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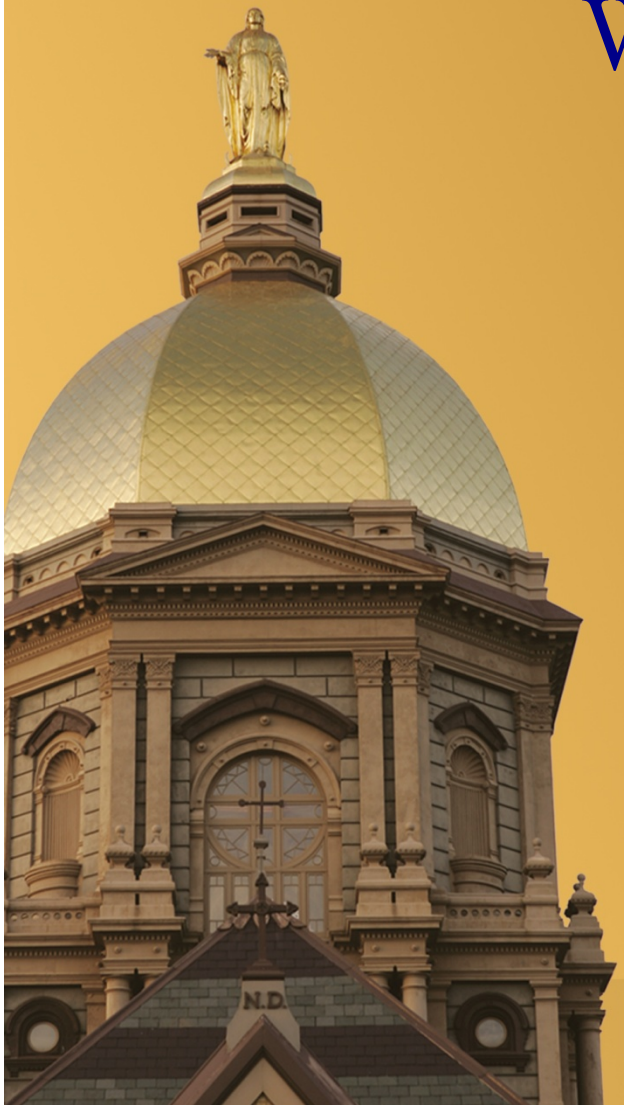


Wind Turbine Performance, Control and Design
AME 40530

Robert C. Nelson and Thomas C. Corke

Lecture #1 Introduction

FlowPAC

Course Description

- This course will present the fundamental concepts and theories that can be used to design an efficient wind turbine.
  - Introduction
  - Wind regimes
  - Aerodynamic modeling of wind turbines
  - Rotor design considerations
  - Wind turbine control
  - Technology to improve wind turbine efficiency
  - Wind Farms

Learning Objectives

- Understand how to characterize the properties of the wind resource from which the power is to be extracted.
- Understand how to predict the performance of a wind turbine using Blade Element/momentum theory.
- Understand the blade design features and aerodynamics that yields an efficient rotor.

Learning Objectives Continued

- Understand how to use distributed active control to enhance turbine performance.
  - For increased energy capture.
  - For reducing unwanted blade loading.
  - To allow blade weight reductions.
- Understand how rotor design considerations influence the wind turbine performance.
- Understand technical and economic issues related to wind turbines and wind farms.

Lecture # 1 Outline

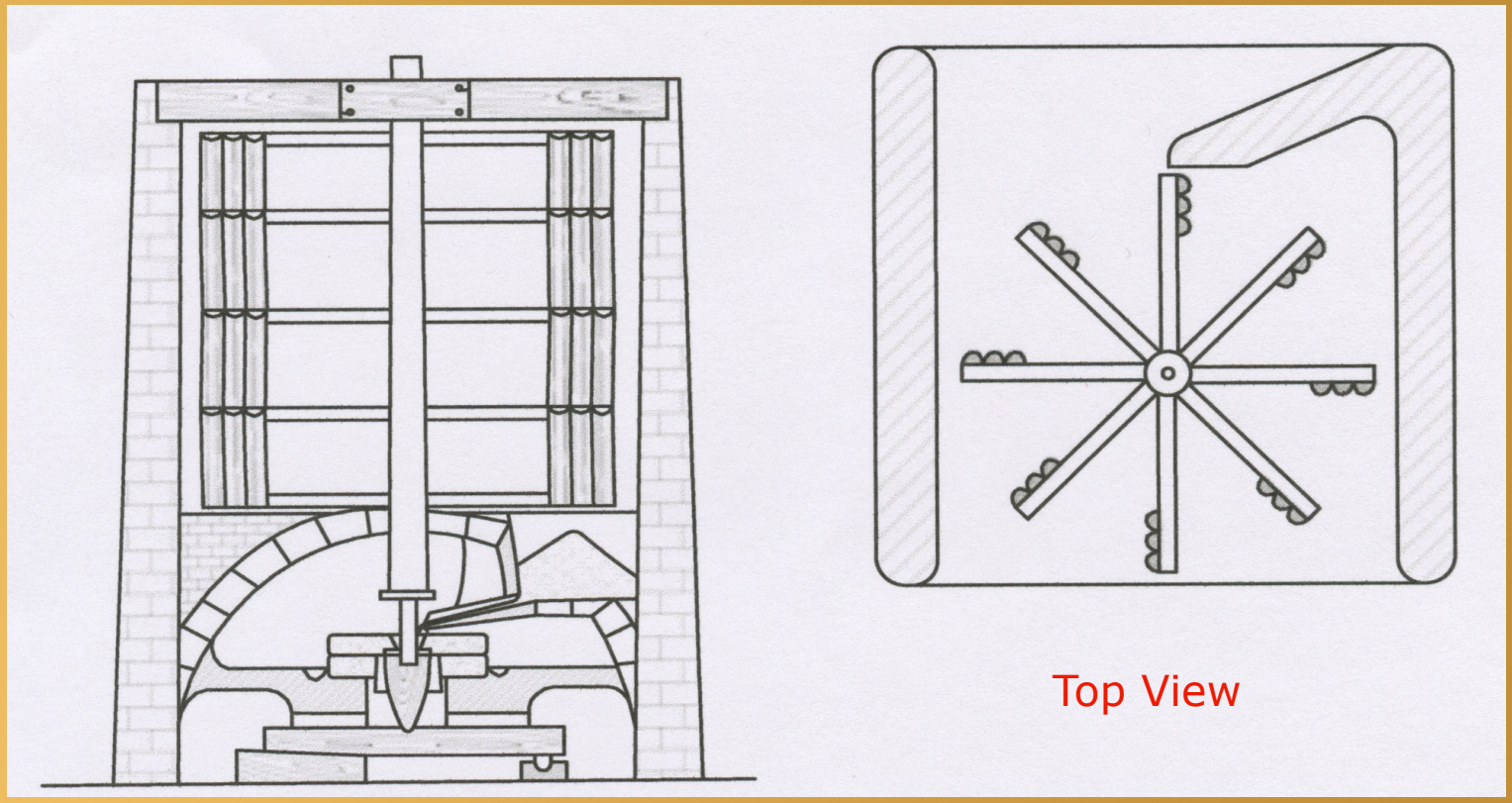
- Brief History of Wind Turbines.
- Modern Wind Turbine Development 1980s to present day.
- What are the Challenges facing the Wind Power Industry.

