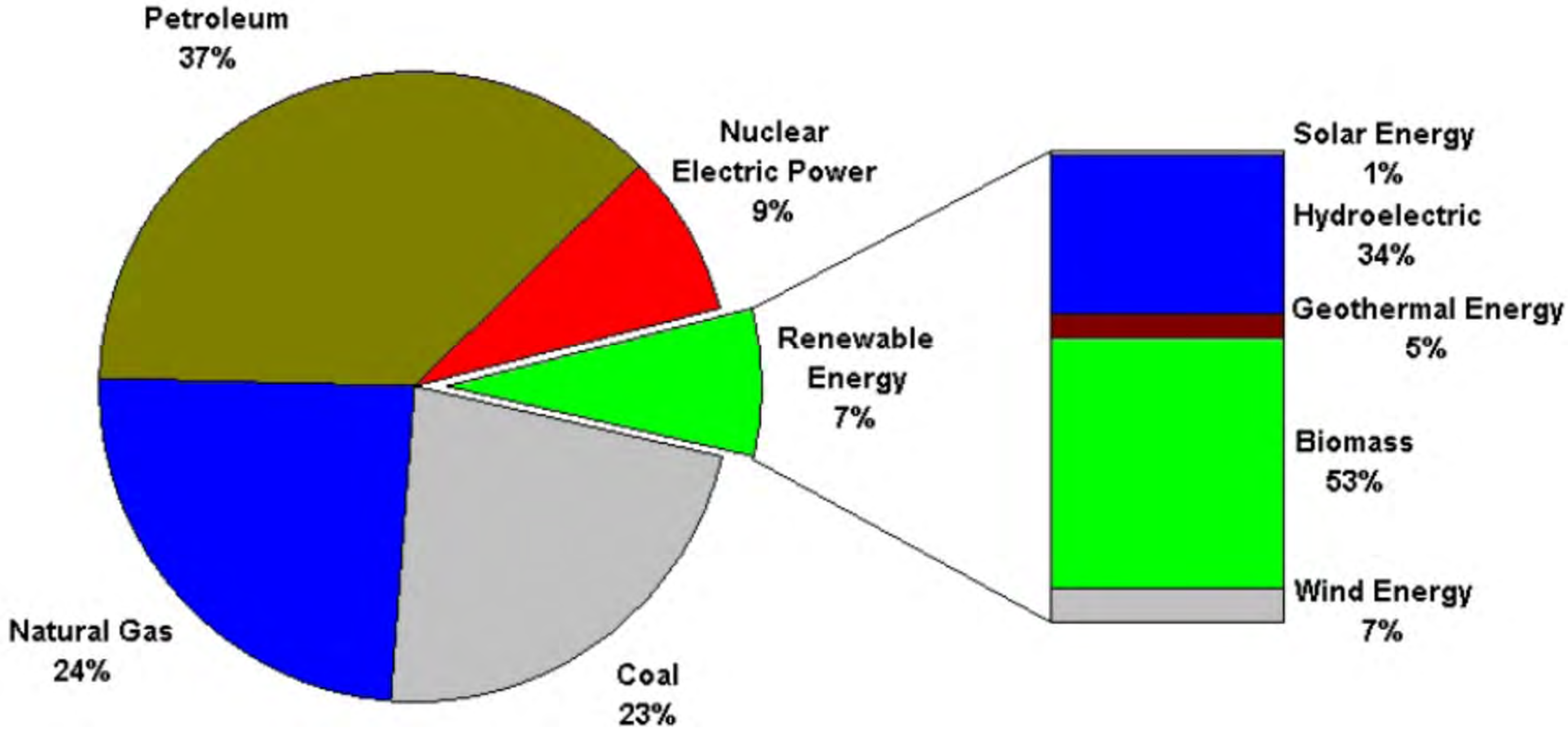


By 2035 it is expected that ~12 quadrillion BTU of the US energy consumption will came from renewable energy

[(2)]Energy Annual Energy Outlook 2010 with Projections to 2035, U.S. Energy Information Administration Office of Integrated Analysis and Forecasting U.S. Department of Energy.

Wind Energy in the US

Renewable energy consumption in the nation energy supply corresponding to the year 2008[(3)]

