

Wind Energy Technology and its Adoption by Business and the Public

Presented at

NASA GRC

Green Energy Forum

June 16, 2009

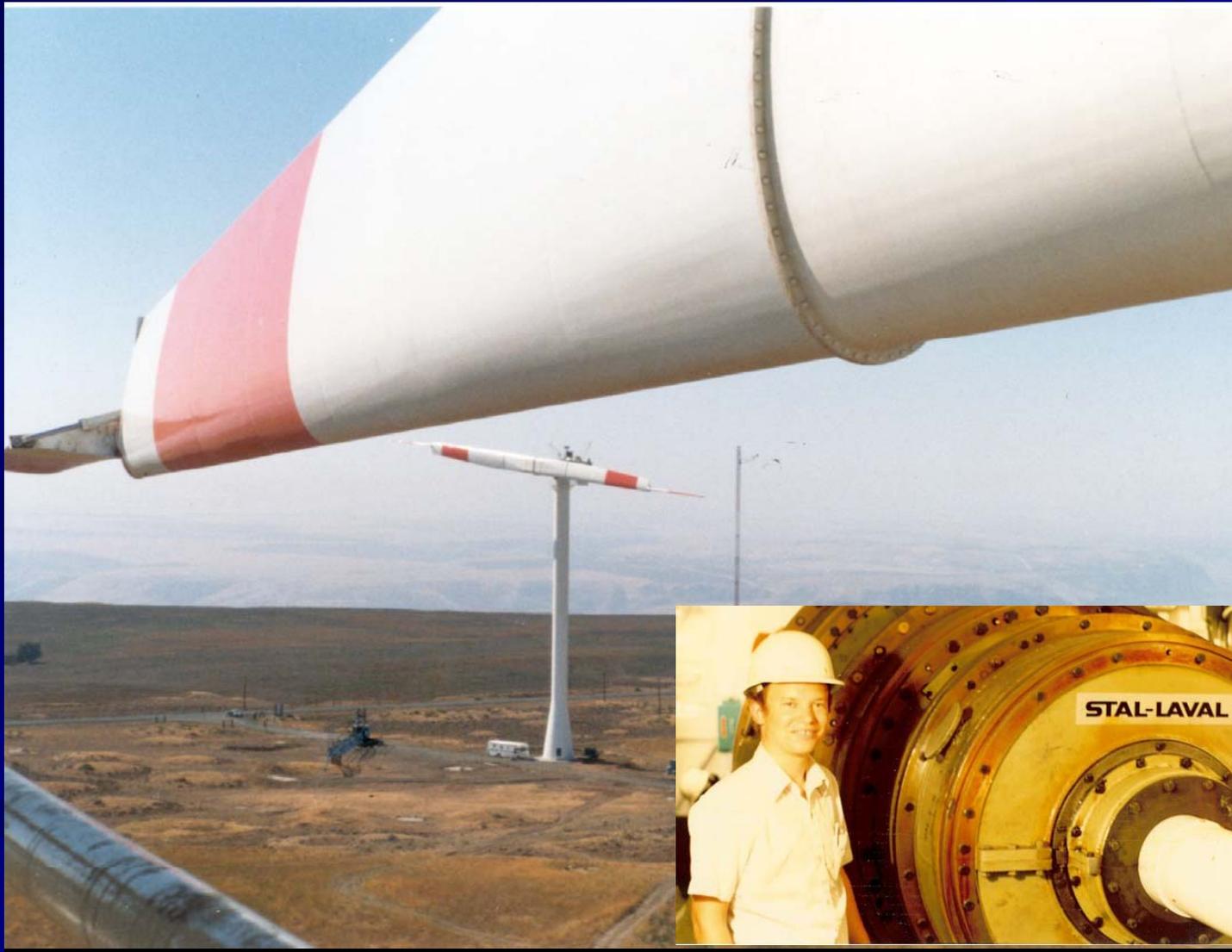
by

Larry Viterna, PhD

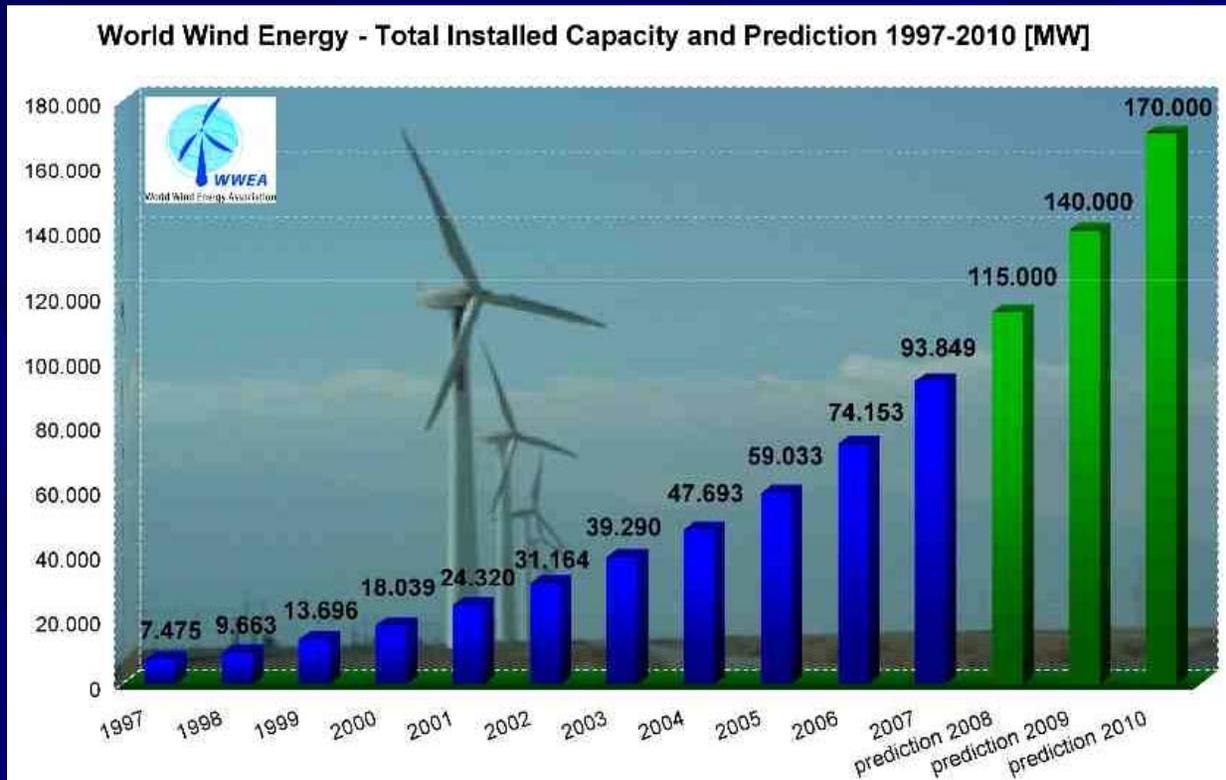
Technical Director, Great Lakes Institute for Energy Innovation