History of the Wind Turbines

- Transforming the kinetic energy of the wind to useful mechanical power dates back to antiquity.
  - Wind energy using a wind turbine along with the energy of flowing water and a water wheel are two of the oldest power sources used by humankind.
  - It is difficult to determine a precise historical date for the earliest use of wind energy. There is however evidence that the Persians used vertical axis wind machines in 1700 B.C. in the region of Iraq and Iran with wind powered scoops to irrigate farm land.
  - In 700 AD the Persian vertical axis wind mill was widely use in the Middle East and Central Asia and they spread to China.

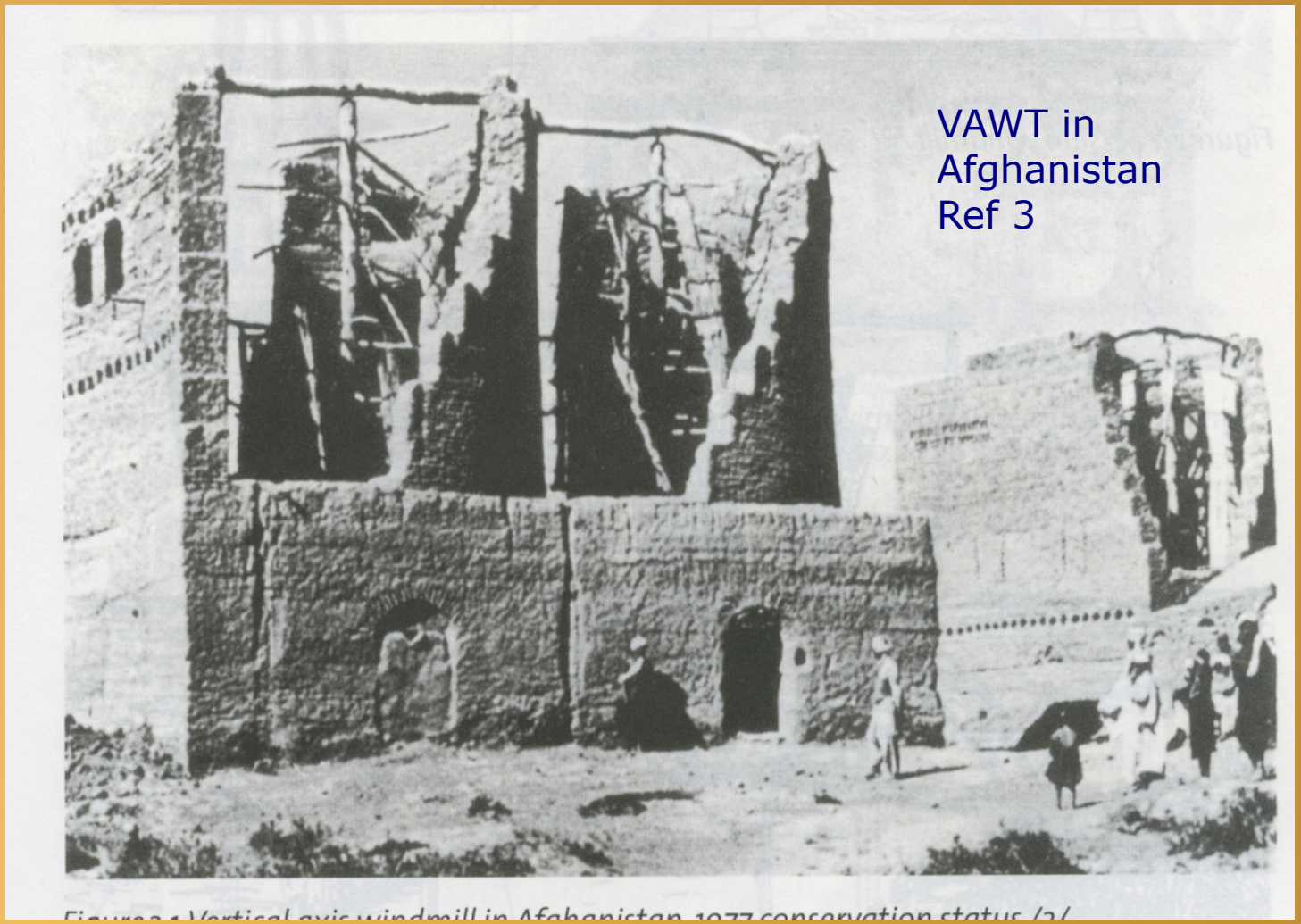