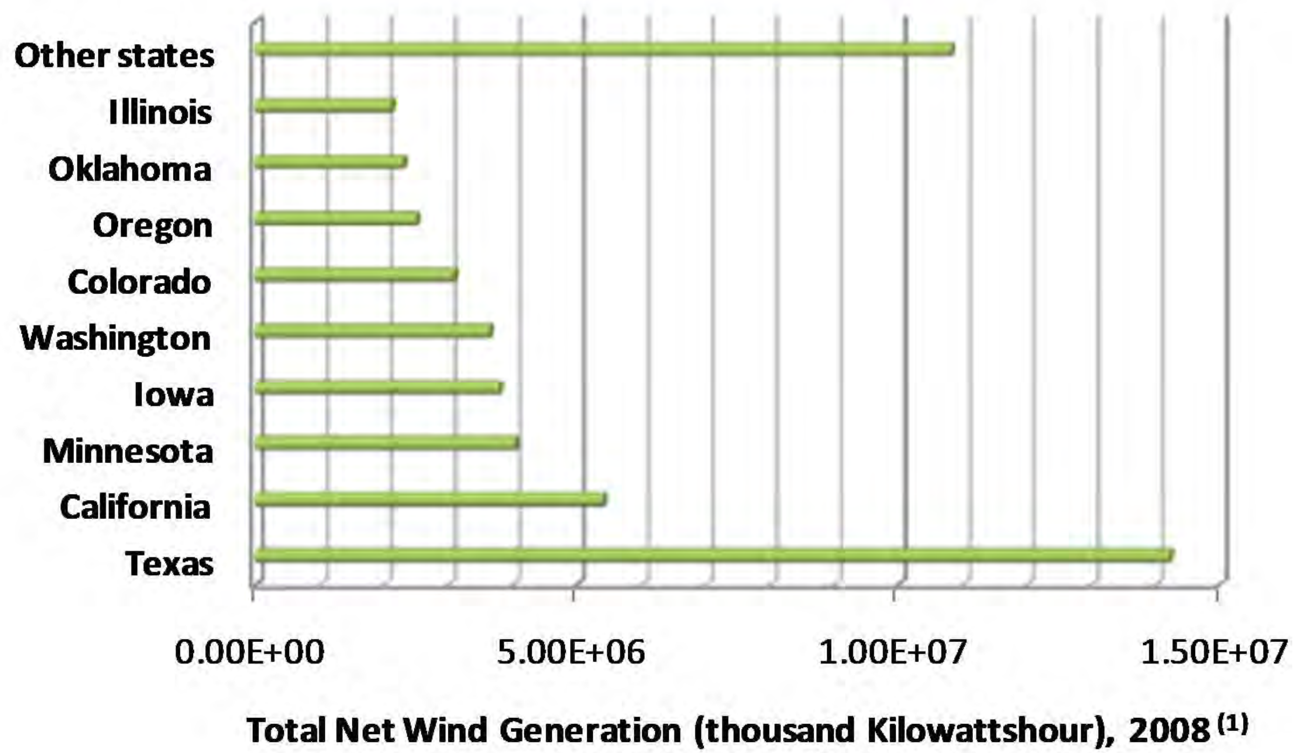


Wind energy represented in 2008 the biggest increase in renewable generation. During this year wind provided ~**1.3 % of the total US energy generation.**

[(3)]Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels U.S. Department of Energy Renewable Energy Consumption and Electricity Preliminary Statistics 2008.

Wind Energy in the US

In 2008 seven states had more than 1 GW of installed wind capacity [2]. The 2009 numbers reveal that 14 states now have more than 1 GB installed [1]. Texas lead the energy generation by wind power in the US.



Wind Energy in Puerto Rico

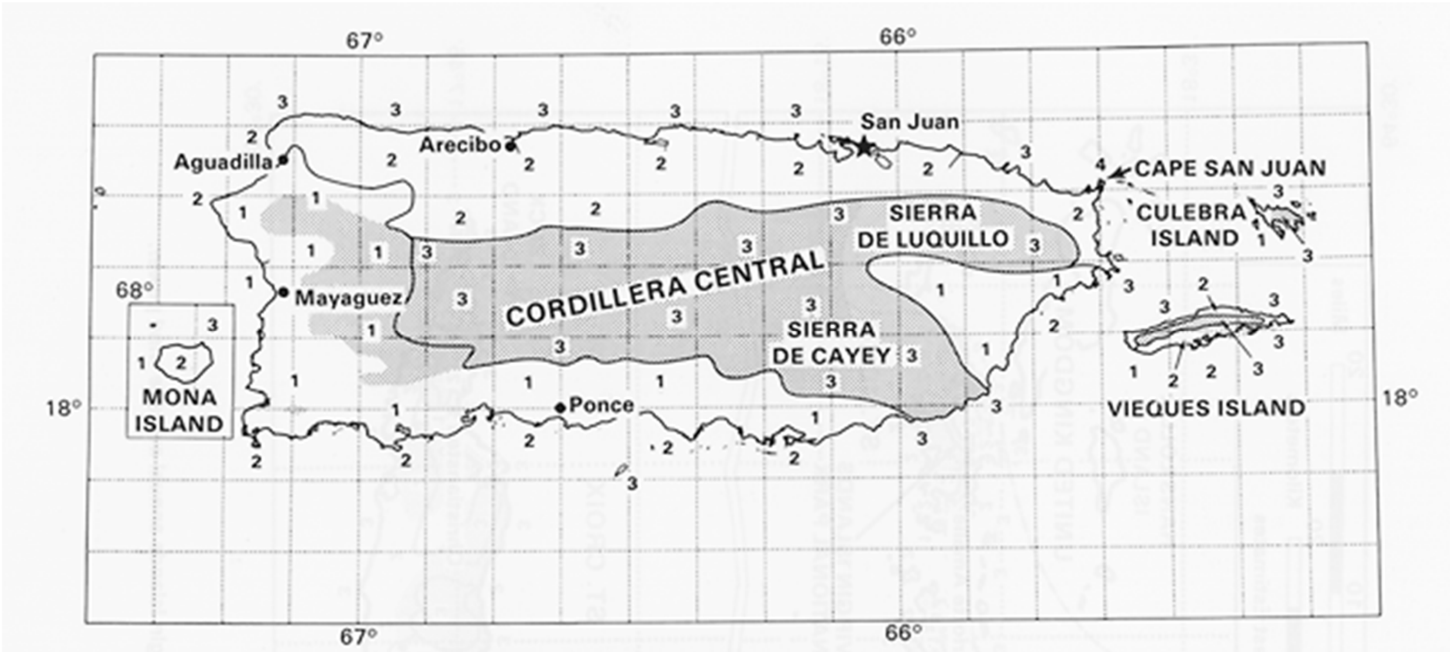
http://multivu.prnewswire.com/mnr/bacardi/43417/

Facts

- There is not yet an official statistic available about the installed wind power capacity in Puerto Rico.
- Bacardi Corporation has installed the largest wind turbine in the Island. The two wind turbines has the capacity to generate 250 kW each one.
- According to NREL Puerto Rico has good wind power offshore.

