ME/ESE 4470
Wind and Tidal Power
Introduction

Introduction

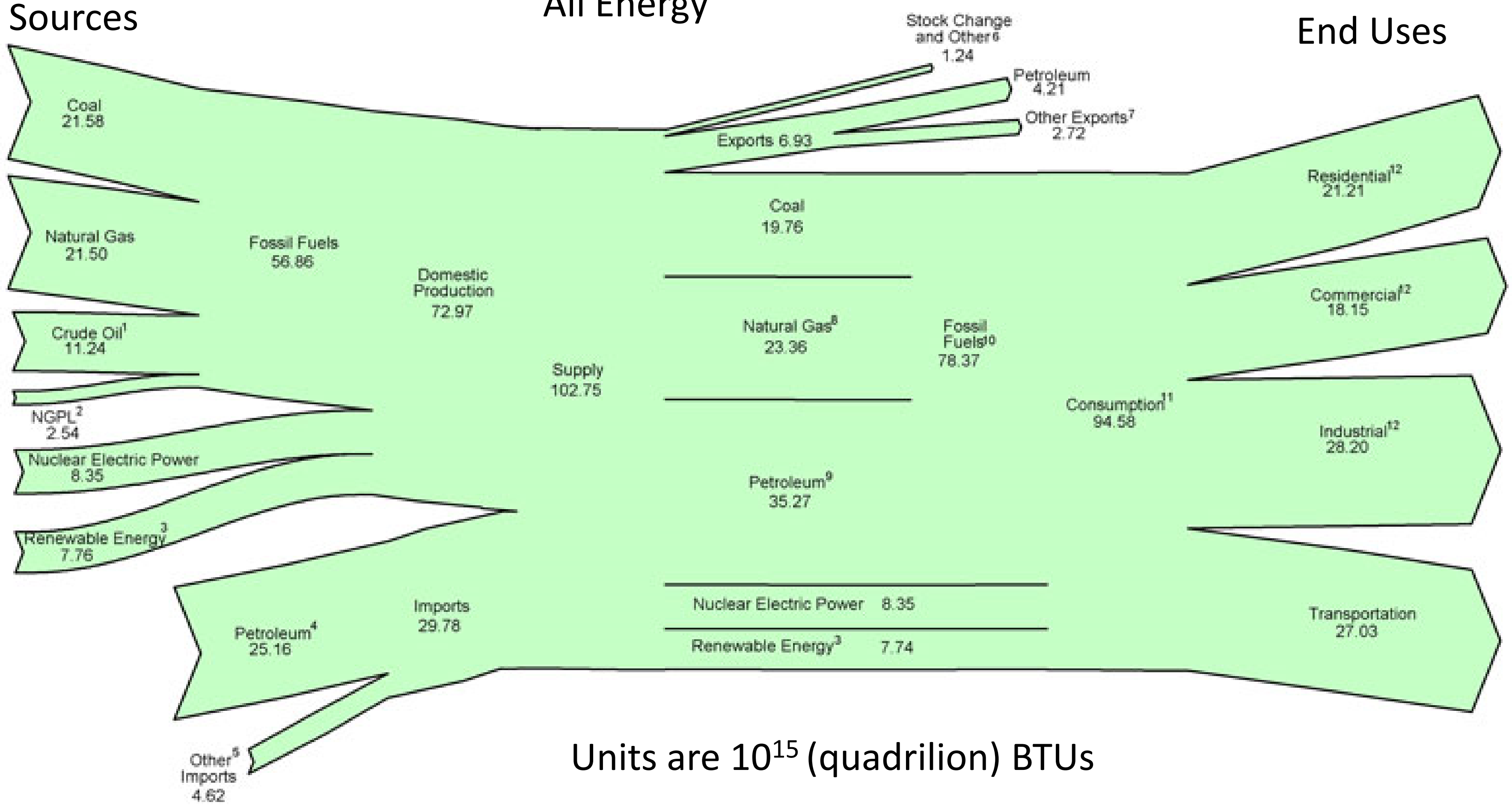
A. The Rise of Wind Energy
   1. Why teach a course specific to wind energy?
      a) Wind and natural gas are the most rapidly growing sources of electrical energy in U.S.
      b) U.S. has vast wind energy resources both onshore and offshore.
   2. Before discussing wind energy, a discussion of the context in which it is being developed is necessary.
      a) Its place among other energy sources
      b) Technology
      c) Political environment
      d) Economics