Ref. 1

Persian Vertical Axis Wind Turbine



Top View

Ref. 1



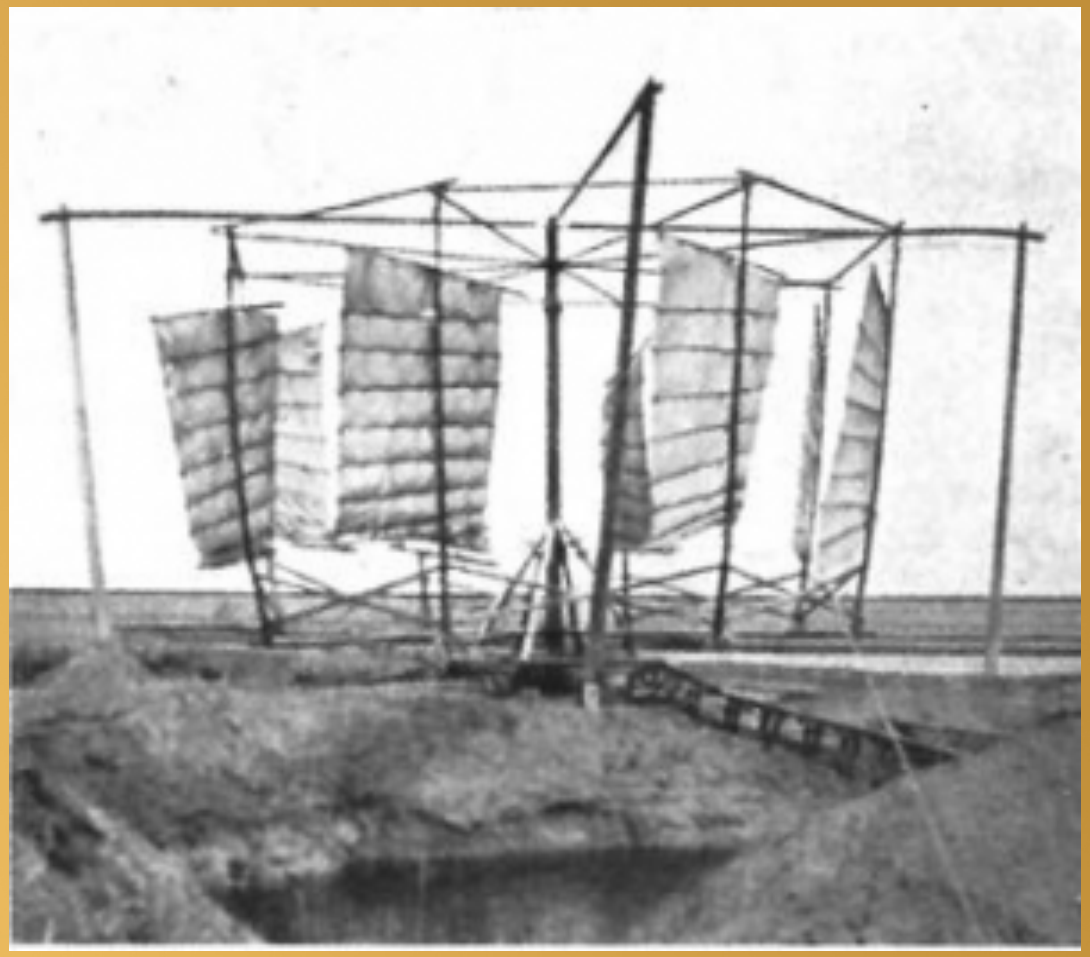
VAWT in Afghanistan Ref 3

Ref. 1

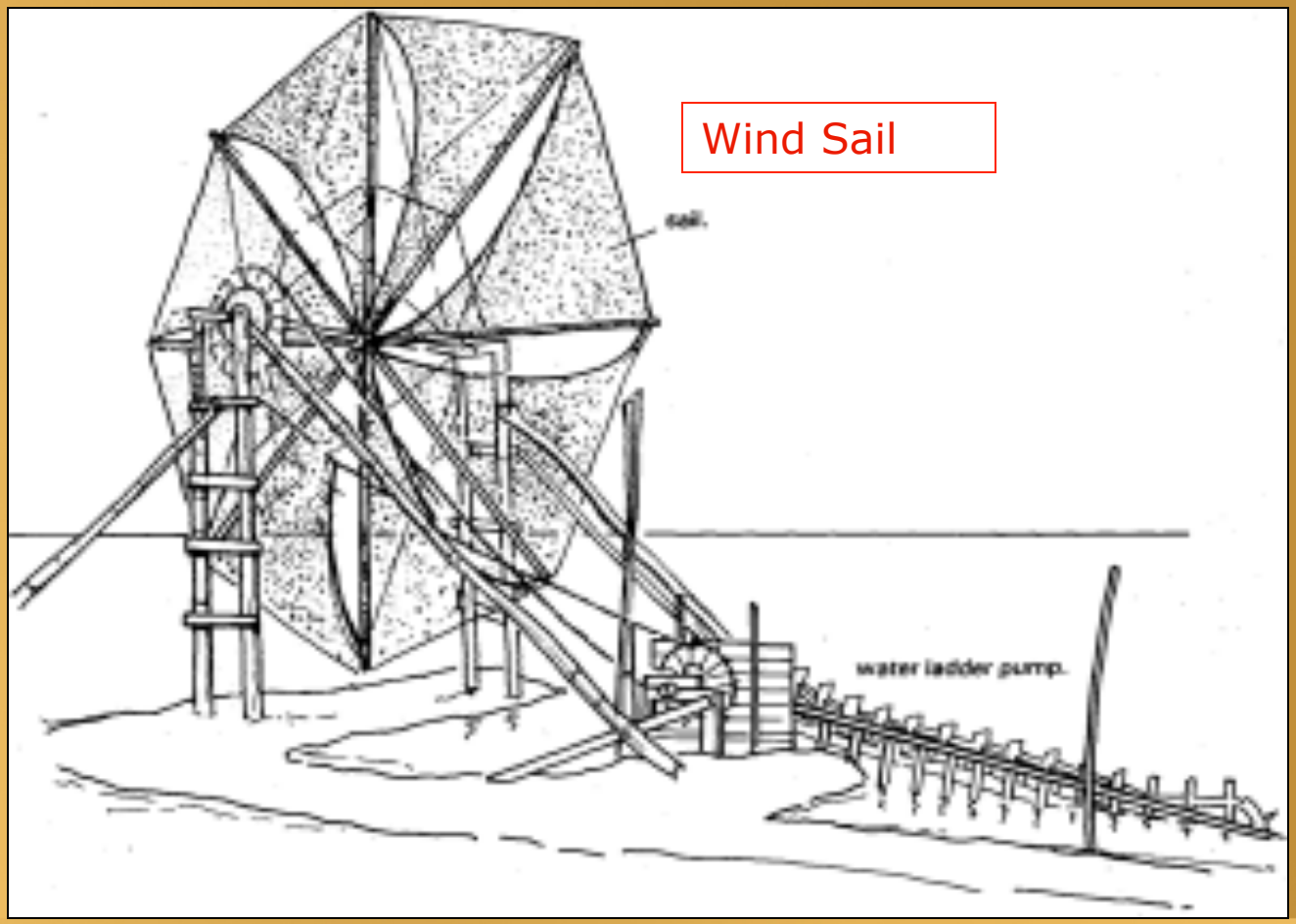
History - Continued

- Wind Turbines.
  - The first evidence of windmills in China is found in a document in 1219AD. The windmill was similar to the Persian design and was used for grinding corn and pumping water.

Chinese Vertical Axis Wind Mill



Chinese Horizontal Axis Wind Turbine used for Irrigation



History - Continued

- Wind Turbines.
  - One difference between the Persian and Chinese windmills was the use of sails that adjusted themselves to the wind direction.