Wind Energy: PR Onshore

Puerto Rico Annual Wind Power Average (8)



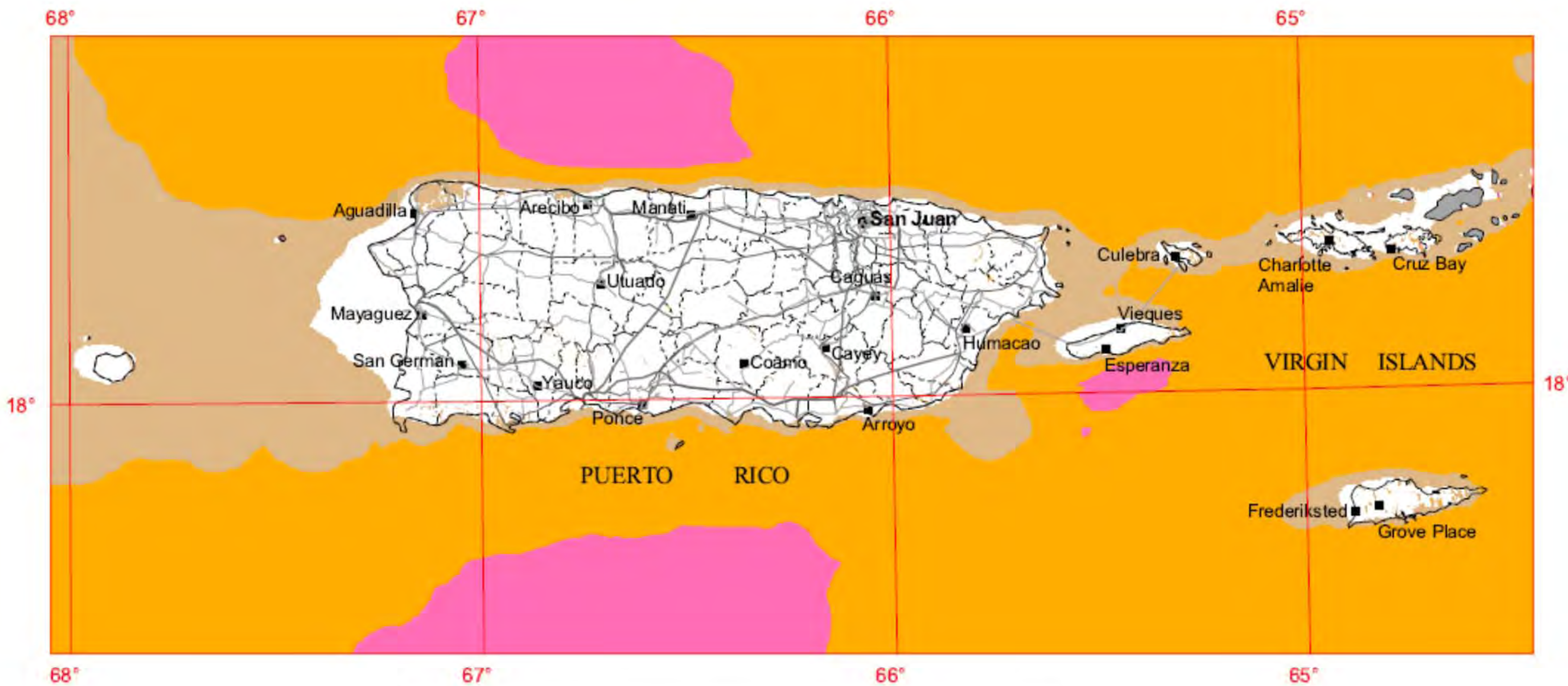
Wind Power	10 m (33 ft)		50 m (164 ft)	
Class	Wind Power Density (W/m^2)	Speed (b) m/s (mph)	Wind Power Density (W/m^2)	Speed (b) m/s (mph)
1	0	0	0	
	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

a. Vertical extrapolation of wind speed based on the 1/7 power law.
b. Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation

(8) http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-71m.html

Wind Energy: PR Offshore

Puerto Rico and US Virgin Islands – 50 m Wind Power



Wind Power Classification

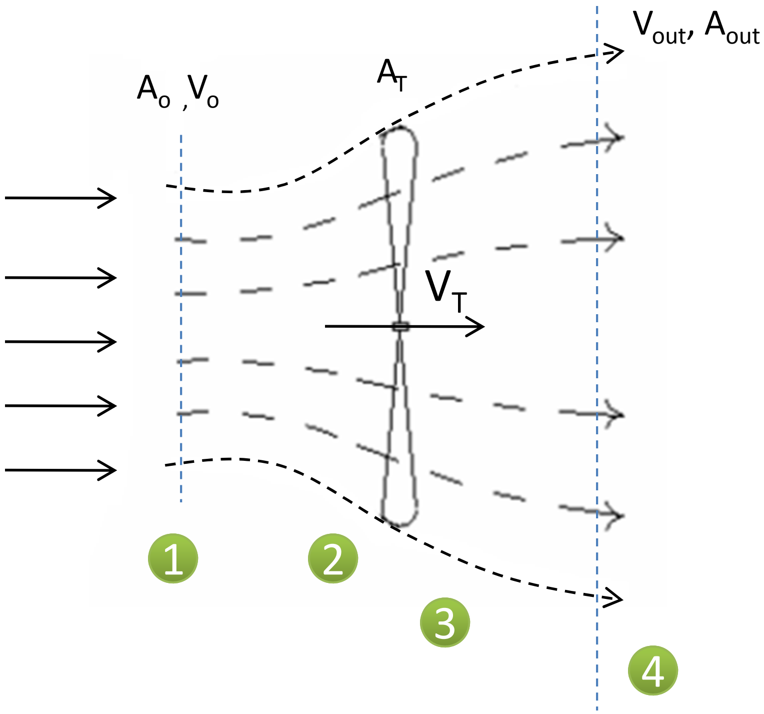
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.8	13.2 - 15.2
3	Fair	300 - 400	6.8 - 7.5	15.2 - 16.8
4	Good	400 - 500	7.5 - 8.0	16.8 - 17.9
5	Excellent	500 - 600	8.0 - 8.5	17.9 - 19.0

[a] Wind speeds are based on a Weibull k of 2.5 at sea level.

http://www.windpoweringamerica.gov/pdfs/wind_maps/pr_vi_50m.pdf

Wind Turbine: Fundamental Analysis

The basic governing equations are used to estimate the mechanical wind power output.



Momentum equation:

$$F = \dot{m}\left(V_o - V_{out}\right)$$

Mass conservation:

$$\dot{m} = \rho V_o A_o = \rho V_T A_T = \rho V_{out} A_{out}$$

Bernoulli's equation:

section (1) - (2)

$$\frac{p_o}{\rho} + \frac{V_o^2}{2} = \frac{p_2}{\rho} + \frac{V_T^2}{2}$$

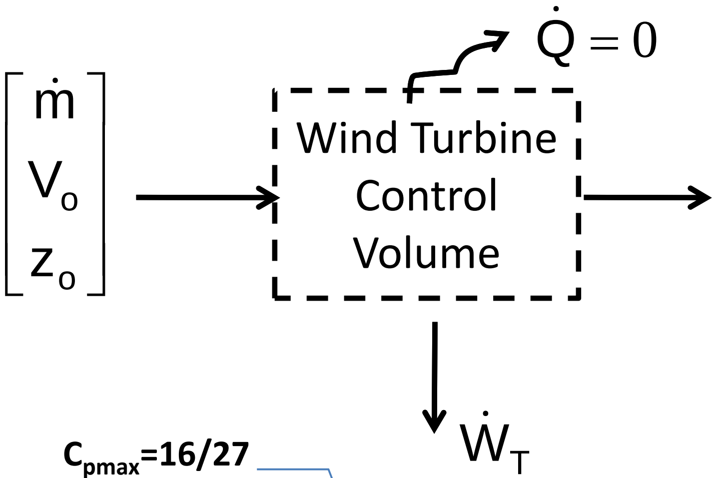
section (3) - (4)

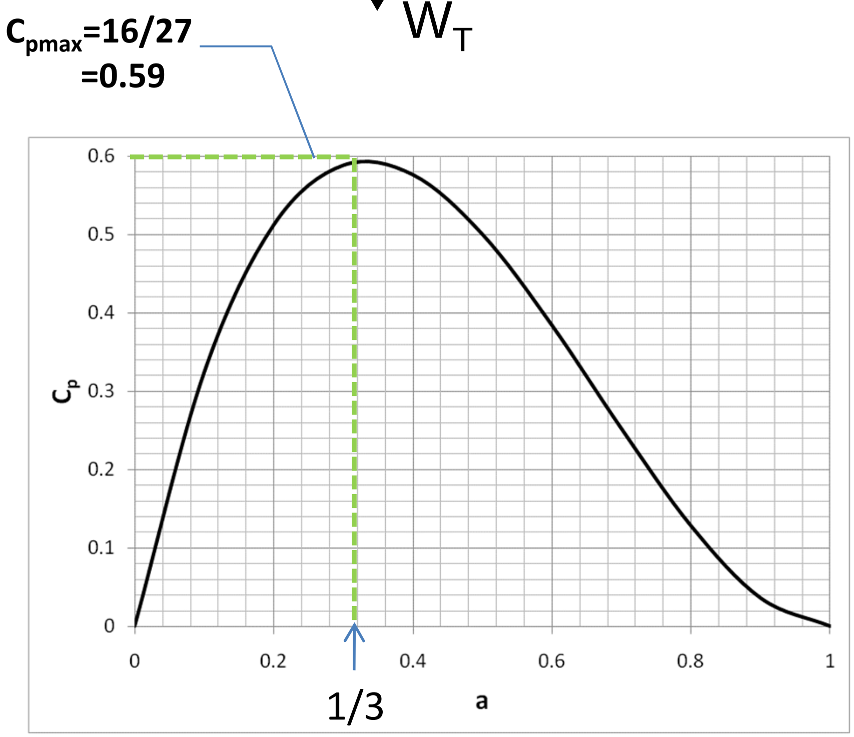
$$\frac{p_3}{\rho} + \frac{V_T^2}{2} = \frac{p_{out}}{\rho} + \frac{V_{out}^2}{2}$$