Introduction

A. The Rise of Wind Energy

1. Current Energy Sources and Uses – U.S.

Energy Information Administration / Annual Energy Review 2009



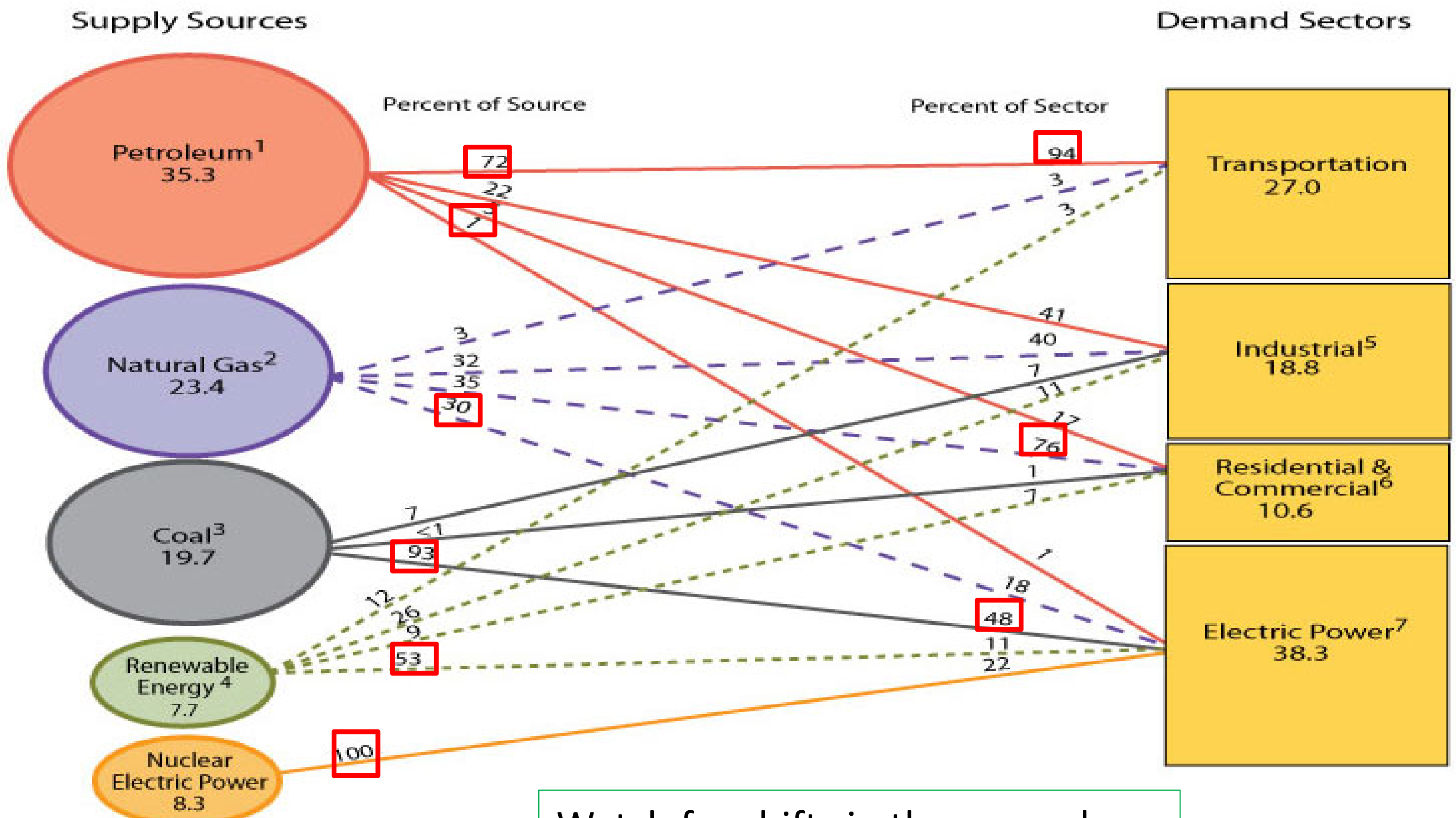
Units are 10^{15} (quadrilion) BTUs

Introduction

A. The Rise of Wind Energy

1. Current Energy Sources and Uses

Energy Information Administration / Annual Energy Review 2009



Watch for shifts in these numbers

Introduction

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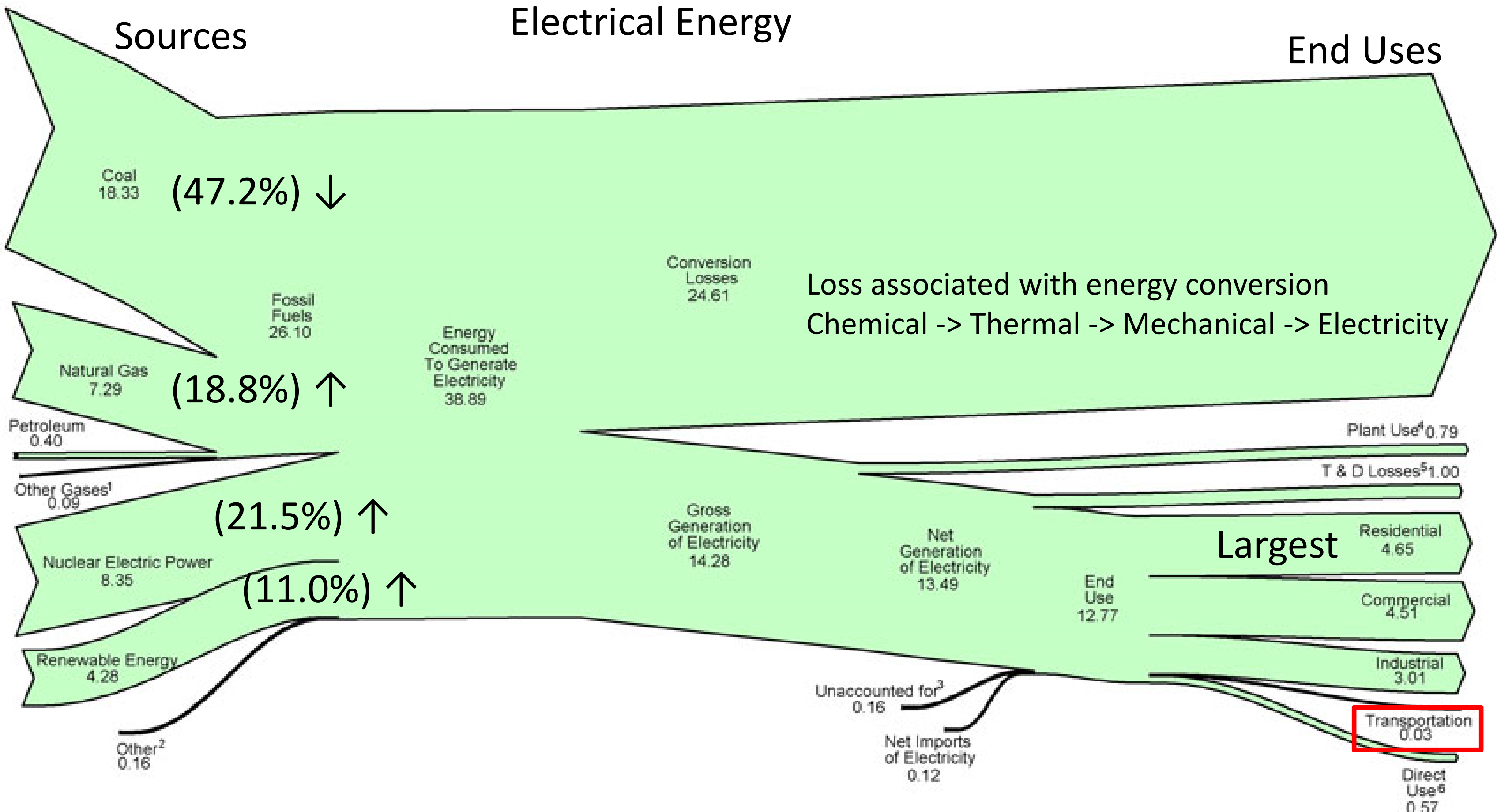
A. The Rise of Wind Energy

1. Current Energy Sources and Uses



20-40% increase expected between 2005 and 2030
Depends on Assumptions
Expect changes in both sources and use

Introduction

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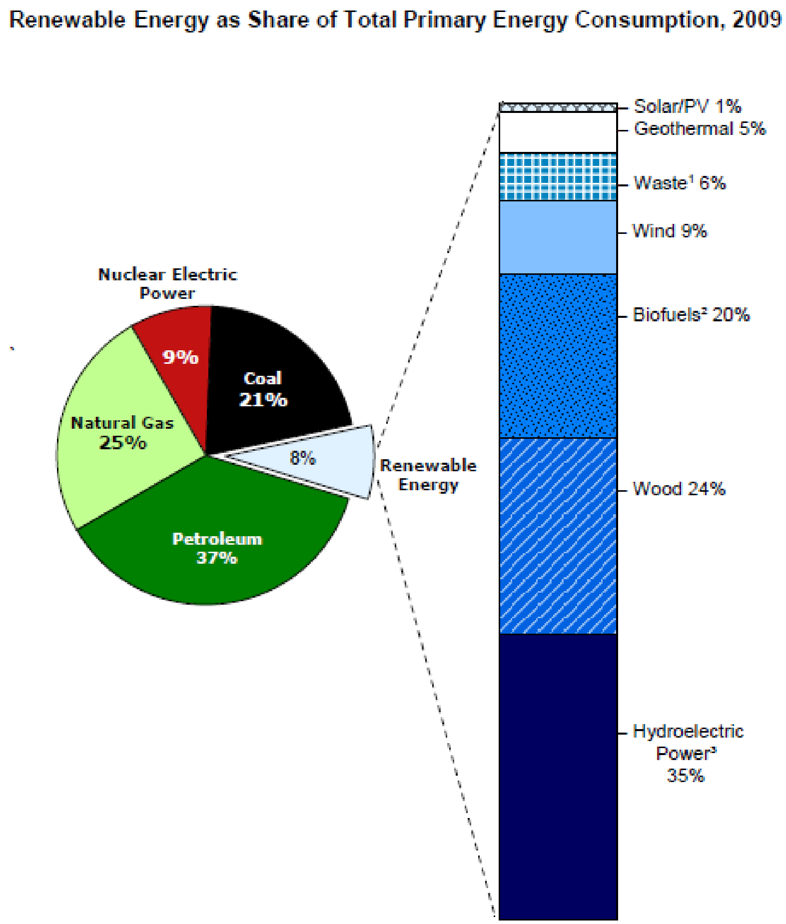
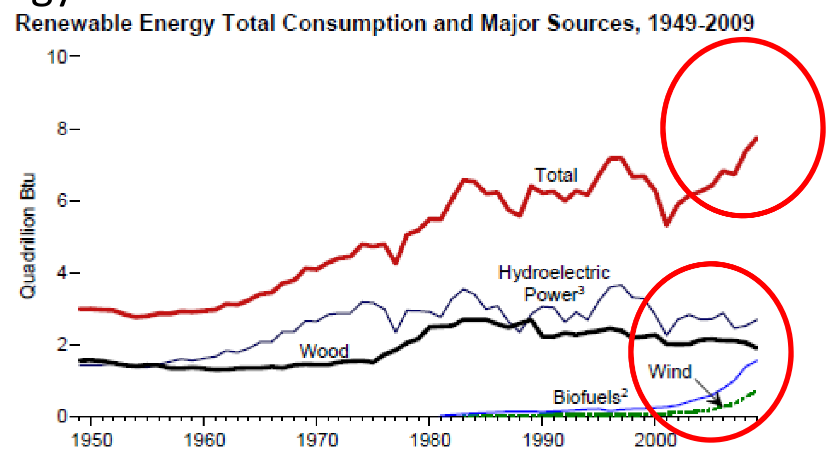
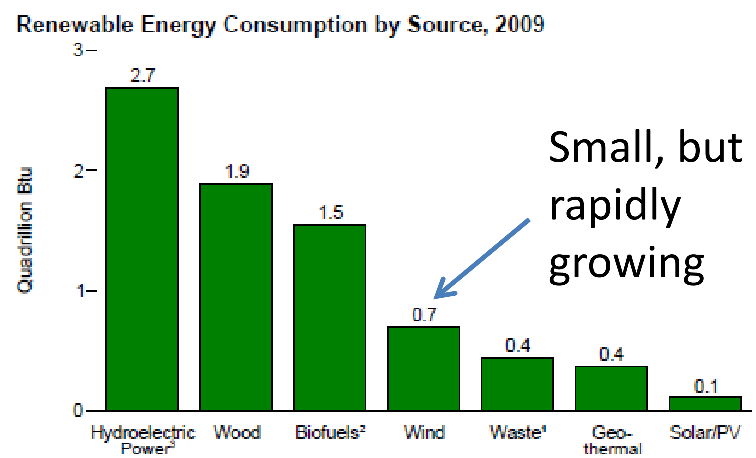
A. The Rise of Wind Energy