  - Horizontal axis windmills were widely used in the southeastern area of China in 1368-1644 AD.

History - Continued

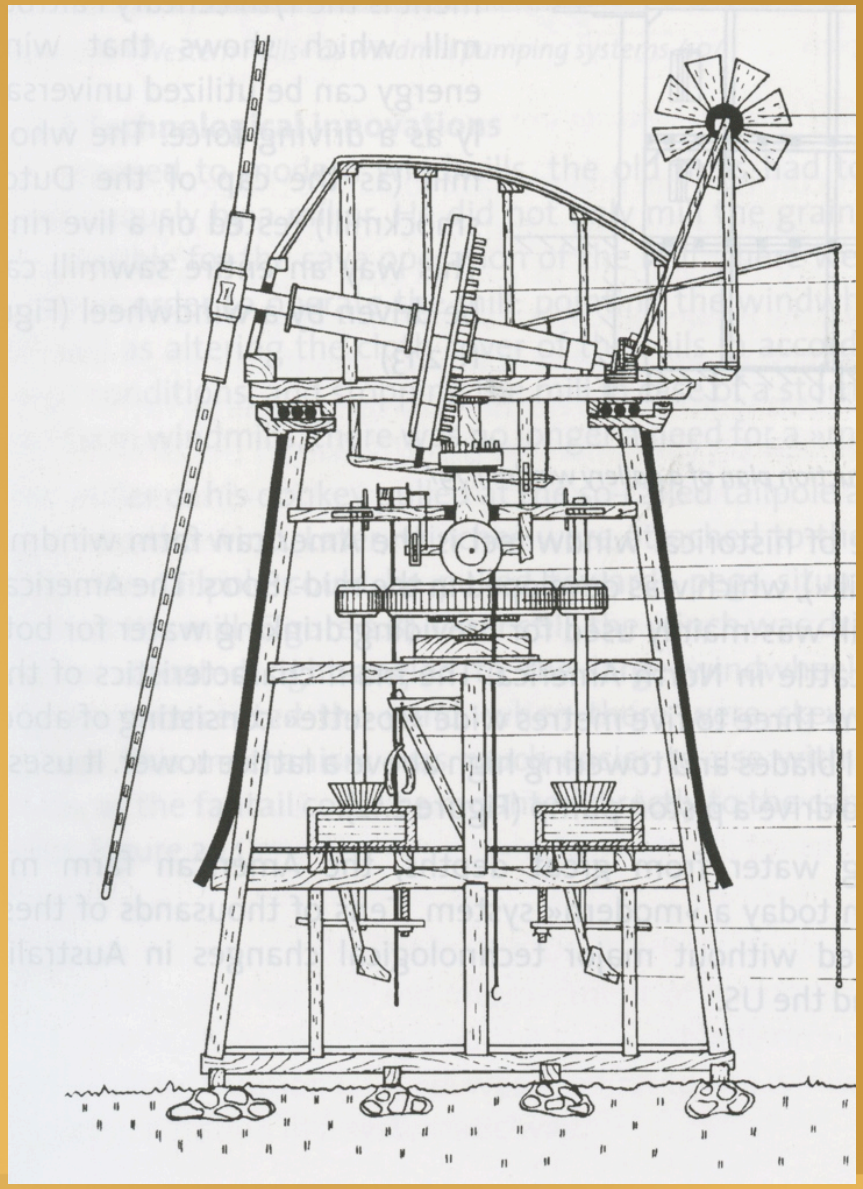
- Wind Turbines.
  - In 1185 the first historical references to a horizontal axis windmill appears in Europe (Yorkshire, England). It is thought that the Roman water wheel provided the insight to change from a vertical to horizontal axis wind turbine.

History - Continued

- The Post mill (Horizontal axis windmill)
  - The first post mill design appears in 1270 AD in Canterbury, England. This design incorporated blades attached to a horizontal shaft that used a wooden cog-and-ring gears to translate the motion of the horizontal shaft to a vertical rotation of the grindstone.