Pressure difference: $F = A_T\left(p_2 - p_3\right)$ between sections (2) - (3)

The factor "a": $a = \dfrac{V_o - V_T}{V_o}$ ⟹ $V_T = V_o(1 - a)$

Wind Turbine: Fundamental Analysis





Energy balance:

$$\dot{W}_T = \dot{m}\left(\frac{V_o^2}{2} - \frac{V_{out}^2}{2}\right) = \frac{1}{2}\rho V_T A_T \left(V_o^2 - V_{out}^2\right)$$

The mechanical wind power in terms of the factor "a":

$$\dot{W}_T = \frac{1}{2}\rho V_o (1-a) A_T \left[V_o^2 - V_o^2 (1-2a)^2\right]$$

$$= \frac{1}{2}\rho V_o^3 A_T \, \boxed{4a(1-a)^2}$$

→ Coefficient of power, Cp

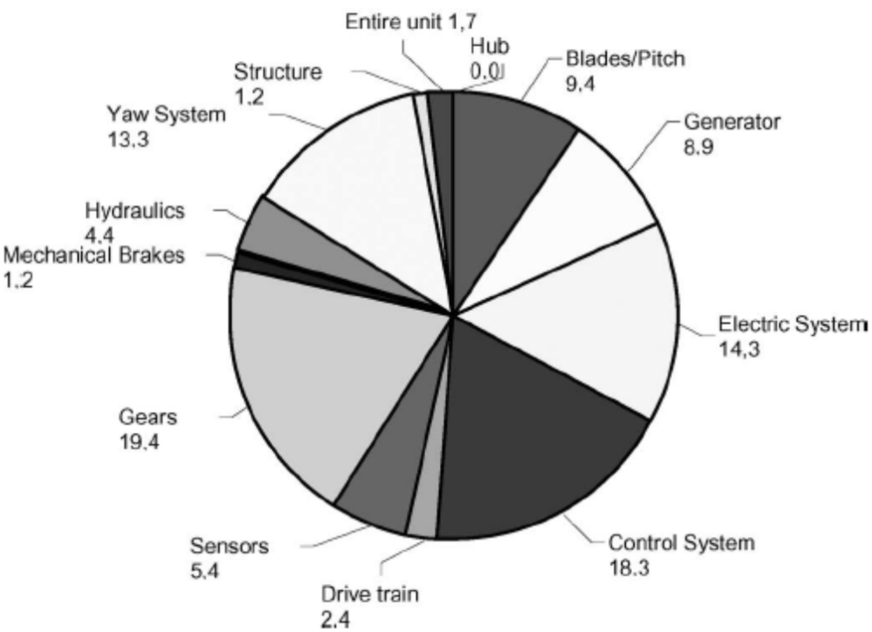
It is also written as:

$$\dot{W}_T = \frac{1}{2}\rho V_o^3 A_T C_p$$

Onshore Wind Power: Challenges

Ribrant et. al. shown that the gearbox is a troublesome component within wind power turbines. They found that 20 % of the downtime is due to gearbox failures, and average gearbox failure takes about 256 hours to repair.

Percentage of downtime per component in Sweden between 2000-2004 [(4)]



Type of gearbox failure [(4)]

Type of reported failure code	Component	Number of failures	Average downtime (hours)	Number of failures, Cause: B1	Average downtime, Cause: B1 (hours)
I-1	Bearings	41	562	36	601
I-2	Gearwheels	3	272	2	379
I-3	Shaft	0	0	0	0
I-4	Sealing	8	52	4	30
I-5	Oil system	13	26	5	36
I-other	Not specified	44	230	19	299

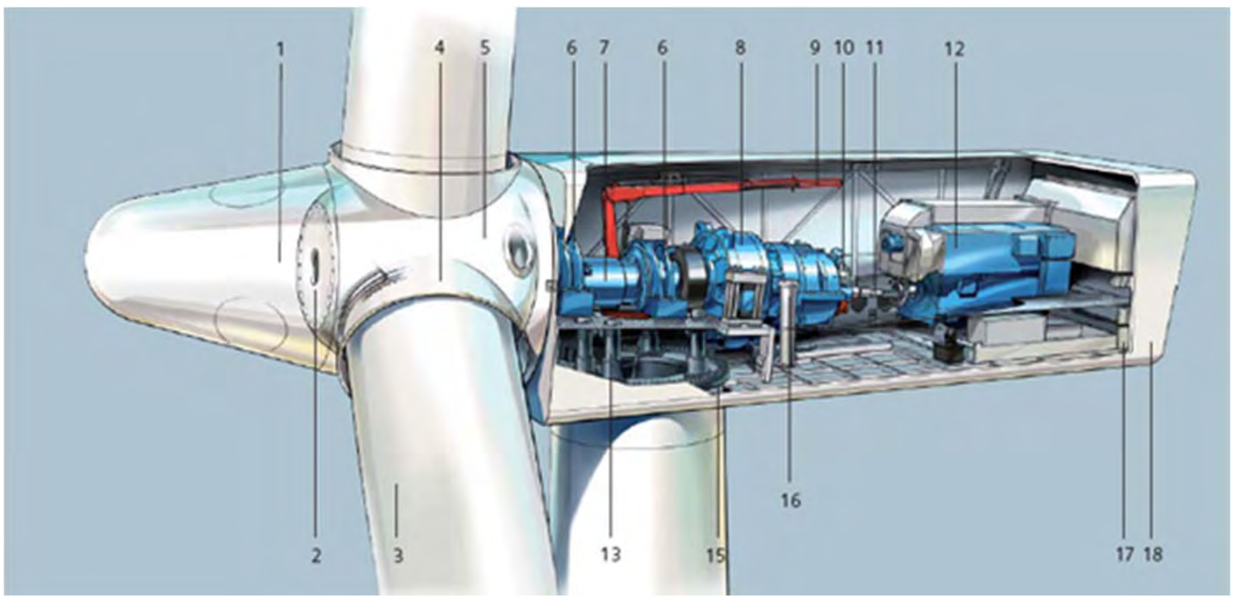
The number of installed turbines used in survey in this study were on average 624 turbines