Case Western Reserve University

1981 - NASA / Boeing 7.5 MW Turbine Cluster



Wind – The Fastest Growing Energy Source



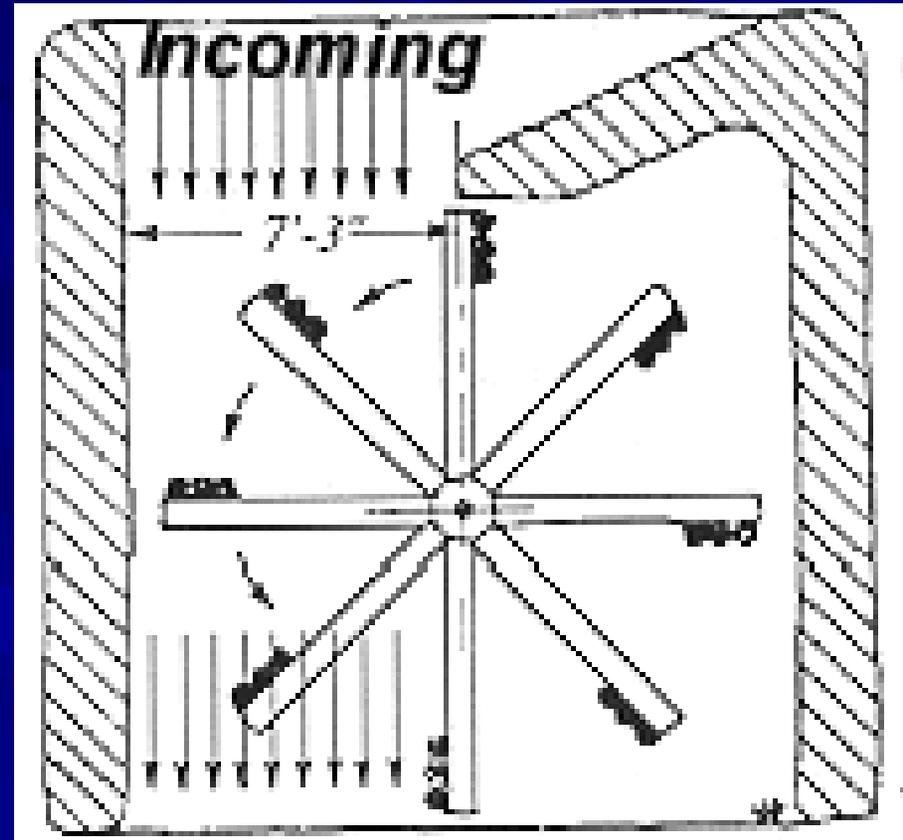
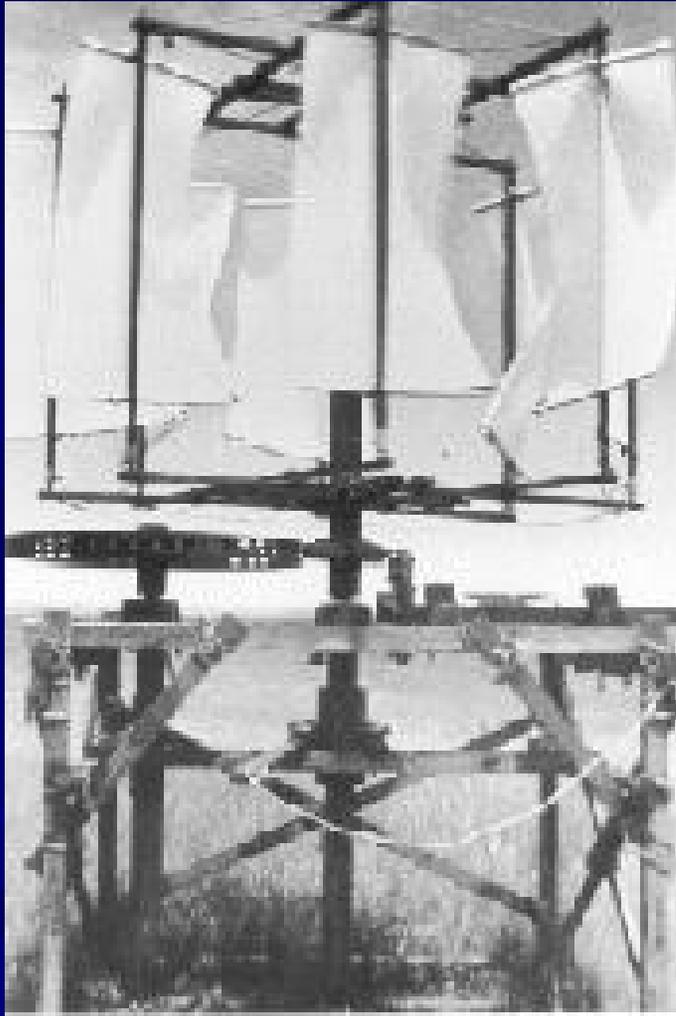
2006-2008 U.S. Market