1. Current Energy Sources and Uses

All Energy







Small, but rapidly growing

Introduction

A. The Rise of Wind Energy

  2. Energy Dilemma

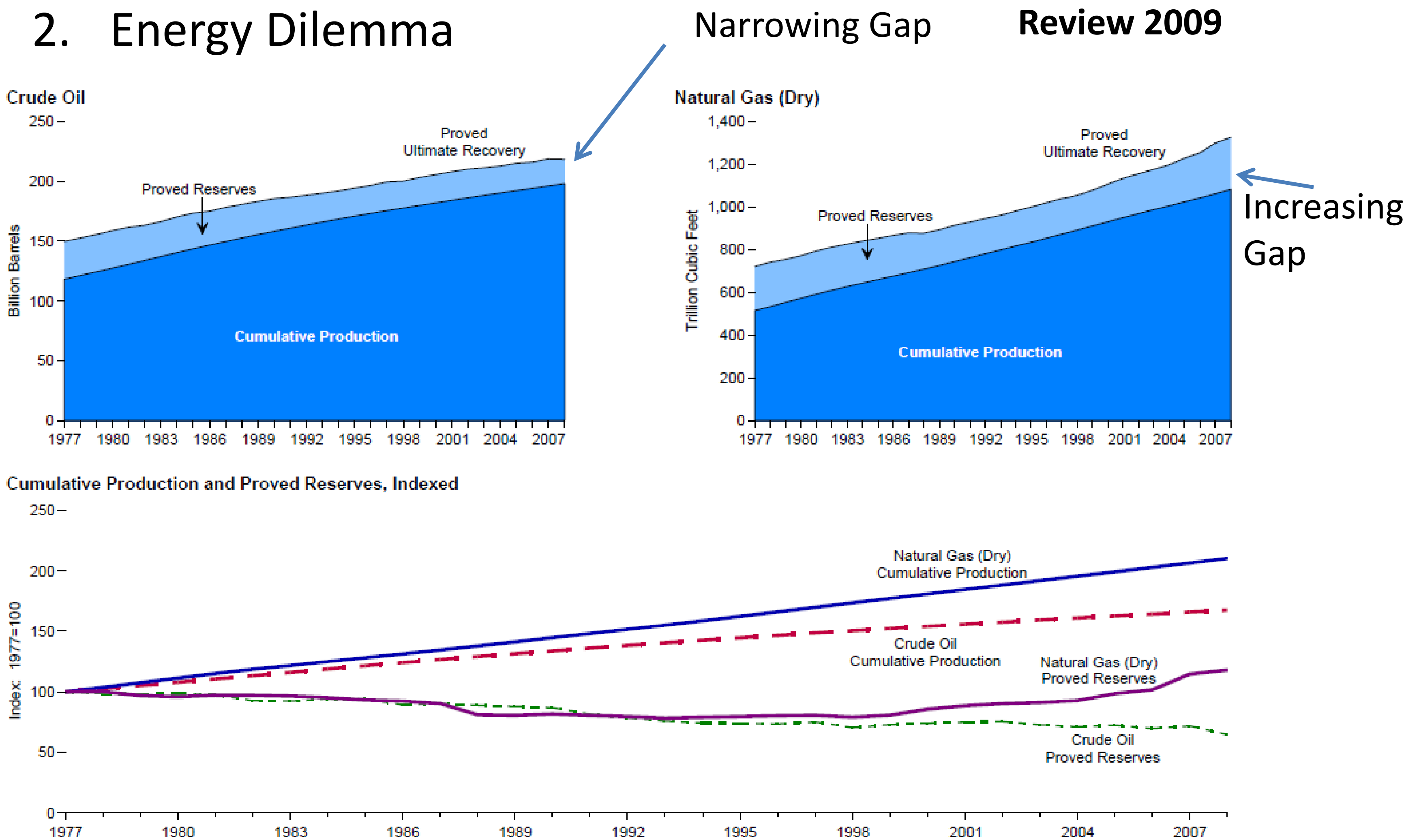
     - Even as demand rises
       - o Reliance on foreign sources is increasing
         - Limited domestic sources
       - o Concern over chemical and CO_2 emissions is increasing
       - o Concern in the Western U.S. and elsewhere over water use
       - o Continued inefficiency with the energy we do use

Introduction

Energy Information Administration / Annual Energy Review 2009

A. The Rise of Wind Energy

2. Energy Dilemma

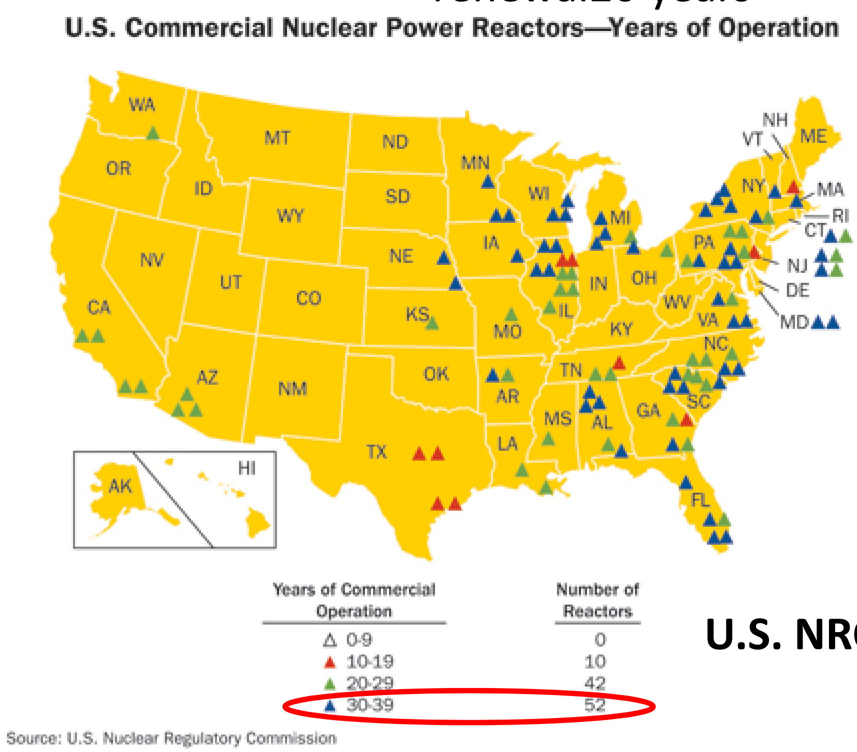


Introduction

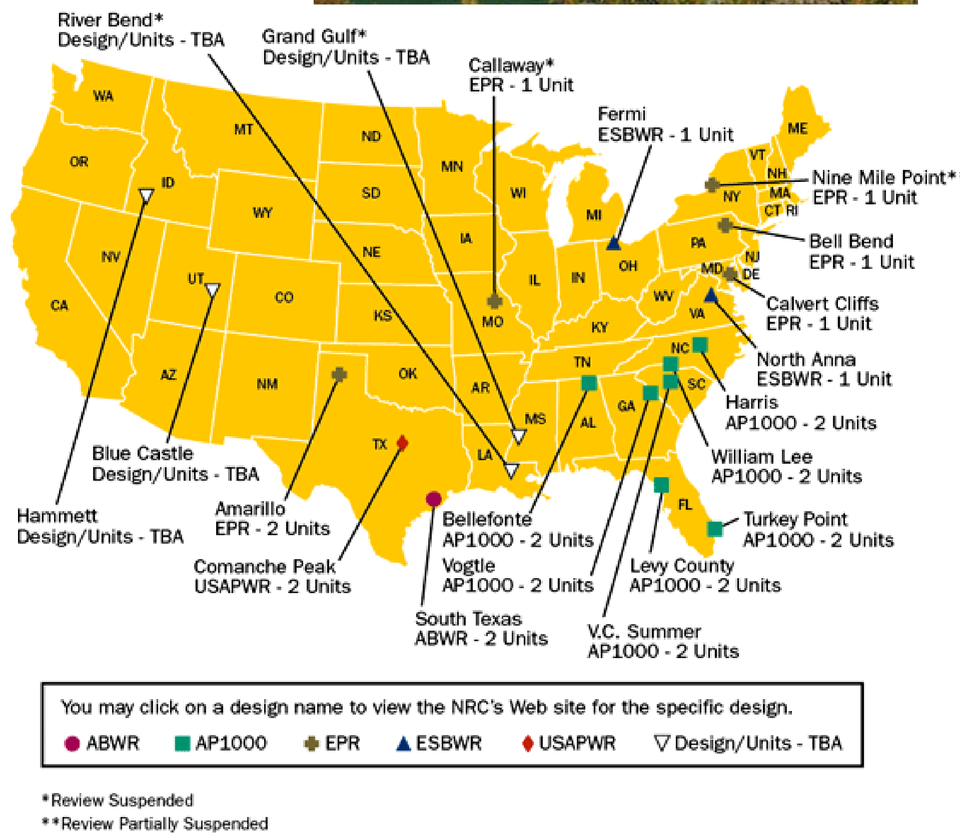
A. The Rise of Wind Energy

2. Energy Dilemma

- No new nuclear start since 1979
- Current permitting
  - Initial 40 years
  - renewal20 years