[(4)]J. Ribrant and L. M. Bertling, Survey of Failures in Wind Power Systems With Focus on Swedish Wind Power Plants During 1997-2005, IEEE Transactions On Energy Conversion, Vol. 22, No. 1, 2007.

Onshore Wind Power: Challenges

The NREL FY 2009 report acknowledged that the most critical component of a wind turbine is the gear box. At present gearboxes are the most expensive component to repair (5).

The NREL project lead for the DOE Wind Turbine Gearbox Reliability Collaborative are conducting a series of dynamometer test and analysis on two identical 750-kW gearboxes.



1	Spinner	10	Brake disc
2	Spinner bracket	11	Coupling
3	Blade	12	Generator
4	Pitch bearing	13	Yaw Gear
5	Rotor hub	14	Tower
6	Main bearing	15	Yaw Ring
7	Main shaft	16	Oil Filter
8	Gearbox	17	Generator F
9	Service crane	18	Canopy

http://www.windenergyplanning.com/wordpress/wp-content/uploads/2008/09/turbine-inside.jpg

(5NREL, A Year of Energy Transformation, FY 2009 National Renewable Energy Laboratory, Annual Report.

Offshore Wind Power

Facts

- To date many countries have become their attention to offshore wind power. Countries with shallow waters can be benefit from offshore wind power.
- UK hold its position as the world's leading market for offshore wind energy, with 883 MW installed at the end of 2009.
- In 2009 the average water depth of offshore wind farm was 10. 6 m, but in 2008 it was 11.5 m. The average water depth did not exceeded the 20m [1].

The technical challenges [6] are :

1. Turbulent winds
2. Corrosion
3. Irregular waves
4. Gravity/inertia
5. Aerodynamics: induction, skewed wake, dynamic stall
6. Elasticity
7. Control Systems, etc.

[6]M. Robison, W. Musial, Offshore Wind Technology Overview , NREL/PR-500-40462 National Wind Technology Center, National Renewable Energy Laboratory, October, 2006.

Wind Power – PREC/UT

Major Research Efforts

The Department of Mechanical Engineering at the University of Turabo has been working closely during the past years with Dr. Luciano Castillo from RPI and Dr. Charles Maneveau (JHU) renowned researchers in the area of wind energy. The major topics of our research are focused on:

i. Energy Optimization and Efficiency: Heat pipe technology application to dissipate the heat generated in the gearbox system.

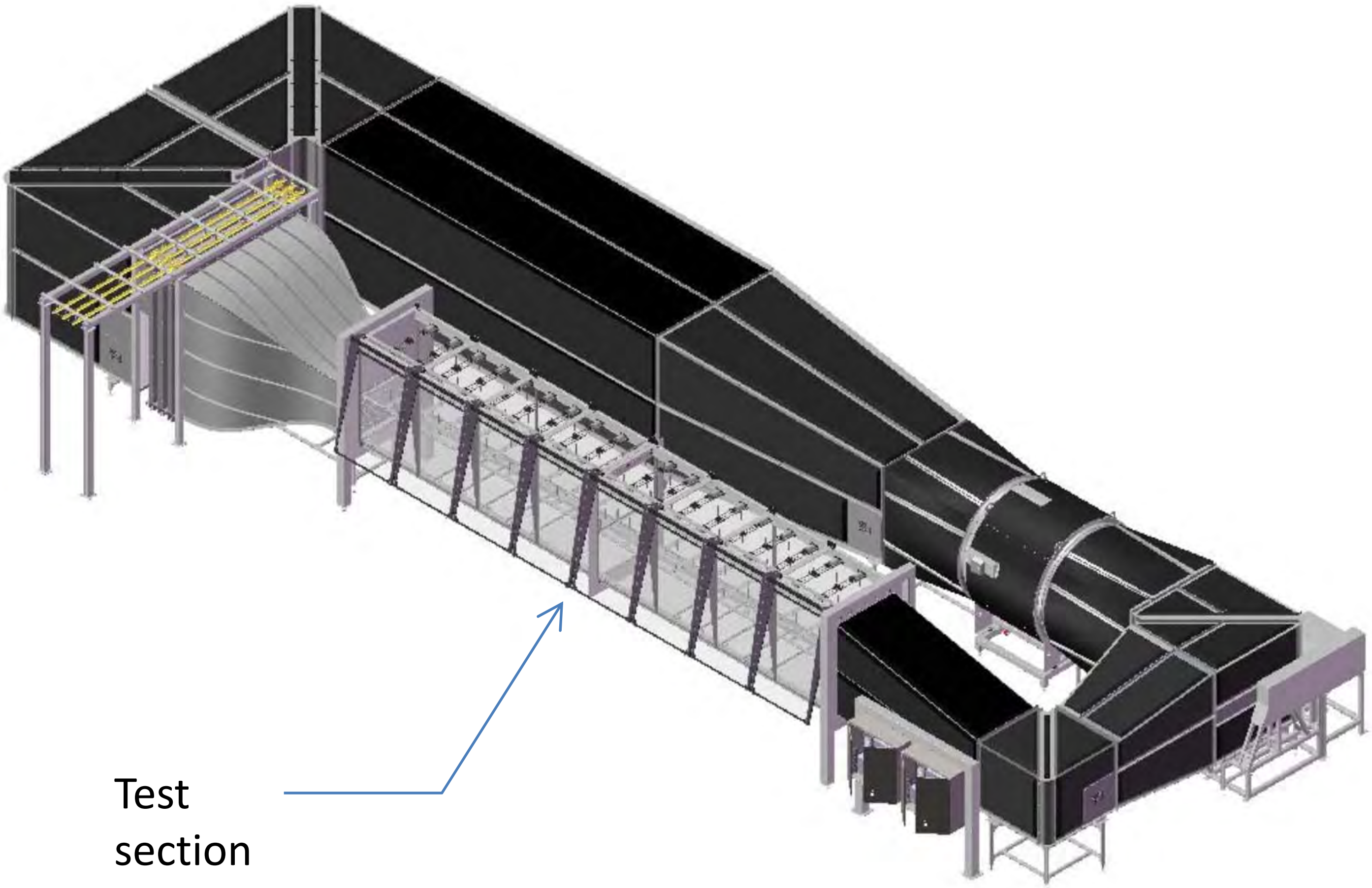
ii. Offshore wind power: the state of the art wind tunnel at the PREC facilities test will be used to test and validate models for offshore wind power. There is an ongoing proposal to built this unique facility in Puerto Rico and the Caribbean Islands. The test section of this tunnel will consist of a 1mx1mx 5m.