Post mill

This design incorporated blades attached to a horizontal shaft that used a wooden cog-and-ring gears to translate the motion of the horizontal shaft to a vertical rotation of the grindstone. The miller could manually rotate the post mill into the wind.



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History - Continued

- The Smock and Tower mill
  - The smock mill was named for its resemblance article of clothing called a smocking. These mills were mainly found in the Netherlands.
  - Improvements in the design includes a fixed base that held the milling equipment and a rotatable cap the held roof, sails, windshaft and brake wheel.
  - This design allowed taller mill than the post mill.

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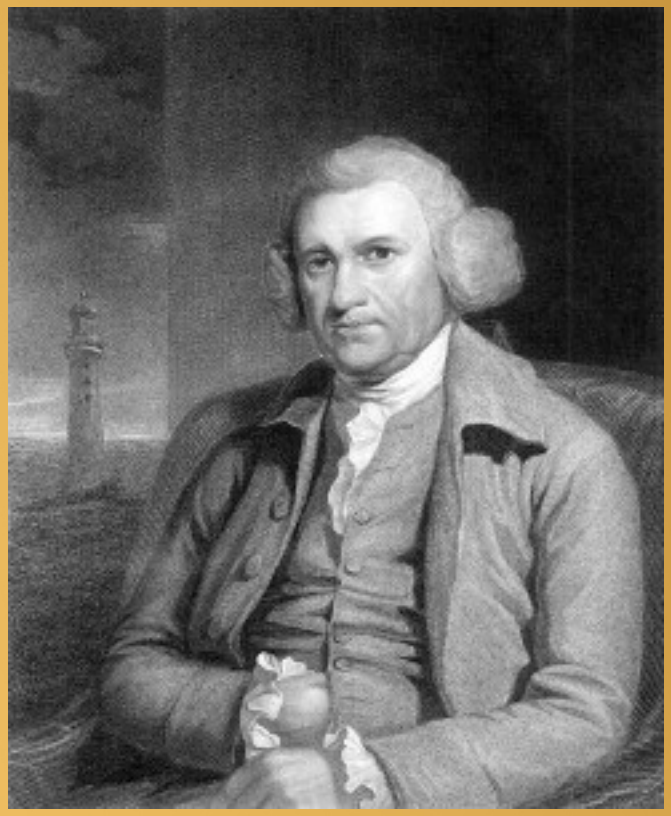


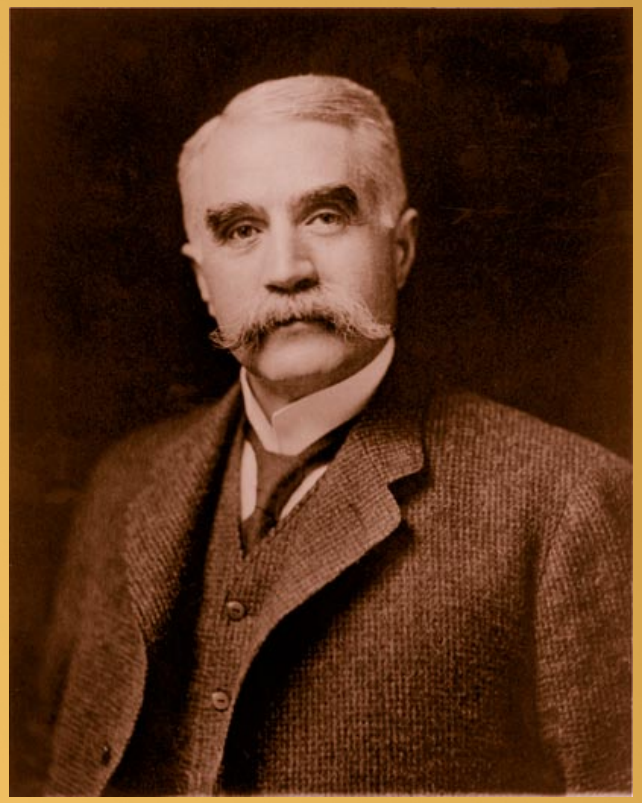
John Smeaton

In the 1750s John Smeaton was the first scientist to develop mathematical models to predict wind mill efficiency. He also showed that the wind turbine blades had to be twisted to get the best efficiency.

James Blyth

The first Vertical Axis wind turbine used to produce electricity was in 1887. Scottish Professor James Blyth from Glasgow, Scotland designed a 12kW turbine with a 17m diameter and was 18m in height

History of Wind Energy



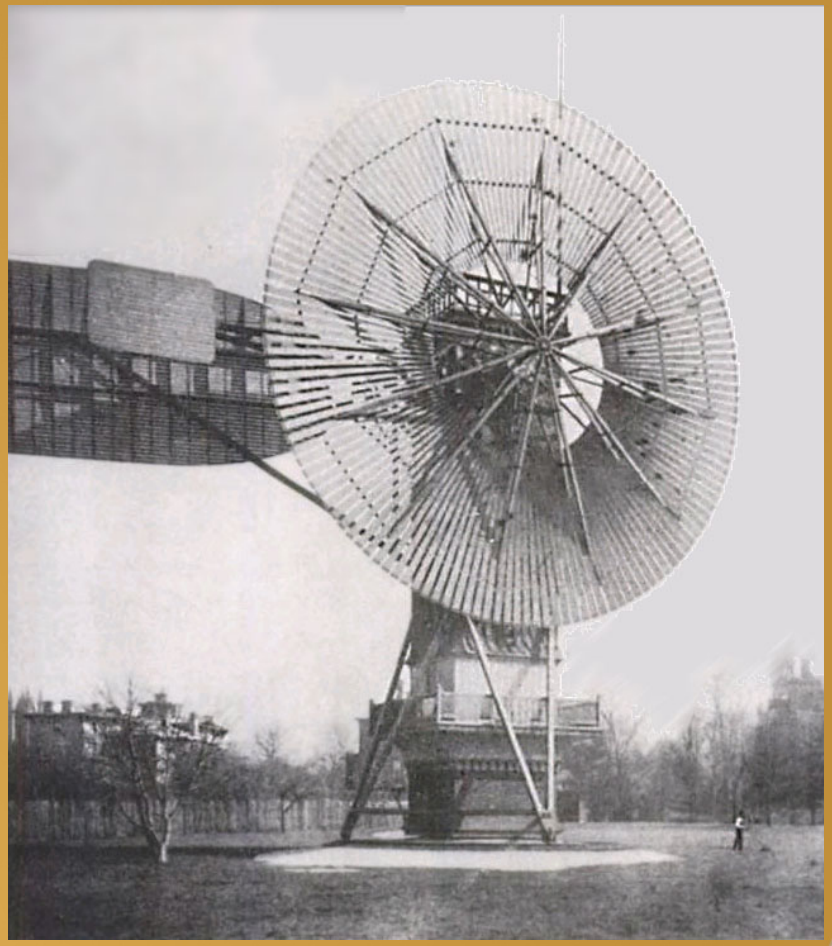
Charles Brush (1849-1929)