U.S. NRC

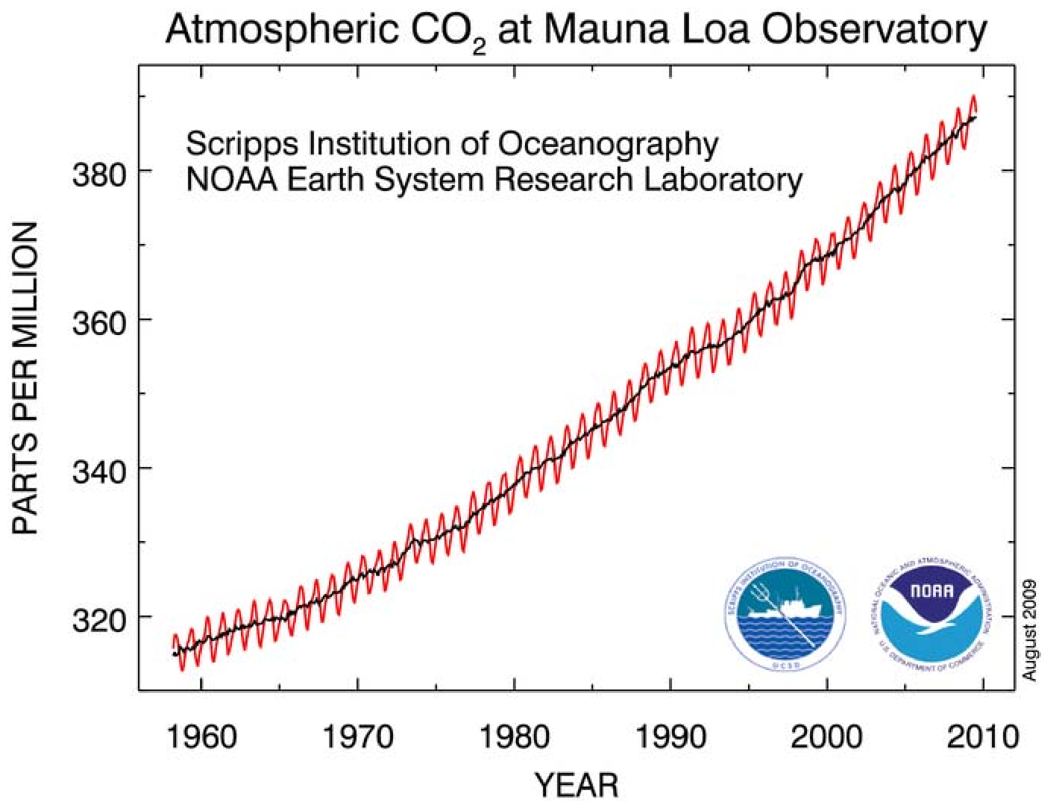


Introduction

A. The Rise of Wind Energy

2. Energy Dilemma

- Atmospheric chemistry ***is*** changing
- Is this something we want to experiment with?
- Carbon legislation is likely at some point
  - Carbon tax
  - Cap/Trade
- How will this effect the costs of the different energy sources?



Introduction

A. The Rise of Wind Energy

3. Failure to Address the Energy Problem Earlier

- We have known that energy supply was going to be an issue since at least 1973
  - OPEC Oil Embargo
- Why didn't something happen?
  - Inexpensive energy cost to consumer
  - Lack of wide-spread understanding of problem by the public
  - Complacency developed – no push for a change
  - Little invested in R&D
  - Continued waste and inefficiency
- One positive development
  - Energy efficiency has improved considerably in many areas
    - Boeing 777-300 burns 1/3 less fuel per passenger than 747-200

Introduction

American Physical Society
National Policy Statements

A. 96.2 STATEMENT ON ENERGY: THE FORGOTTEN CRISIS
(Adopted by the Council -- 6 May 1996)

B. Our nation's complacency about the energy problem is dangerous. While the understandable result of currently abundant supplies of energy at low prices, such complacency is short-sighted and risky. Low-cost oil resources outside the Persian Gulf region are rapidly being depleted, increasing the likelihood of sudden disruptions in supply. Energy-related urban air pollution has become a world-wide threat to human health. Atmospheric concentrations of carbon dioxide, other greenhouse gases and aerosols are climbing; this will cause changes in temperature, precipitation, sea level, and weather patterns that may damage both human and natural systems.

C. The introduction of non-fossil-fuel energy sources, new ways of producing and using fossil fuels, and myriad energy-efficient technologies have helped to improve our energy security and to reduce environmental stress. In an era of growing global energy demand, such innovations must continue.

D. The Council of the American Physical Society urges continued and diversified investments in energy research and development, as well as policies that promote efficiency and innovation throughout the energy system. Such investments and policies are essential to ensure an adequate range of options in the decades ahead. Our national security, our environmental well-being, and our standard of living are at stake.

E. http://www.aps.org/statements/96_2.cfm

Introduction

American Physical Society
National Policy Statements

A. 00.3 ENERGY STATEMENT (Adopted by the Council, 19 November 2000)

B. Energy Policy for the Twenty-first Century

C. On May 6, 1996, as part of its "Statement on Energy: The Forgotten Crisis," the American Physical Society cautioned,
"Our nation's complacency about the energy problem is dangerous. While the understandable result of currently abundant supplies of energy at low prices, such complacency is short-sighted and risky."

D. Since 1996, demand for oil and natural gas has continued to grow with the expansion and globalization of the world's economy. In addition, our nation's dependence on imported energy has increased, and the effects of burning fossil fuels on the global environment are becoming a major concern. The Council of the American Physical Society believes that the use of renewable energy sources, the adoption of new ways of producing and using fossil fuels, increased consideration of safe and cost effective uses of nuclear power, and the introduction of energy-efficient technologies can, over time, promote the United States' energy security and reduce stress on the world's environment.

E. Therefore, the Council of the American Physical Society urges the Administration and Congress to make a significant increase in Federal investment in energy research and pre-commercial development. Further, we urge the adoption of policies that promote efficiency and innovation throughout the energy system, including conservation and the development of alternatives to fossil fuels.

F. The United States will remain dependent on imported energy for the foreseeable future. Investment in a broad portfolio of energy research is essential for providing the options that will allow us to effectively manage this dependence. Our national security, the preservation of our environment and our standard of living are all at stake.

G. http://www.aps.org/statements/00_3.cfm

Introduction

A. The Rise of Wind Energy

4. What has changed?

- Increased demand for energy worldwide
  - Led by China and India
- Decreased resources
  - Non-renewable resources are being depleted
- War in the Middle East/Terrorism
  - Increased energy price, other hidden costs
- Natural and Man-Made Disasters
  - Katrina, Gulf oil spill
- Decaying infrastructure
  - Transmission capability, pipeline deterioration
- Environmental Concerns
  - CO2 content in the atmosphere
  - Chemical pollution
  - Nuclear fuel disposal
  - Energy infrastructure impacts

a) All of these issues affect
  - Decisions concerning energy
  - Cost of energy (COE)

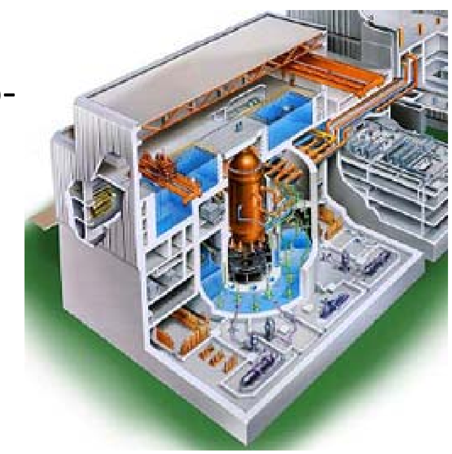
Introduction

A. The Rise of Wind Energy

5. So What do We Do Now?

- Develop a wide range of energy resources for energy supply
  - Consider new factors affecting these decisions
- Increase efficiency of end uses
  - Transportation
  - Buildings, etc.
- Consider time constant associated with energy source changes
  - 10 – 50 years
- Apply different strategies
  - Mid-Term
    - Nuclear fission, gas-fired turbines, wind energy, geo-thermal
  - Long Term
    - Fusion, solar electric, wave/ocean, large energy storage strategies

Good energy policy *should* be easy to sell
- Environmental
- Strategic
- Economic