iii. Wind turbine array optimization.

iv. Wind turbine array an the microclimate.

Wind Power – PREC/UT

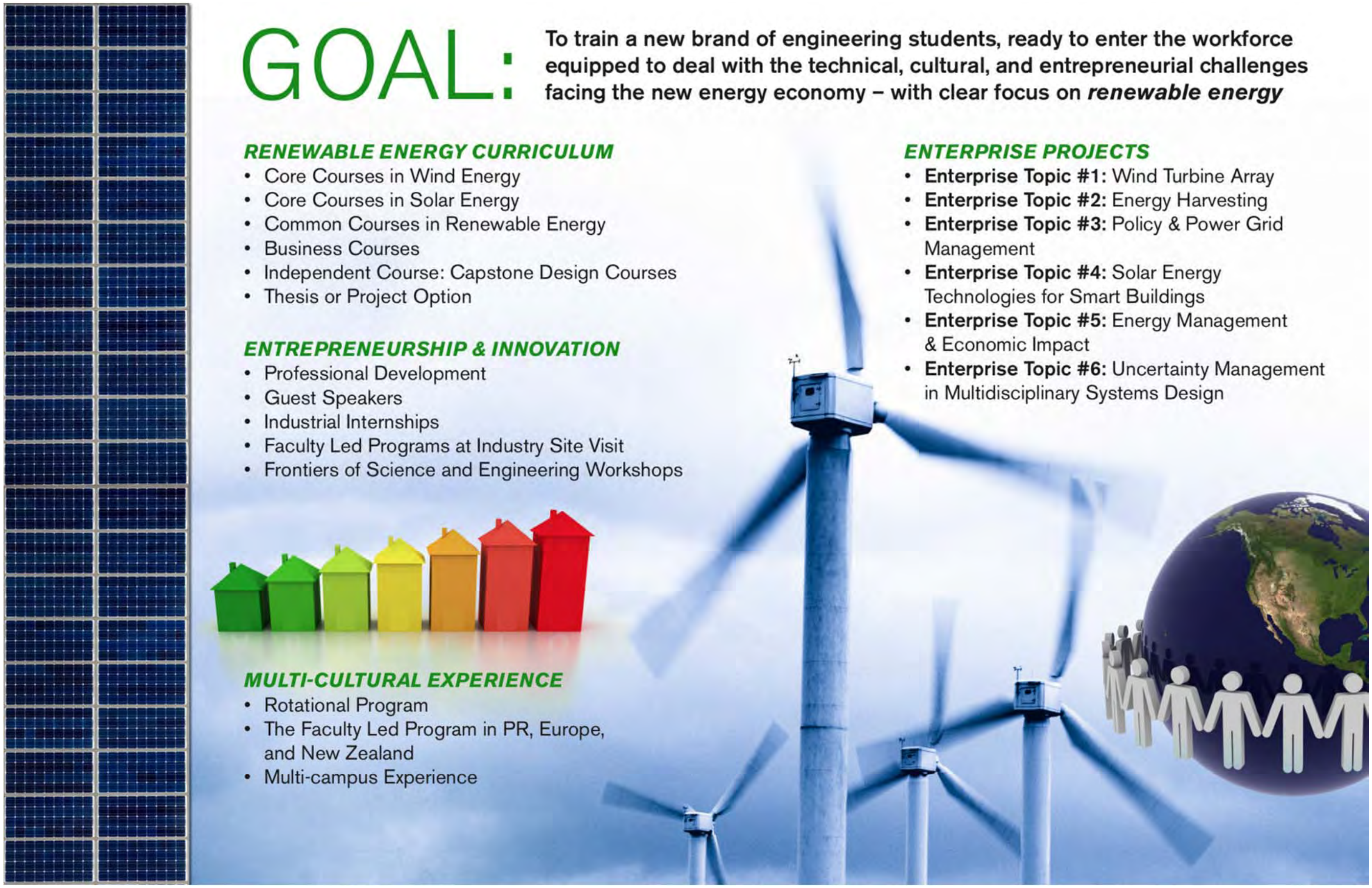
Wind Energy Facility - PREC



Test section

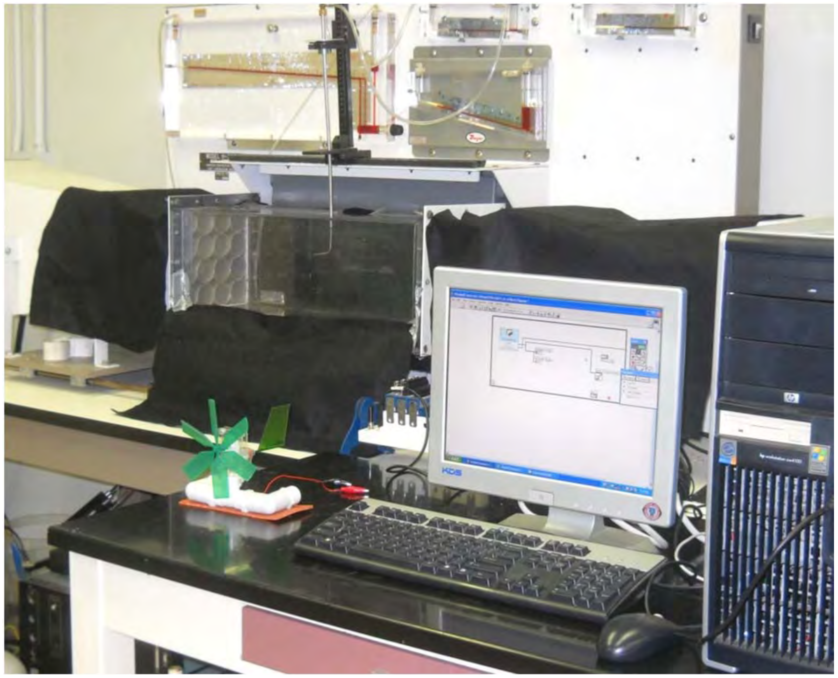
Wind Power – PREC/UT

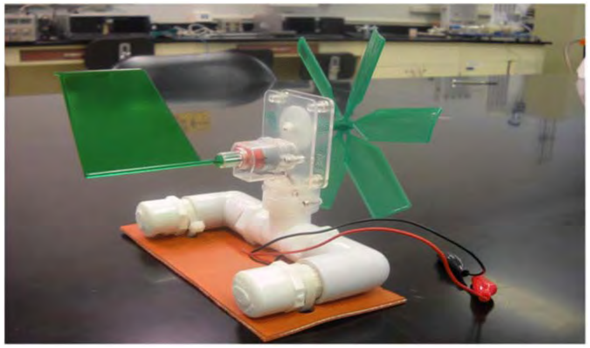