■ 45% growth in installed wind energy capacity

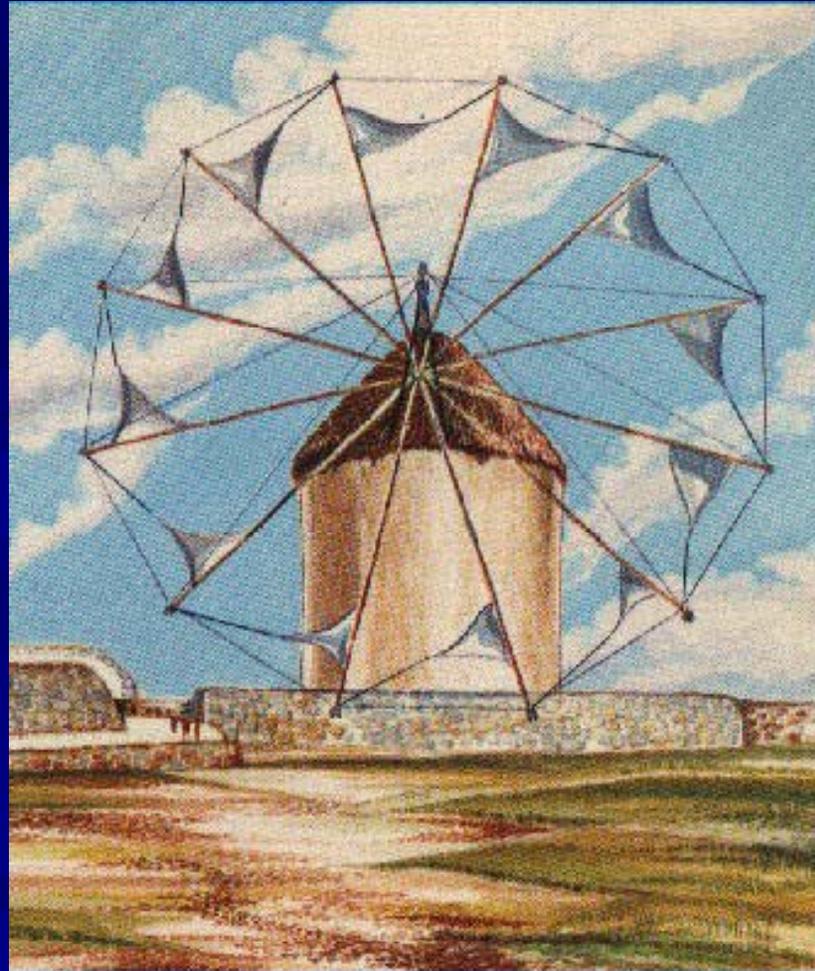
Challenges Remain



First windmills, Persia 200 AD

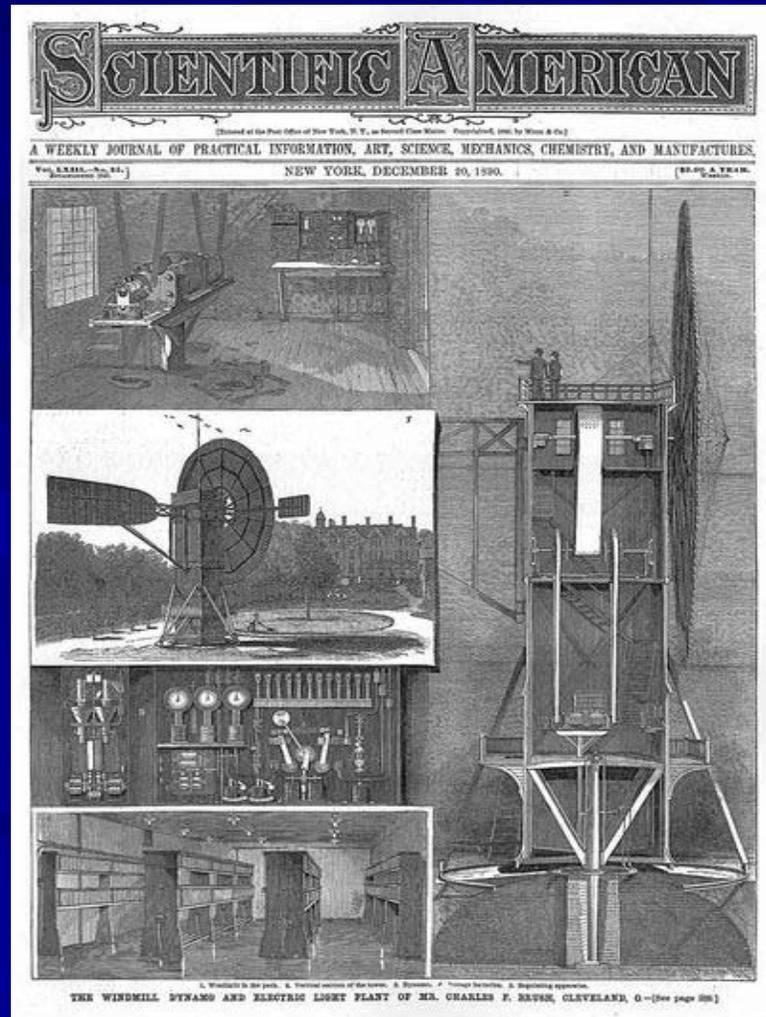


Greeks Grinding Mill - 1150 AD



An ancient grinding mill on the Greek island of Mykonos.