- One of the founders of the American electrical Industry.
- Invented:
  - Wind turbine for Electric Power
  - an efficient DC dynamo used in a public grid,
  - an efficient method for manufacturing lead-acid batteries
- Brush Electric merged with Edison Electric under the name of General Electric Co. (GE)

Brush Windmill (U.S. 1887)

First automatically operating wind turbine for electricity generation.

- 50 ft. diameter
- 144 blades made of cedar
- Operated for 20 years
- 12kW power rating



Paul la Cour (Denmark 1897)

Paul la Cour (1846-1908)

- Originally trained as a meteorologist
- One of the pioneers of modern aerodynamics
  - Built his own wind tunnel
- Concerned with the storage of energy
  - Used electricity from his wind turbines for electrolysis to produce hydrogen for gas lights
- Founded Soc. Wind Electricians (1905)

La Cour Wind Turbines 1897

Two test wind turbines at Askov Folk High School, Askov Denmark

Had to replace the windows of several buildings several times when the hydrogen exploded.

Johannes Juul (Denmark 1950s)

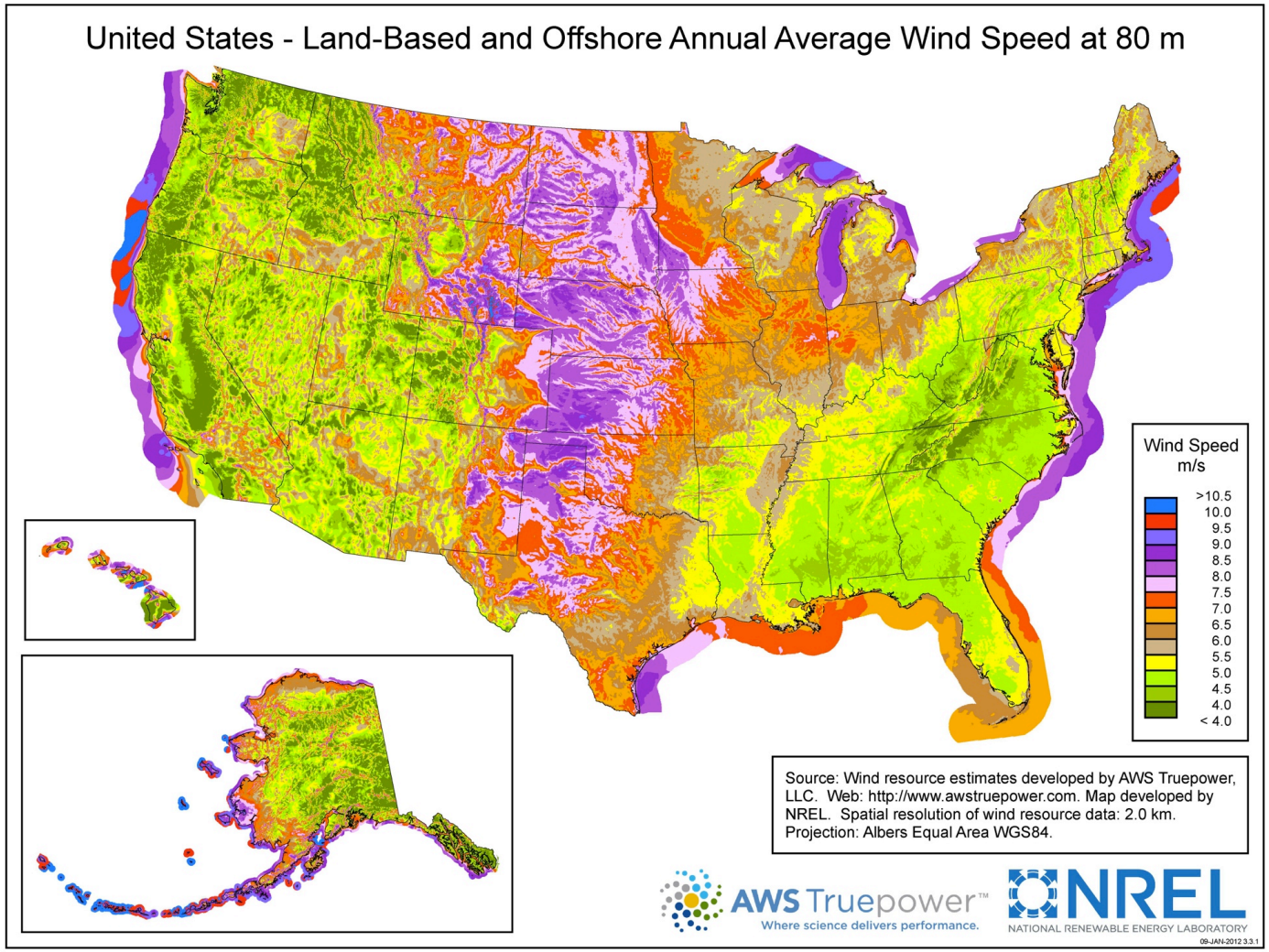
- One of the first students of la Cour in 1904 course on "Wind Electricians"
- Pioneer developer of world's first AC wind turbine (Vester Egesborg, Denmark)
- 200 kW Gedser wind turbine (1956) was pioneering design for modern wind turbines
  - Stall control
  - Emergency braking
- Operated for 11 years without maintenance
- Refurbished in 1975 at request of NASA to provide data for U.S. wind energy program.