Master Program – Master in ME with Specialization in Renewable Energy



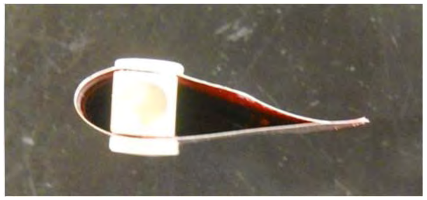
Wind Power – PREC/UT

Experimental Setup

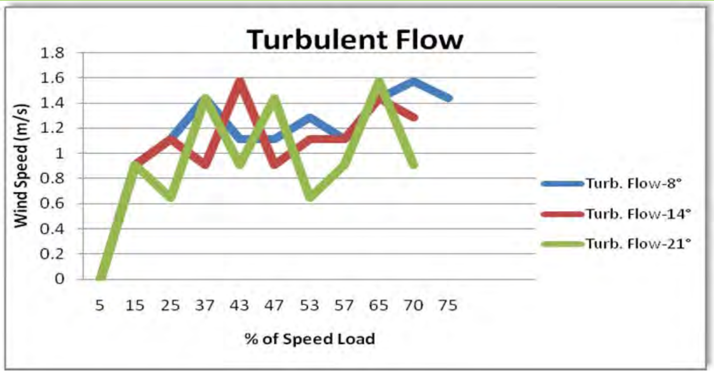


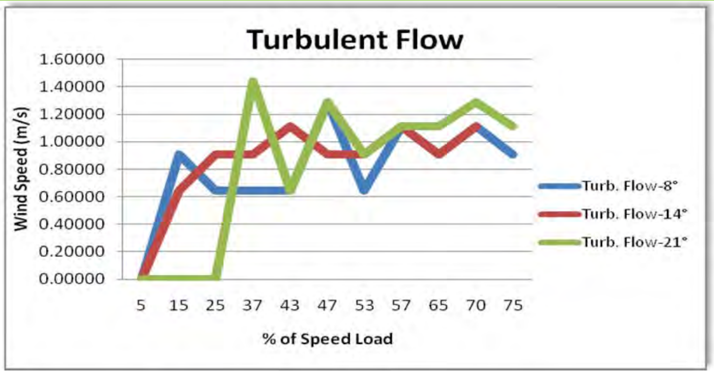


adjustable blade



Experimental Results





Thanks for your attention!