Charles Brush Wind Turbine - 1887



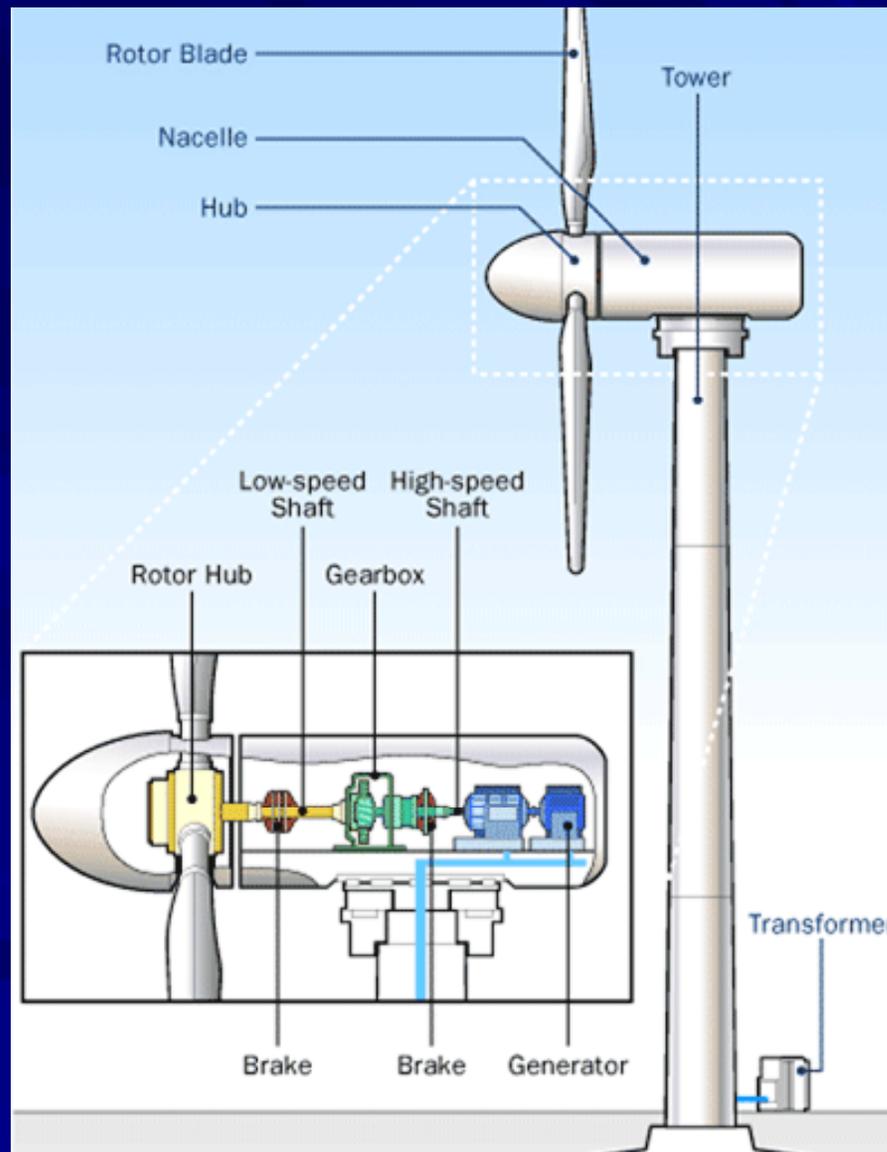
NASA Mod-0 Wind Turbine - 1975



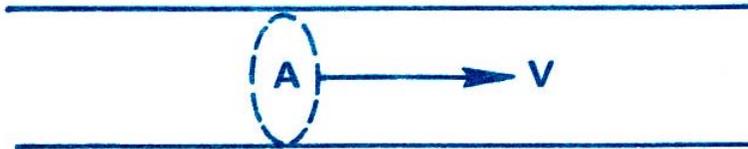
NASA / GE Mod-1 - 1979



Wind Turbine Terminology



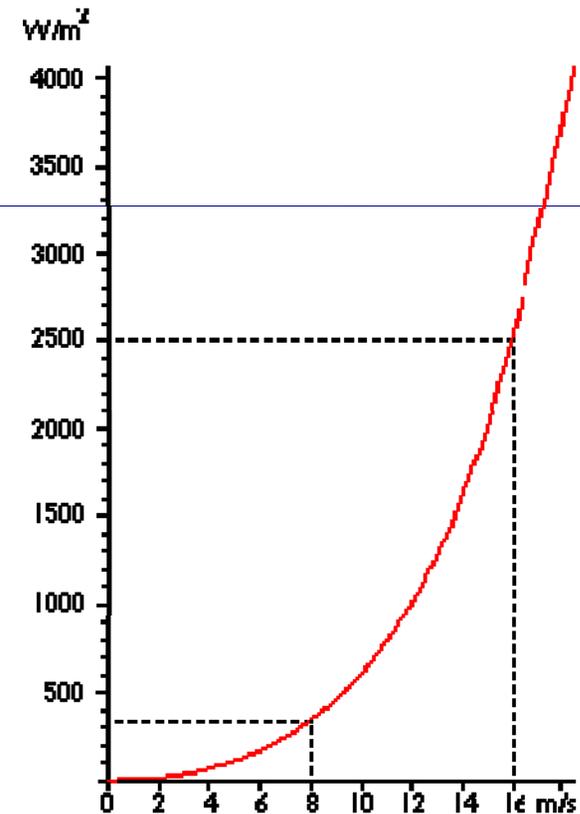
Power in the Wind Stream



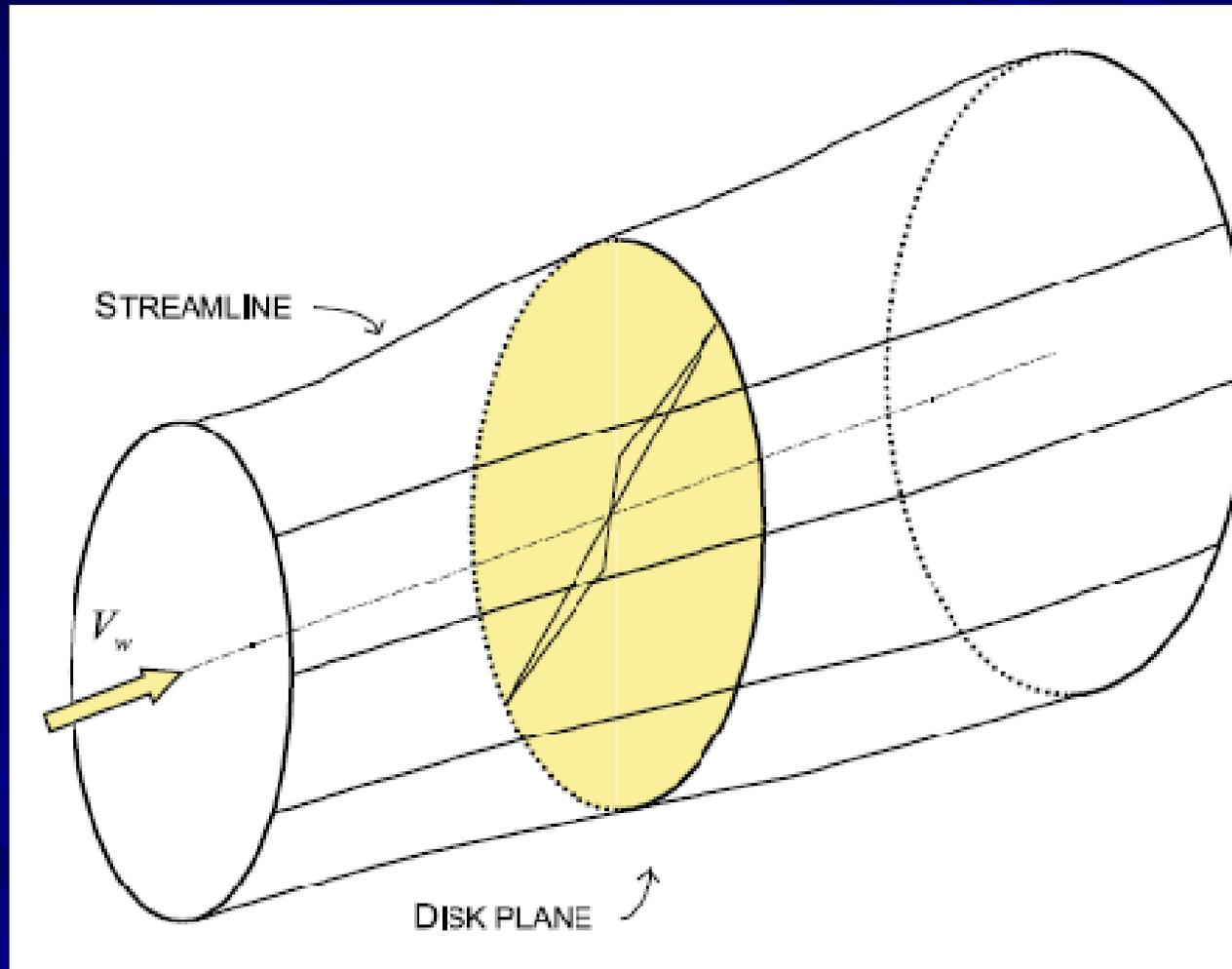
**POWER = (VOLUMETRIC FLOW RATE)
x(KINETIC ENERGY PER UNIT VOLUME)**

$$P = (AV) \times \left(\frac{\rho v^2}{2} \right)$$

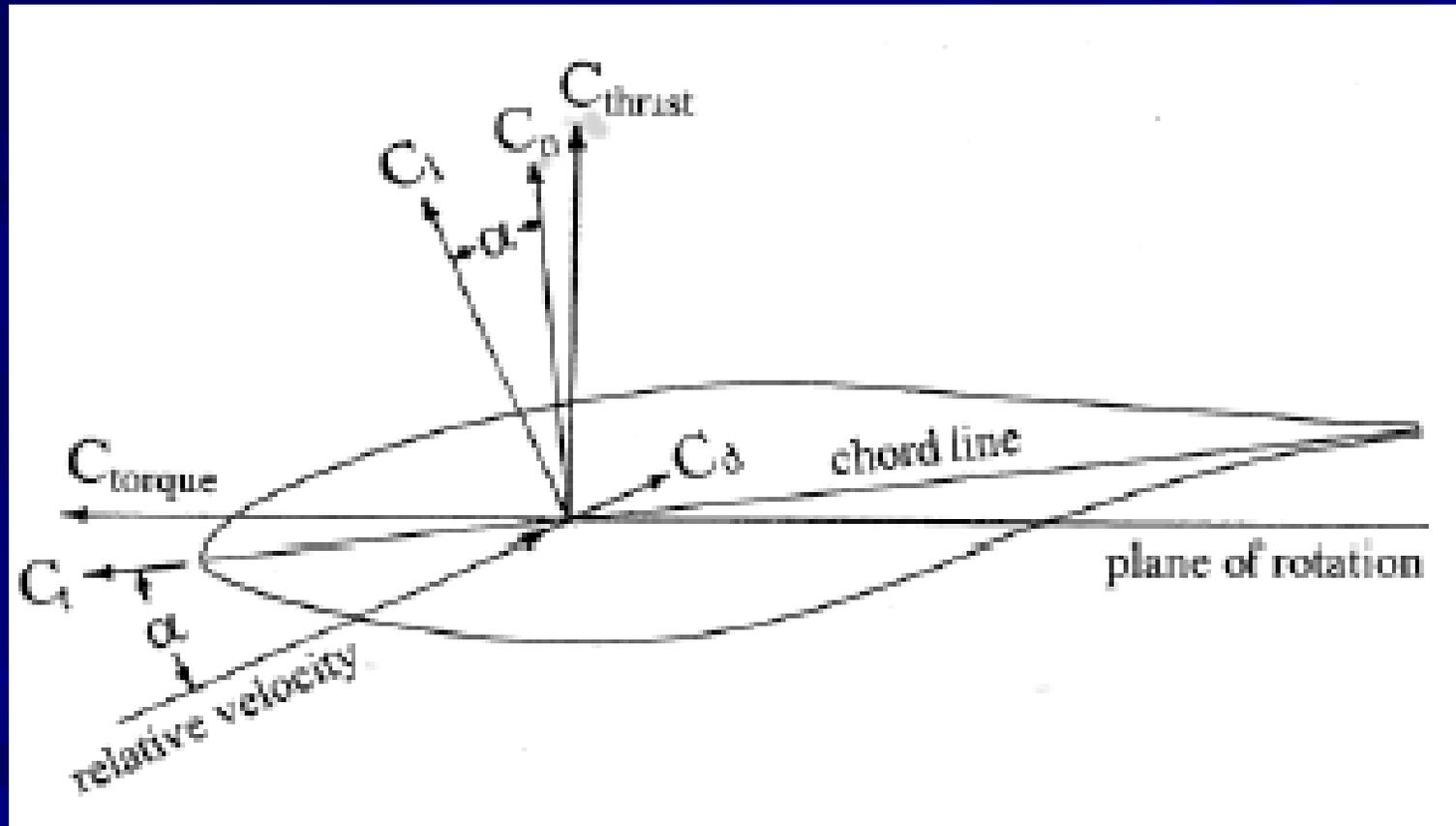
$$\text{or } P = \frac{\rho AV^3}{2}$$



Momentum Theory



Blade Airfoil Element Analysis



Aerodynamic Power Control is Critical

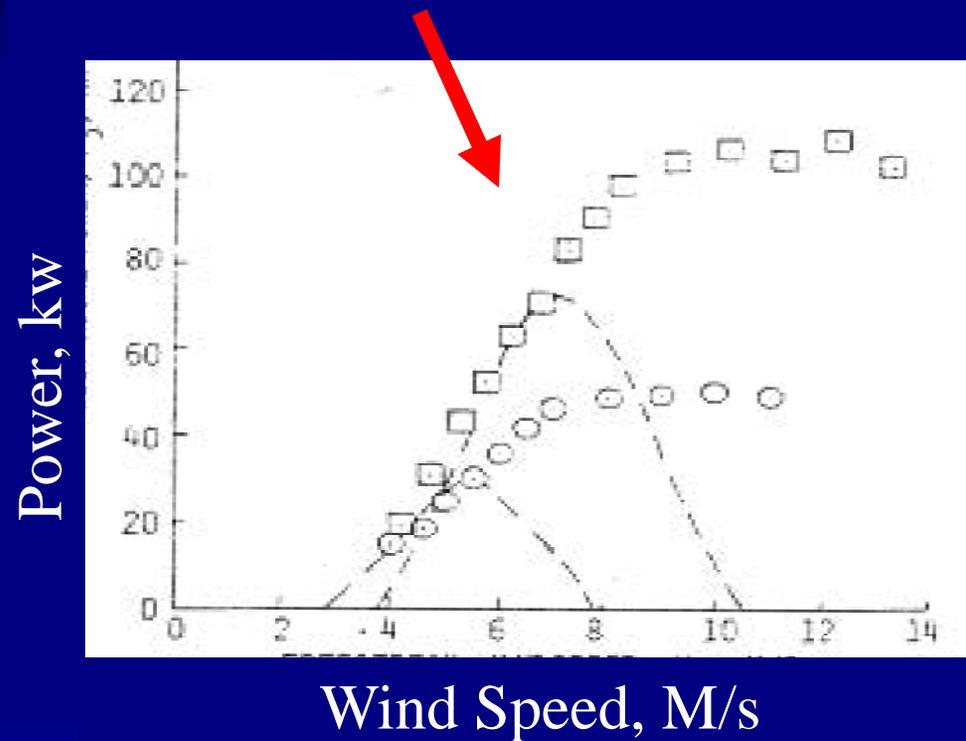
Early options included:

- Shut down in High Wind
- Furling Out of the Wind
- Complex Pitch Control



Aerodynamic Stall & Passive Power Control

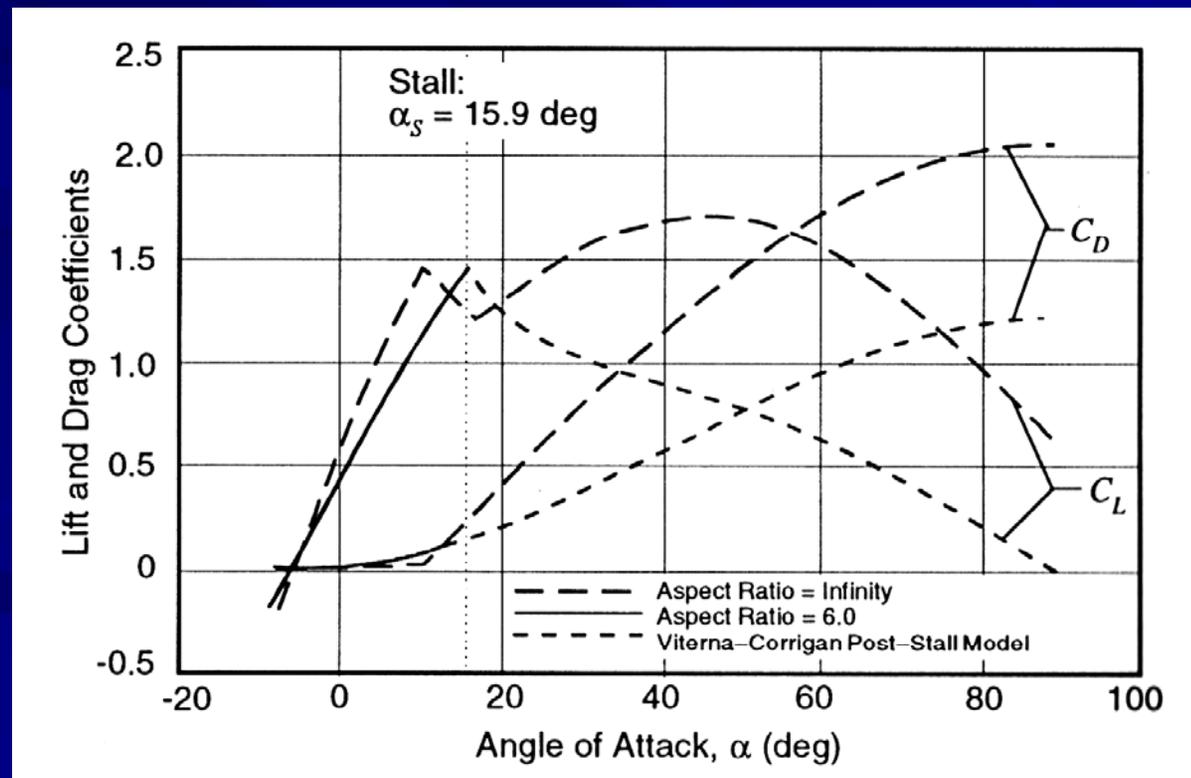
1980 – Design methods miscalculated power output and forces on wind turbines by nearly double



Adoption Inertia in the Technical Community

Classical Blade Element Momentum theory used two-dimensional wind tunnel airfoil data.

Viterna “reverse engineered” a 3-D aerodynamic model. It was presented in 1981 to a unenthusiastic response



10 Years Later (1992)



As mentioned in previous sections, designers have not been able to predict high wind speed characteristics with confidence. Viterna (Viterna 1975) characterized wind tunnel data with a stall angle correction that remained constant. Viterna speculated that airfoil stall characteristics were not affected by spanwise flow reattachment, based on peak power. This model in the US, even though it was used in design codes, was not confirmed by physical mechanisms. More recent tests have confirmed Viterna's speculation of rotating blade stall characteristics.

1992 - 60 percent
of the wind
turbines in the
world used
passive stall
control

controlled turbines. Viterna's model in the US, even though it was used in design codes, was not confirmed by physical mechanisms. More recent tests have confirmed Viterna's speculation of rotating blade stall characteristics.

The Role of Politics and Business in the Adoption of Technology

'70s Crises Impacts U.S. Energy Use



Public Policy – U.S. Congress 1980

Wind Energy Systems Act

CONFERENCE REPORT

[To accompany H.R. 5892]

- (1) The United States is faced with a finite and diminishing resource base of native fossil fuels and, as a consequence, must develop as quickly as possible a diversified, pluralistic national energy capability and posture;

resource base of native fossil fuels and, as a consequence, must develop as quickly as possible a diversified, pluralistic national energy capability and posture;

(2) the current imbalance between supply and demand for fuels and energy in the United States is likely to grow for many years;

(3) it is in the Nation's interest to provide opportunities for the increased production of electricity from renewable energy sources;

(4) the early wide-spread utilization of wind energy for the generation of electricity and for mechanical power could lead to

relief on the demand for existing non-renewable fuel and energy supplies;

(5) the use of large wind energy systems for certain limited applications is already economically feasible;