Introduction

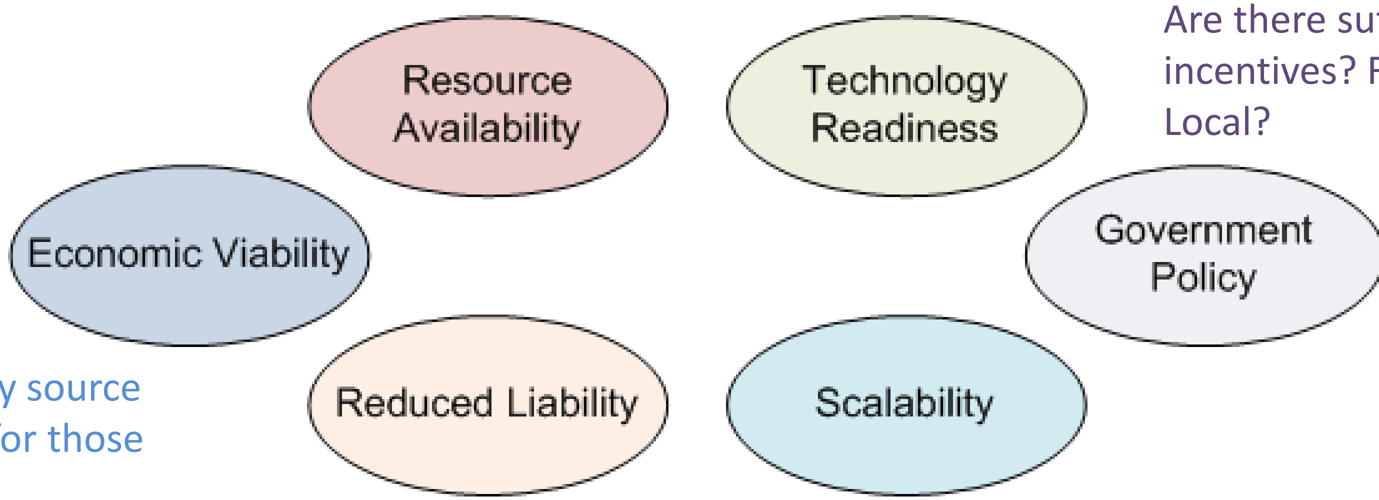
B. Why Wind Energy Now?

1. Driving Attributes

Is the technology mature enough to be a reliable source?

Is there enough resource and is it in the right places?

Are there sufficient incentives? Federal, State, Local?



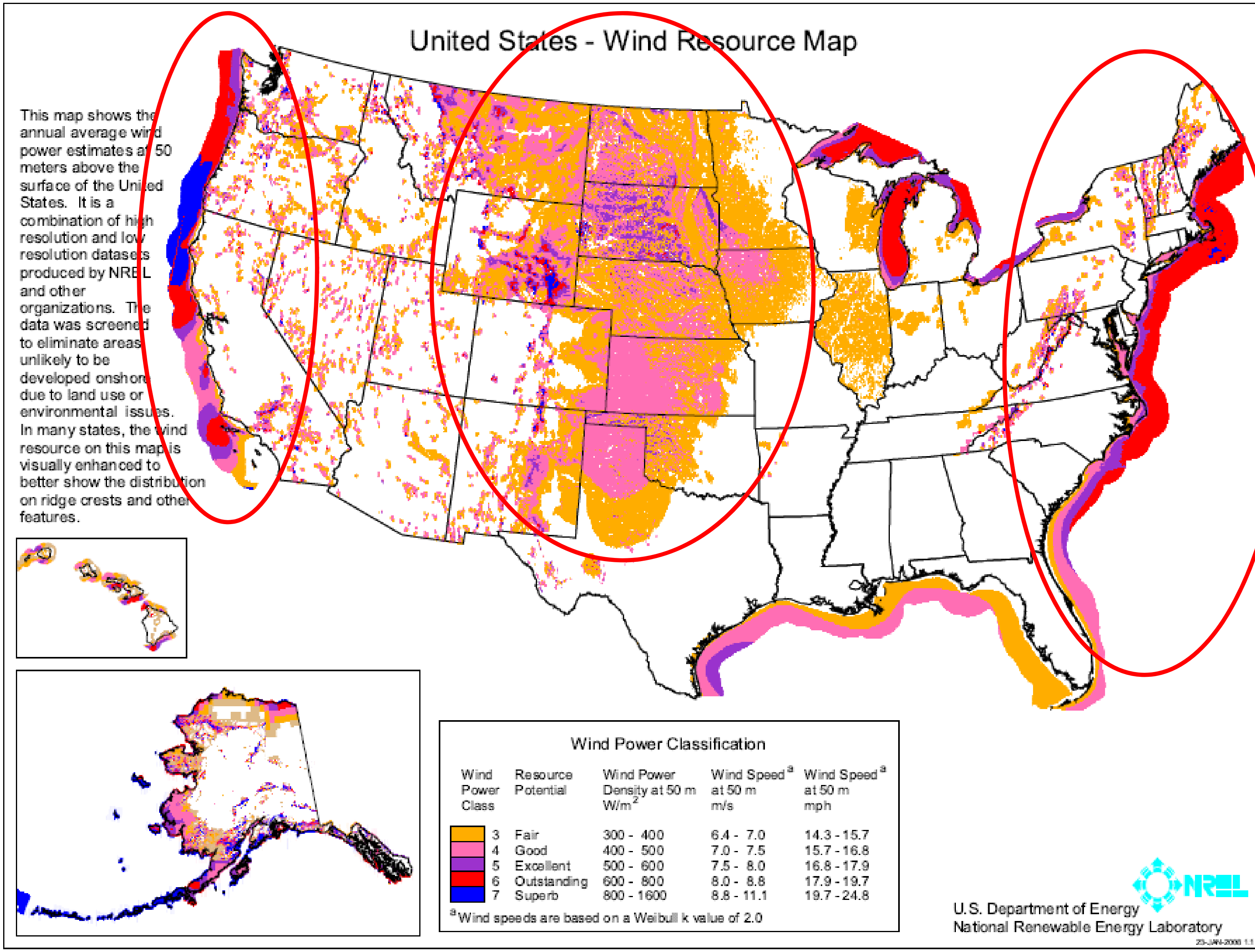
Can the energy source make money for those involved?

Does the source reduce the negative impacts relative to other sources?

Can the source of energy scale to meet a significant portion of the need?

Introduction

Resource Availability



Introduction

Technology Readiness

1979: 40 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

2000:
4 - 6 cents/kWh

NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

- Continued technology development needed
  - Higher reliability/availability
  - Develoment of offshore technology
  - Storage technology