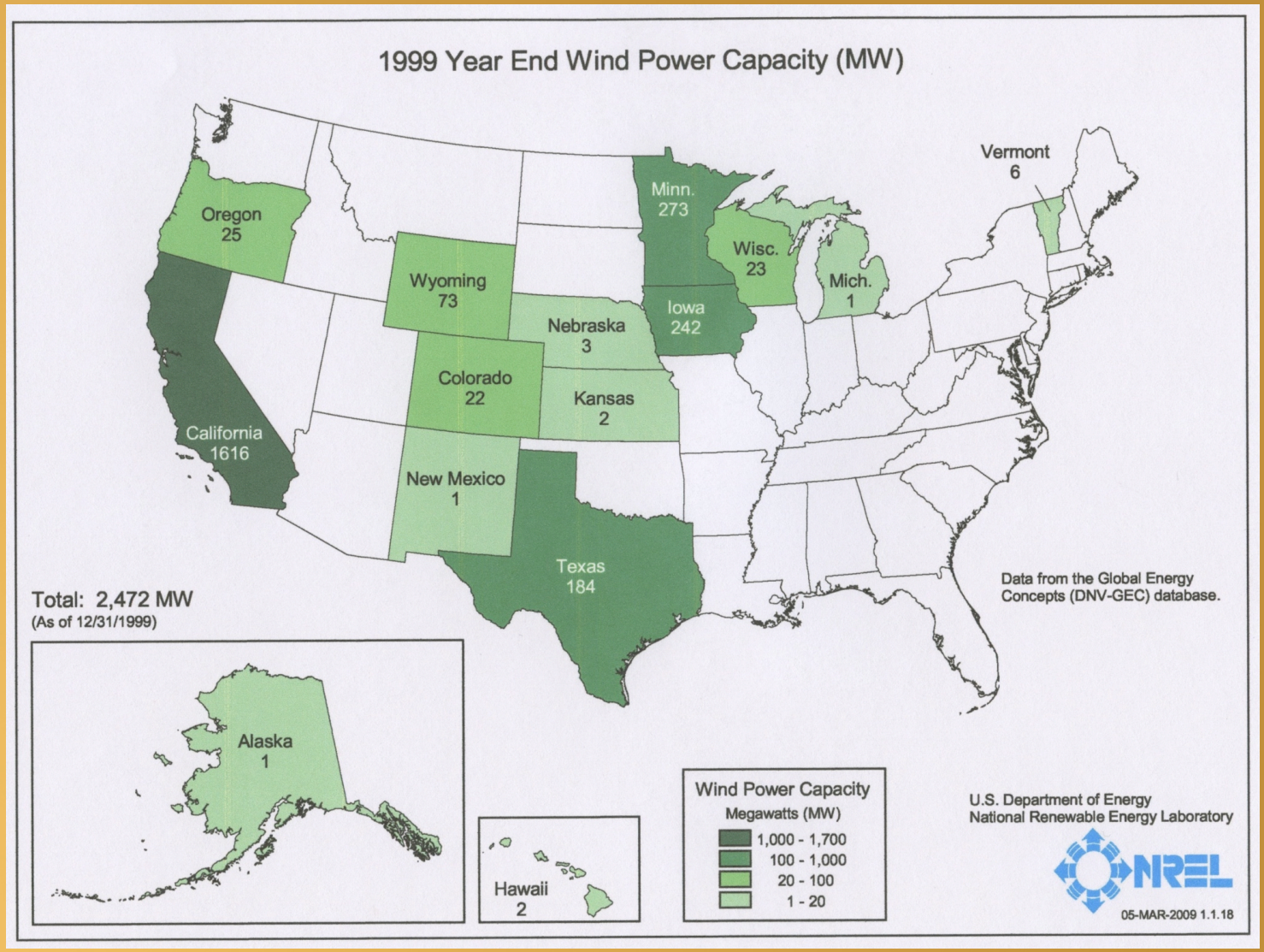

Gedser wind turbine (1956)