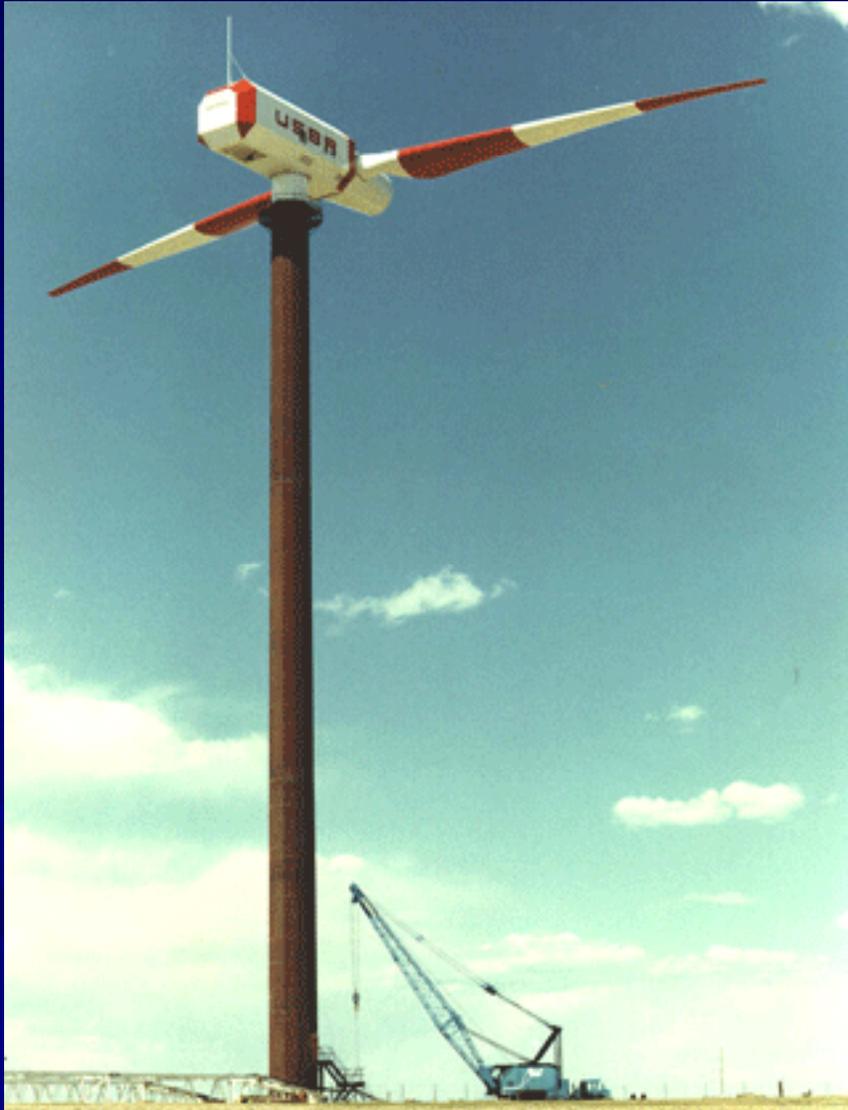
(6) the use of small wind energy systems for certain applications is already economically feasible, and therefore, the Federal Government should not undertake any financial incentive or financial initiative which may detrimentally affect commercial markets for small wind energy systems;

(7) an aggressive research, development and demonstration program to accelerate widespread utilization of wind energy should solve existing technical problems of converting wind energy into electricity and mechanical energy and, supported by an assured and growing market for wind energy systems during the next 20 years, should maximize the future contribution of wind energy

- (7) an aggressive research, development and demonstration program to accelerate widespread utilization of wind energy should solve existing technical problems . . .

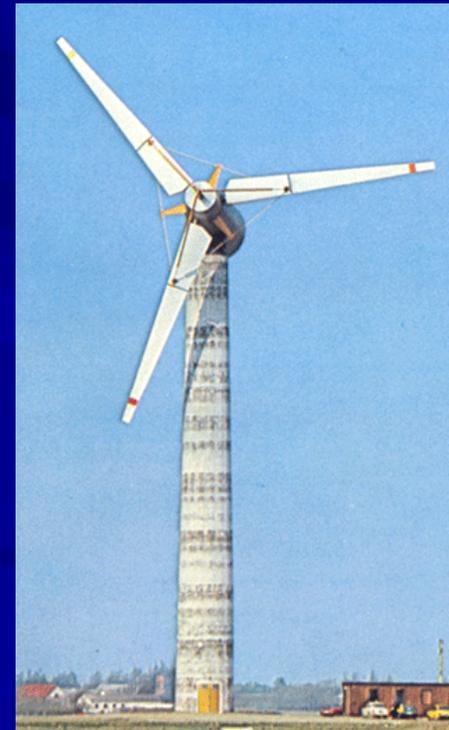
nents and systems for converting wind energy into electricity and mechanical energy can be fostered through encouraging direct contact between the manufacturers of such components and systems and utilities and other persons interested in utilizing such components and systems; and

The U.S. Leads the Early Race



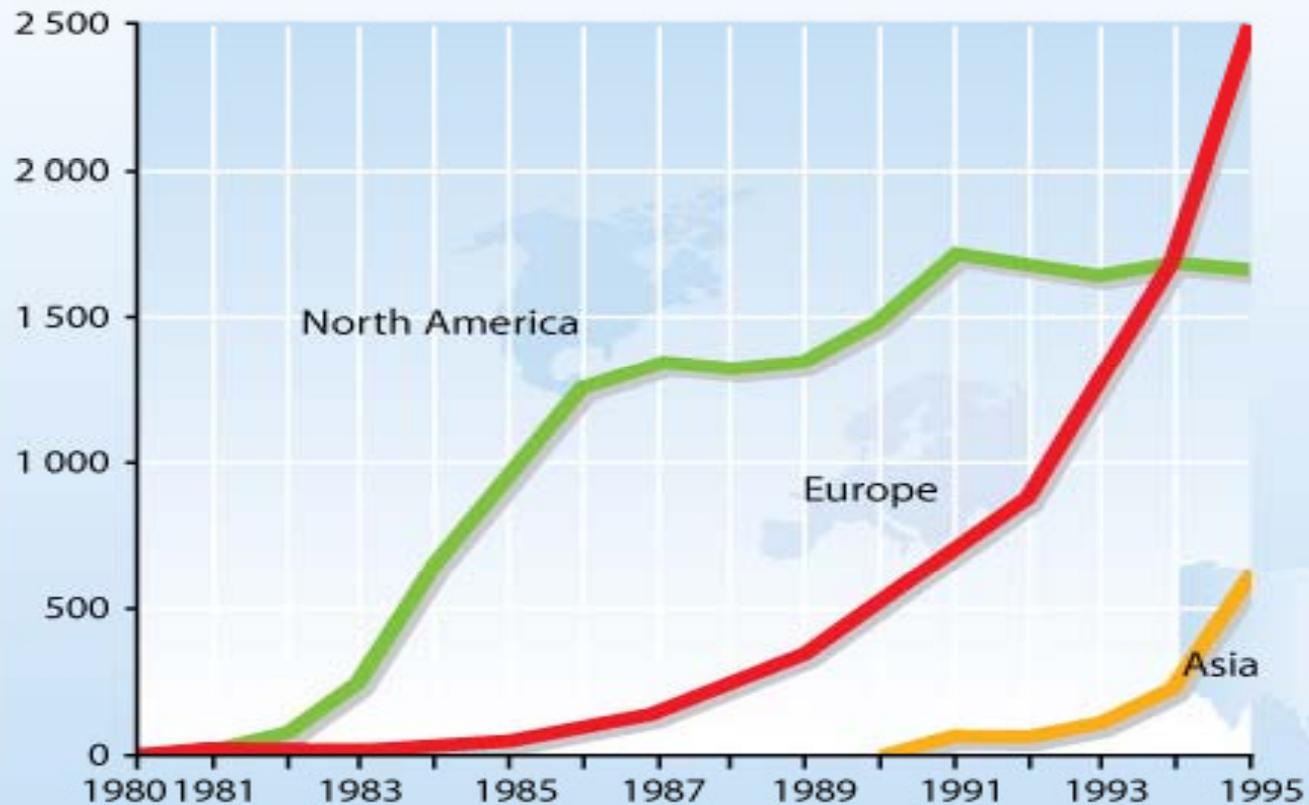
Left - U.S. WTS-4, 4000 kw, 1982

**Below – Danish Nibe A, 600kW,
1981**



Wind Energy – Early Growth

Capacity, MW 1980 - 1995



A Change in U.S. Public Policy - 1986

HEI wind turbine funding OK'd

By Nina Berglund
Advertiser Business Writer

bine after its completion,
decided the funding deferral as
"not only shortsighted, but also



when the wind is 12 mph
can operate in wind speed
great as 60 mph. The unit

An
turbine
Shore
blades
renew
its cor
Pre
press
gress
others
Tuesd
for co
bine
world
The
the ce
wind
and c
late la

“ . . . construction was halted when the Reagan administration deferred \$10.2 million in funding for the project this year”

But in January, after millions of dollars in federal and private funds already had been spent on the turbine's development, construction was halted when the Reagan administration "deferred" \$10.2 million in funding for the project this year.