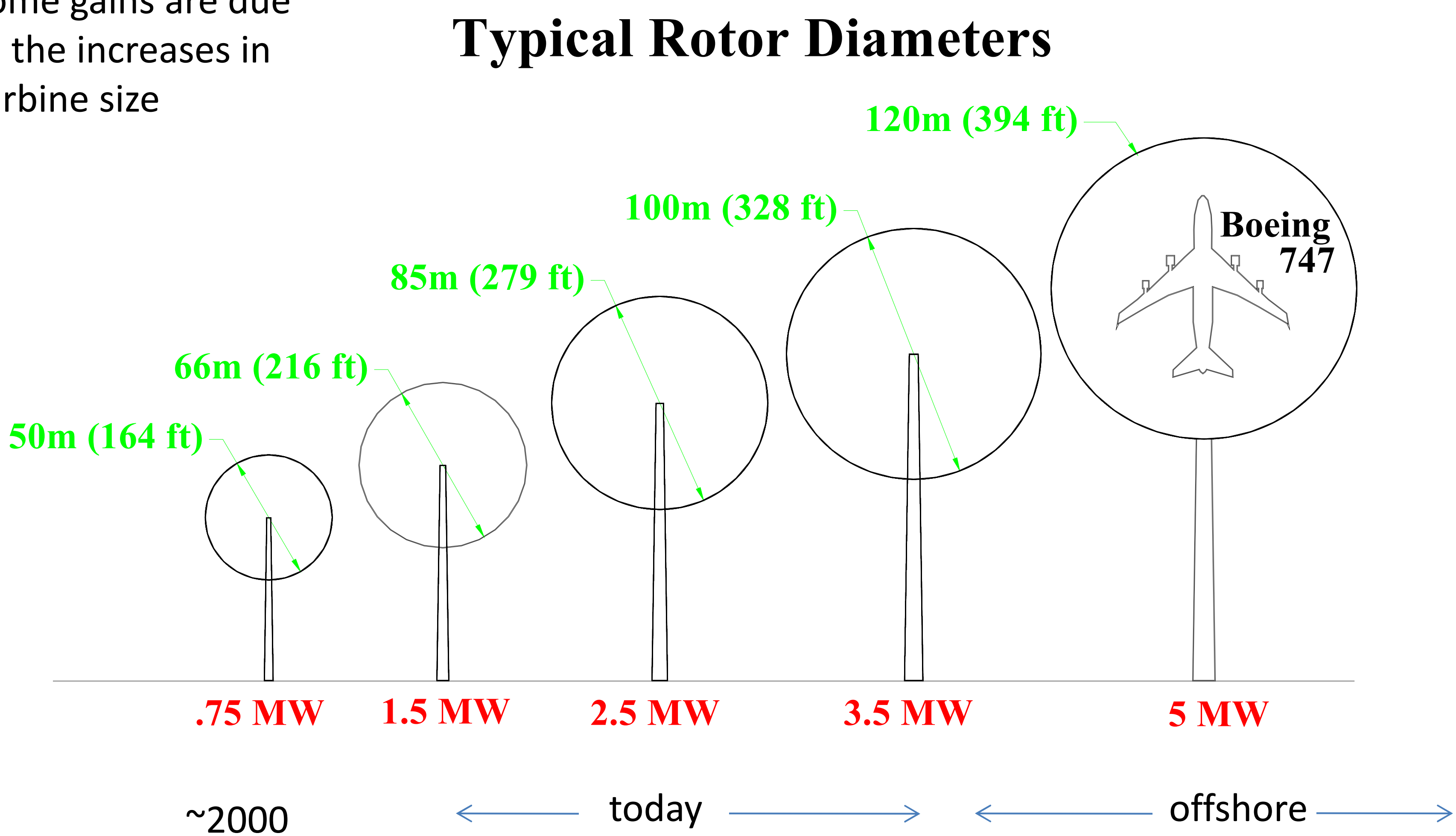
2004:
3 - 5 cents/kWh

Similar to Fossil Fuels

Introduction

Technology Readiness

Some gains are due to the increases in turbine size



Introduction

Scalability

- Technology Readiness
- Acceptable Environmental Impacts
- Sufficient Resources
- Manufacturing Capability
- Workforce Availability
- Transmission Capability and Capacity

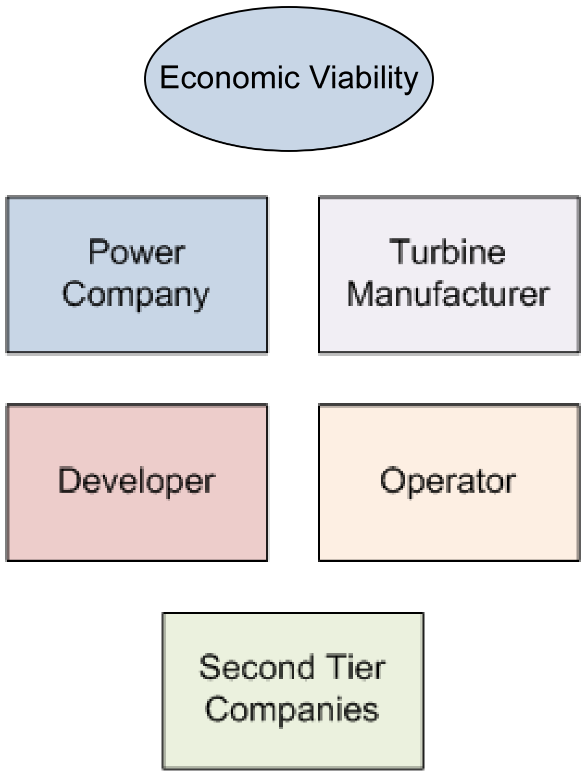
Can the energy source be scaled to meet a significant portion of the need?

Reduced Liability

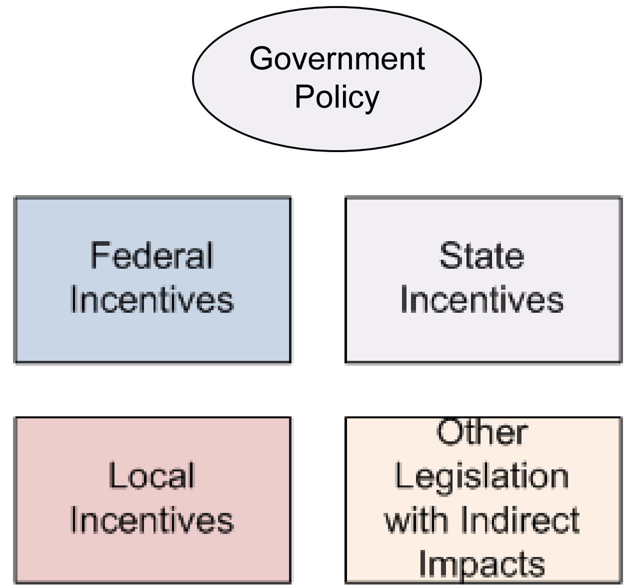
- No CO_2 Emissions
- No H_2O Required
- No Chemical Emissions
- Dual Land Use
- Renewable Resource
- Energy Security
- Economic Engine

Does the source reduce the negative impacts relative to other sources?

Introduction



Can the energy source make money for those involved?



Are there sufficient incentives?

Federal, State, Local?

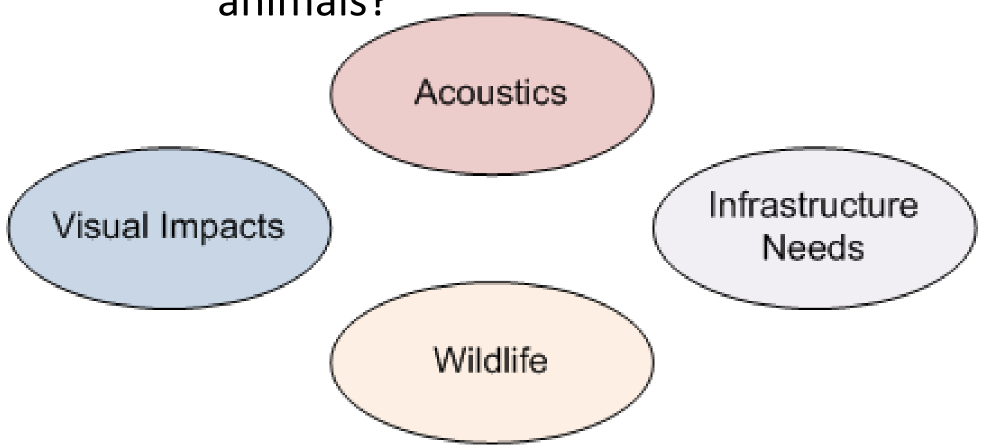
Introduction

B. Why Wind Energy Now?

2. Limiting and Negative Attributes

How much sound do wind turbines produce and how does it affect people and animals?

How do wind plants affect viewscapes?



What infrastructure needs are there and what are their impacts?

Roads, Transmission, etc.

How do wind plants affect wildlife?

Birds and bats
Large game animals

Introduction

AWEA Annual Wind Industry Report 2009

B. Why Wind Energy Now?

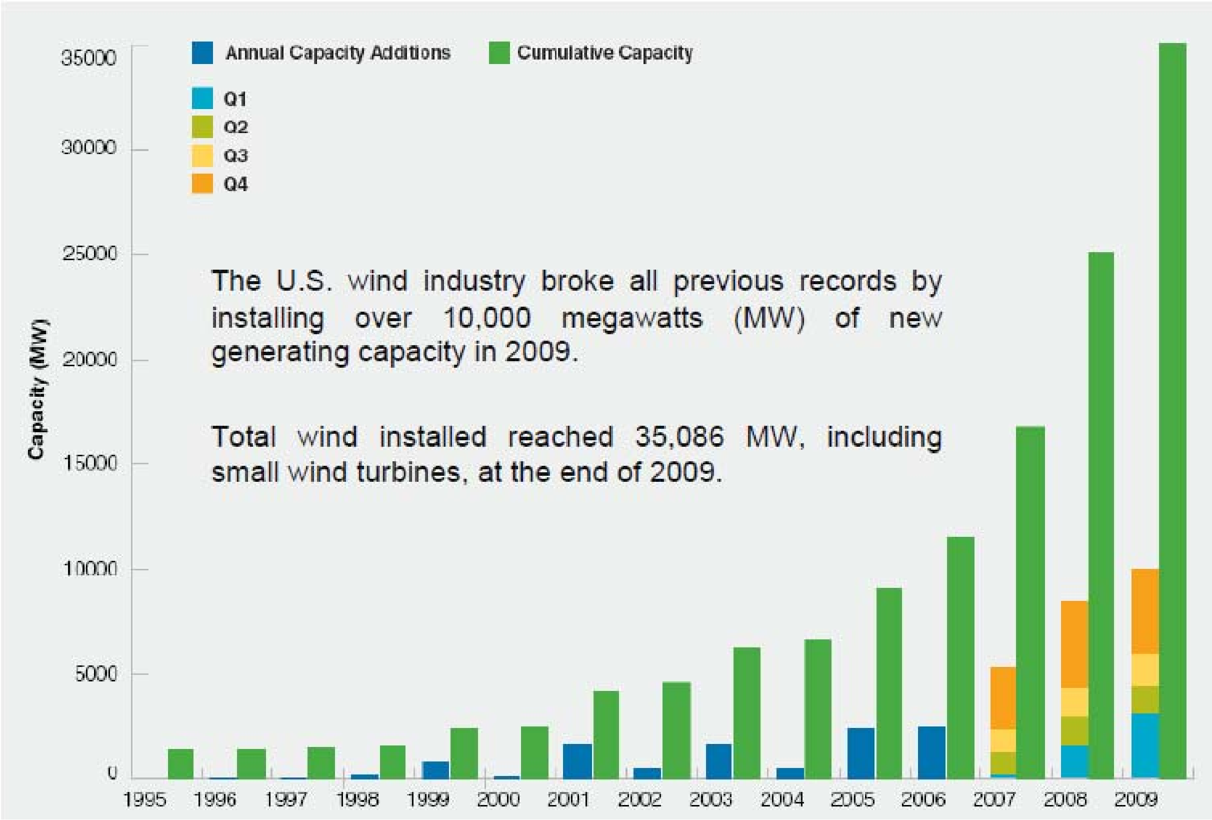
3. Current Statistics

a. US surpassed 35,000 MW of installed power at the end of 2009

b. Installations expected to be much lower in 2010

c. In 2009, generating capacity increased by 10,000 MW (a 40% increase)