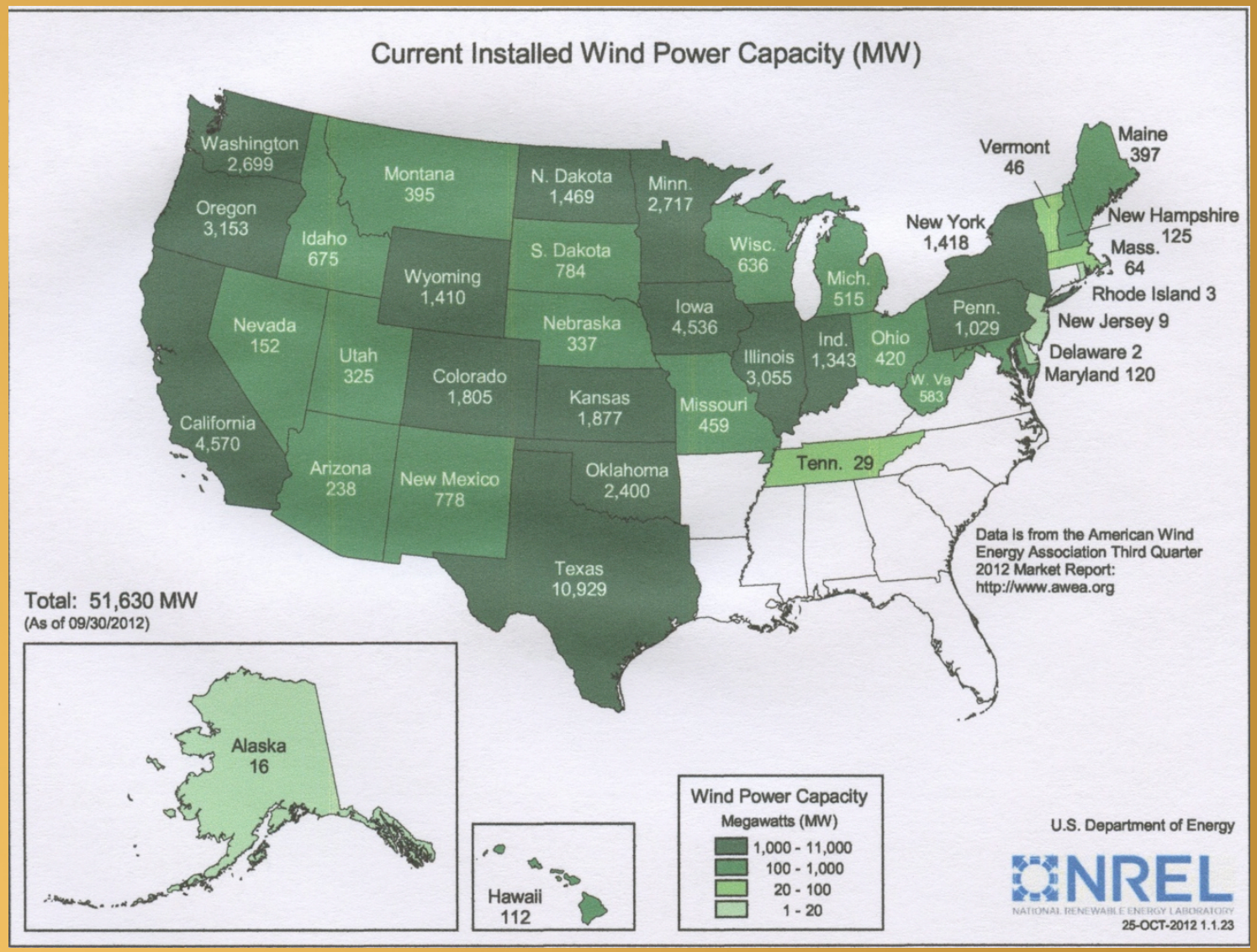
In 1941 the first megawatt wind turbine connected to an electrical distribution system was installed in Vermont. Wind turbine only operated for 1,100hours before a blade failed.

Smith-Putman
Wind Turbine

Growth of Wind Power in the USA 1980 - 2012


United States - Land-Based and Offshore Annual Average Wind Speed at 80 m
Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.
AWS Truepower™
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
09-JAN-2012 3.3.1


1999 Year End Wind Power Capacity (MW)
Oregon 25
Wyoming 73
Minn. 273
Wisc. 23
Mich. 1
Vermont 6
Nebraska 3
Iowa 242
Colorado 22
Kansas 2
California 1616
New Mexico 1
Texas 184
Total: 2,472 MW
(As of 12/31/1999)
Data from the Global Energy Concepts (DNV-GEC) database.
Alaska 1
Hawaii 2
Wind Power Capacity
Megawatts (MW)
1,000 - 1,700
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
05-MAR-2009 1.1.18


Current Installed Wind Power Capacity (MW)
Washington 2,699
Oregon 3,153
California 4,570
Idaho 675
Nevada 152
Montana 395
Wyoming 1,410
Utah 325
Colorado 1,805
Arizona 238
New Mexico 778
N. Dakota 1,469
S. Dakota 784
Nebraska 337
Kansas 1,877
Oklahoma 2,400
Texas 10,929
Minn. 2,717
Iowa 4,536
Missouri 459
Wisc. 636
Illinois 3,055
Mich. 515
Ind. 1,343
Ohio 420
W. Va 583
Penn. 1,029
New York 1,418
Vermont 46
Maine 397
New Hampshire 125
Mass. 64
Rhode Island 3
New Jersey 9
Delaware 2
Maryland 120
Tenn. 29
Alaska 16
Hawaii 112
Total: 51,630 MW
(As of 09/30/2012)
Data is from the American Wind Energy Association Third Quarter 2012 Market Report: http://www.awea.org
Wind Power Capacity
Megawatts (MW)
1,000 - 11,000
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
25-OCT-2012 1.1.23

Challenges For Wind Energy Industry

- The major challenges of this century will be to provide enough energy, water and food without harming the environment and depleting these resources for future generations.
- Renewal energy sources such as wind and solar energy must play a more important role in our energy future.
- Today wind power only contributes about 2% of the electrical power generated in the United States, however our country has excellent wind resources that potentially could provide up to 20% our electrical power need.
- The next generation wind turbines must improve their efficiency, lower the acquisition cost, improved reliability and have a cost /kWh that is competitive with fossil fuel electric power plants.

Questions

Grading

- Homework problems will be assigned on a weekly basis.
- Grade Distribution

Examinations (2) @25% each	50%
Homework	10%
Projects 20 % each	40%
Total	100%

Examination Schedule

- Examination # 1 February 27, 2013
- Examination # 2 April 21, 2013
- Project # 1 Due April 7, 2013
- Project # 2 Due by 5:00pm May 1, 2013

Projects

- Project # 1 - Develop a computer code that can be used to estimate the performance of a wind turbine.
- Project # 2 - You will be given information on the wind characteristics of a given region that is to be developed for a wind farm. Knowing the wind information your task is to design the lowest cost wind turbine for the proposed wind farm. You will be given cost models that are based on wind turbine geometry.