C. Dudley Pratt Jr., president of Hawaiian Electric Industries, which intends to buy the tur-

thank you."

The \$71.4 million MOD-5B turbine — which will feature a rotor blade span as wide as a football field — is being built on a windy ridge above Kahu-

Upon completion, the turbine is expected to produce more



C. Dudley Pratt Jr.

"A very special thank you"

than 15 million kilowatt-hours of electricity annually for sale to Hawaiian Electric Co., reducing annual oil consumption here by an estimated 25,000 barrels.

The turbine itself is designed to begin generating power

Washington can be expected so that further delay will be minimized."

Pratt said the huge "state-of-the-art" turbine along with nearby medium-size wind turbines on the North Shore "a unique asset for the people of our state and for ever studying and developing energy throughout America and the Pacific."

Hawaiians get
Boeing's last
wind machine



**“ We don't plan to build any more units” said Boeing ...
“we are planning to leave the market because low oil prices are keeping windmills for electricity uneconomical”**

LAURENCE BY WERNER

The wind machine — the world's largest operating wind turbine of the traditional horizontal axis type — was so big it had to be hauled in sections and accompanied by a 250-ton crane. There were no cranes in Hawaii large enough to lift its 320,000-pound rotor.

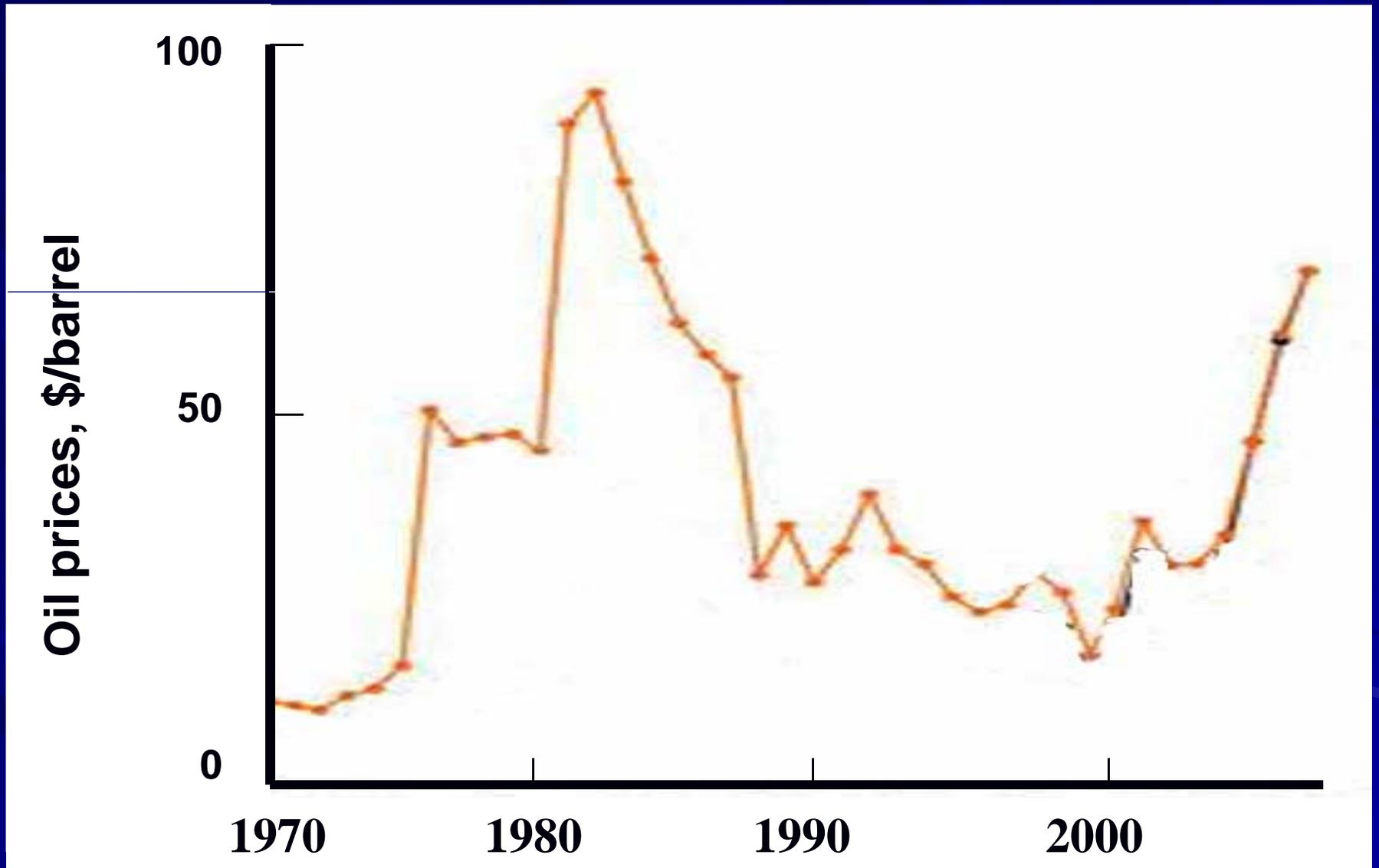
The turbine stands 360 feet tall from its base to the tip of its 158-ton blades. It weighs a total of 469 tons.

Dubbed MOD-5B by Boeing Aerospace Co.



Major U.S. manufacturers leave the market

Oil Price Variability



Denmark (& Europe) Approach 1980 -2000

- Long-term Public Strategy on Energy
- Focus on Implementing Wind Power Production
- Created a Research and Manufacturing Capability
- Managed the Technology and Market by Developing International Certification Standards

Technology Adopted

- Steel tube (soft) towers
- Fiberglass composite blades
- Variable speed generators
- Microprocessor control
- NACA 63, 64 series airfoils
- . . .



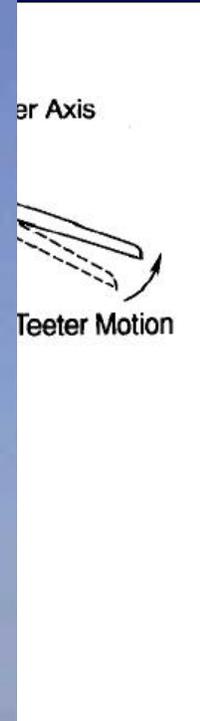
What Happened to the Two-Blades?

Advantages:

- Reduced Cost
- Reduced Loads

Challenges:

- More Complex Structural and Acoustic Design Analyses



Current Technical Challenges



Gearbox Reliability – Today's #1 Challenge

- As turbines get larger – torque and hung weight is skyrocketing
- We are reaching physical limits of materials



What Future Course will the U.S. Take?