d. At the end of 2009, the US now produces enough wind-generated electricity to power 1.8% of the U.S. electricity.

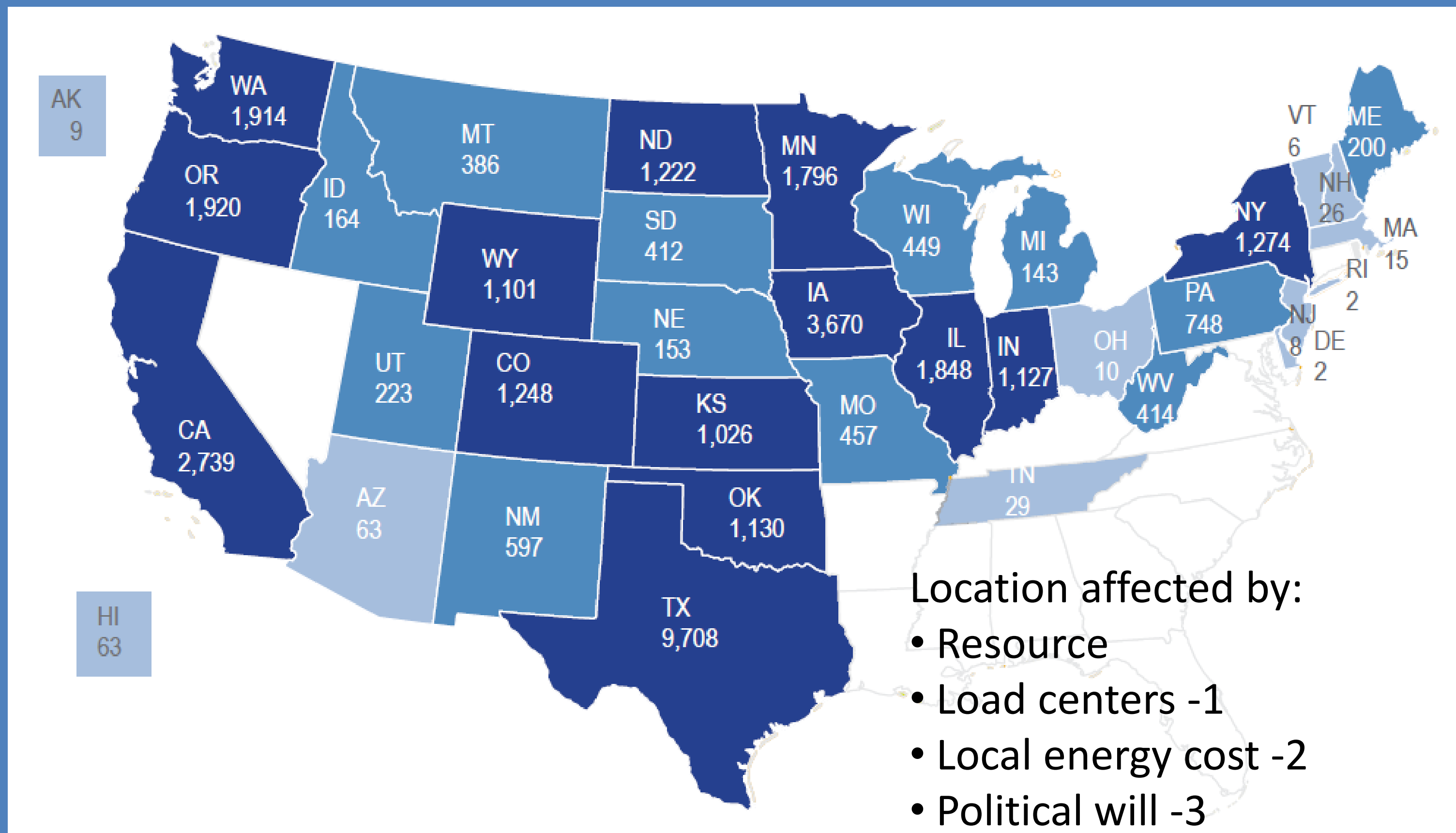


Introduction

AWEA 2nd Quarter 2010 Market Report

B. Why Wind Energy Now?

3. Current Statistics



Location affected by:
- Resource
- Load centers -1
- Local energy cost -2
- Political will -3

Introduction

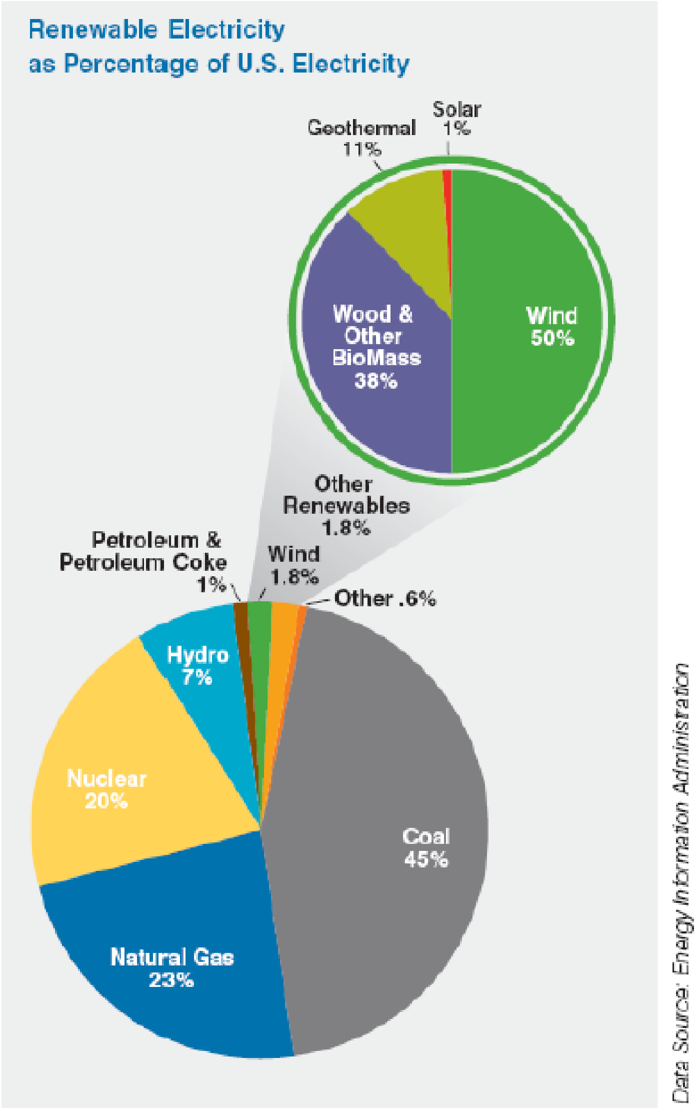
AWEA Annual Wind Industry Report 2009

B. Why Wind Energy Now?

3. Current Statistics

e. Wind generated electricity represented 1.8% of the nation's electricity in 2008.