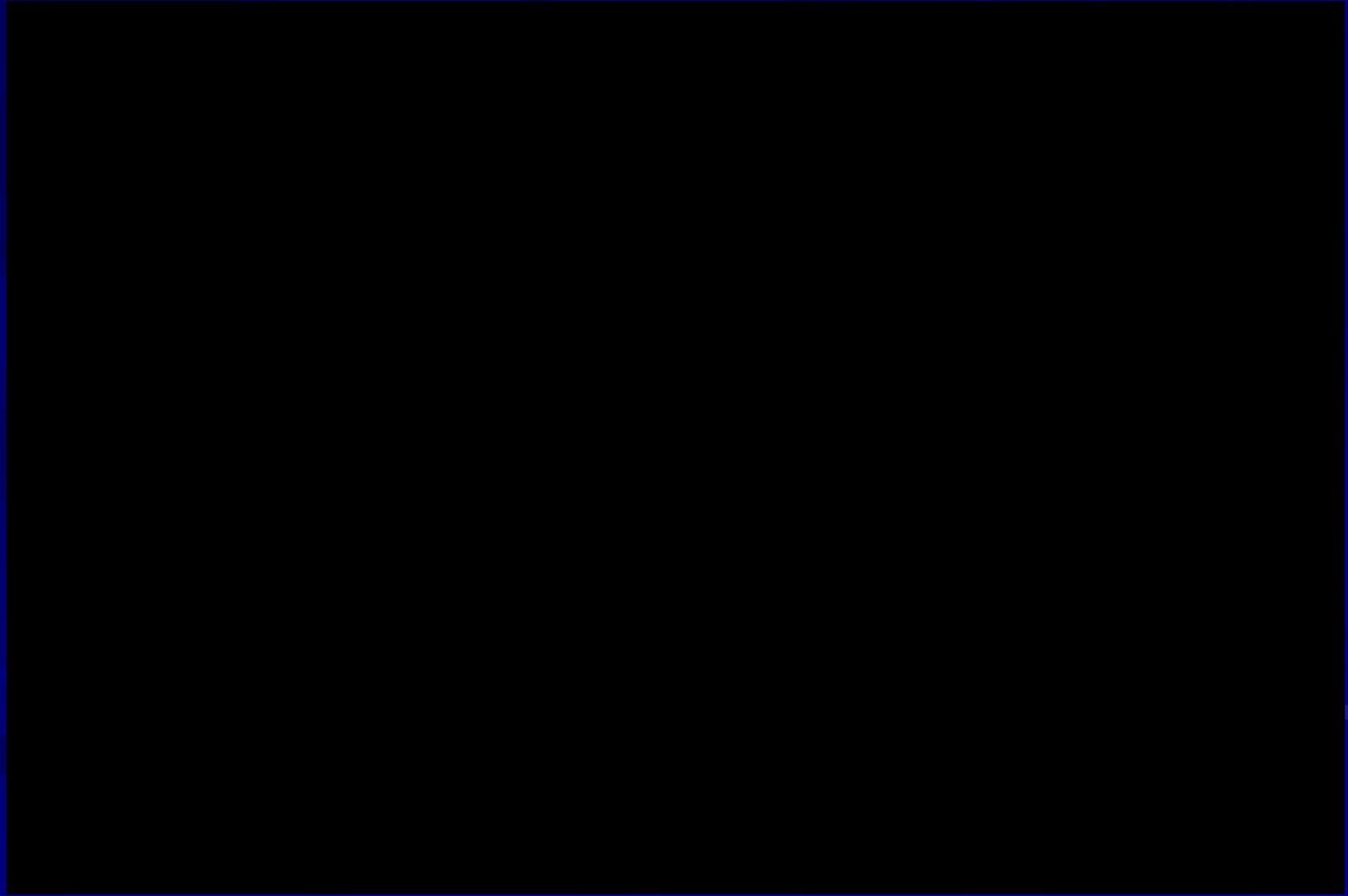
- Public Policy
- New Technologies and Markets

National Security / Energy Independence



Oil fields Burning after 1990
Iraq invasion of Kuwait

Policy Decisions on Climate Change



Observed Climate Change

Polar Cap 1979



Polar Cap 2003



Glacier National Park, Montana



The background is a dark blue gradient with several diagonal lines of varying shades of blue, creating a sense of movement and depth. The lines are most prominent in the upper right and lower left quadrants.

A Future Market Opportunity – Offshore Wind Energy

Offshore Wind Energy is Emerging in Europe

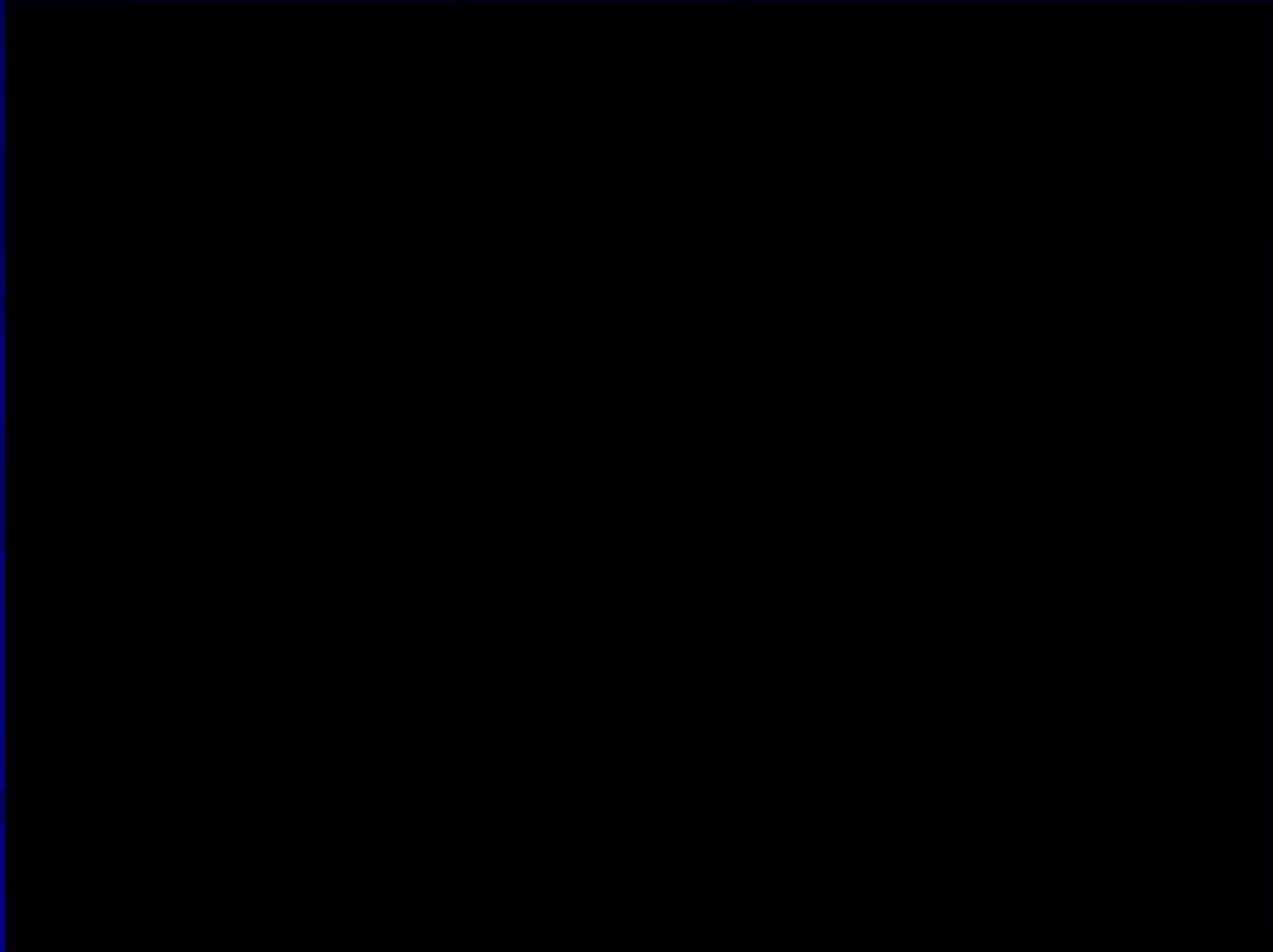
160 MW Offshore Wind Site in Denmark - Eighty 2 MW Turbines



Installation Challenges for Offshore



Possible Offshore Installation Technology



Take Aways

- Adoption of renewable energy technologies requires a substantial research investment and a long-term strategy in public policy and business
- Today's success of wind turbines in the marketplace suggests the potential viability of other alternative energy technologies
- The future offers potentially vast opportunities for advanced wind energy technologies and products