f. All renewable energy grew to 10.5 % of the nation's electricity



Introduction

AWEA Annual Wind Industry Report 2009

B. Why Wind Energy Now?

3. Current Statistics

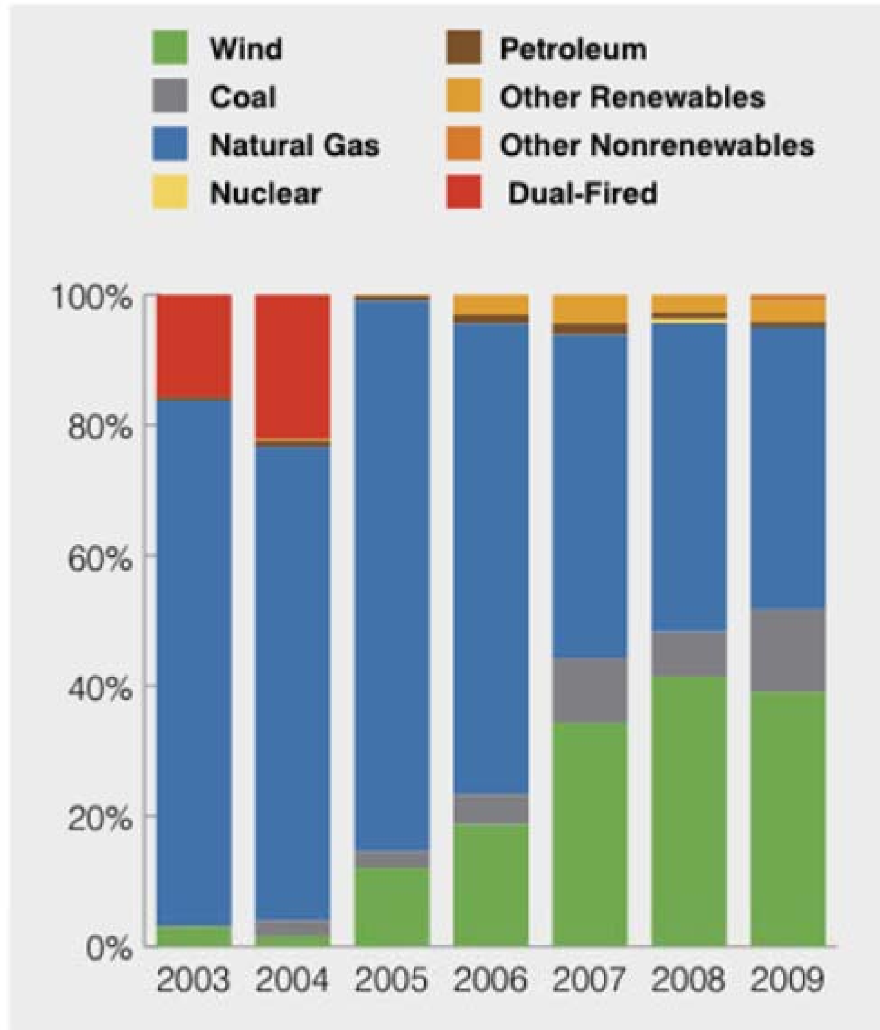
f. Wind generated electricity addition in 2008 accounted for 39% of all power producing capacity added in that year.

g. Wind and natural gas have accounted for nearly 90% of all new generation added since 2005.

Notice how change in energy addition mix has changed

Natural gas and wind likely to dominate in the near future while nuclear fission will start to make an impact soon

New capacity additions by type and year



Source: AWEA, SEIA, SNL, Lawrence Berkeley Laboratory

Introduction

AWEA Annual Wind Industry Report 2008

B. Why Wind Energy Now?

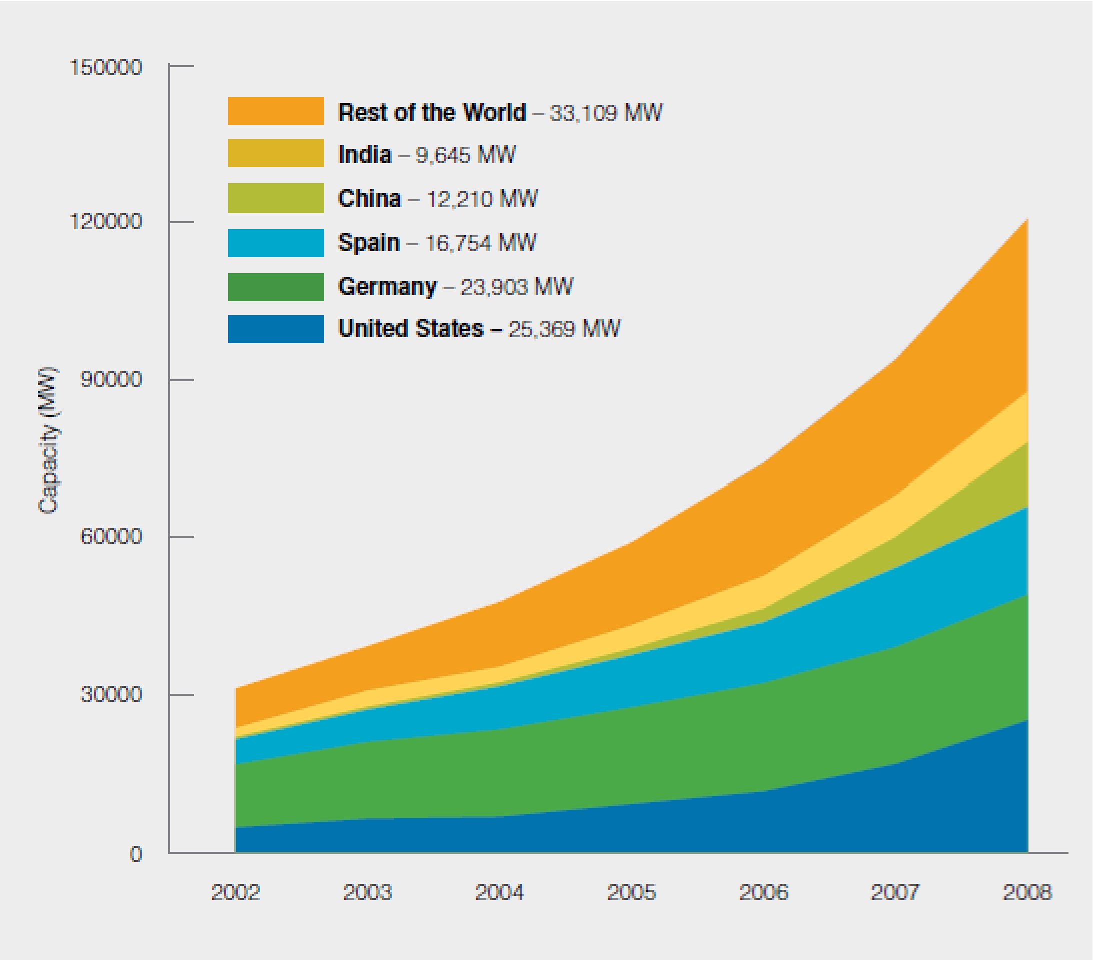
3. Current Statistics

h. In 2008, the U.S. overtook Germany as the country with the most wind power capacity installed.

i. In 2009, both Europe and China exceeded the installations in the U.S.

Other countries doing better in a relative sense

U.S. 1.8%
Denmark >20%



Introduction

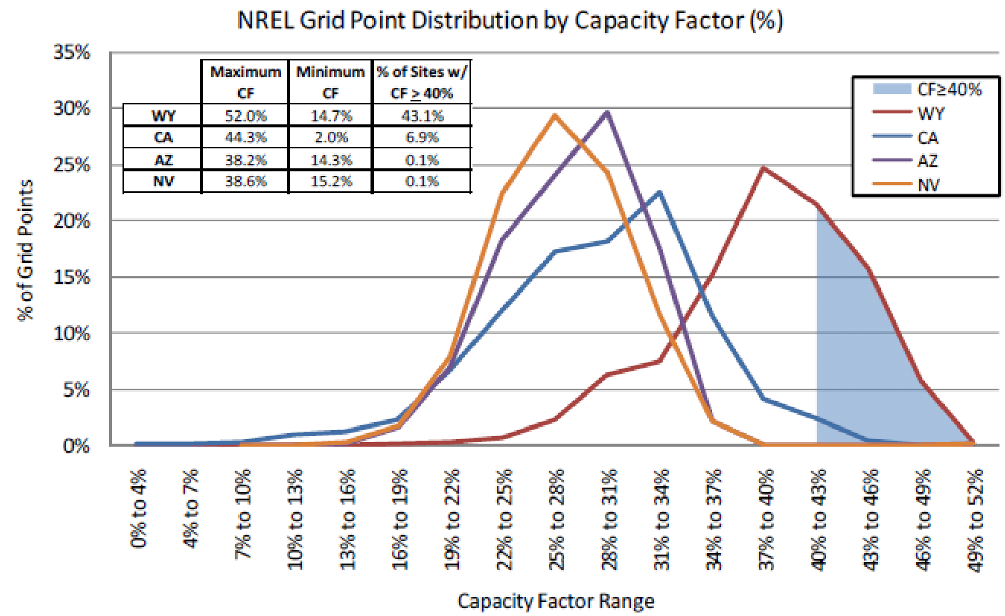
B. Why Wind Energy Now?

4. Wyoming and Wind Energy

a. Statistics

- 816 MW installed
- 13th in the nation
- 7th in potential
- 1st in terms of class 6 and 7 sites
- High capacity factors relative to other states

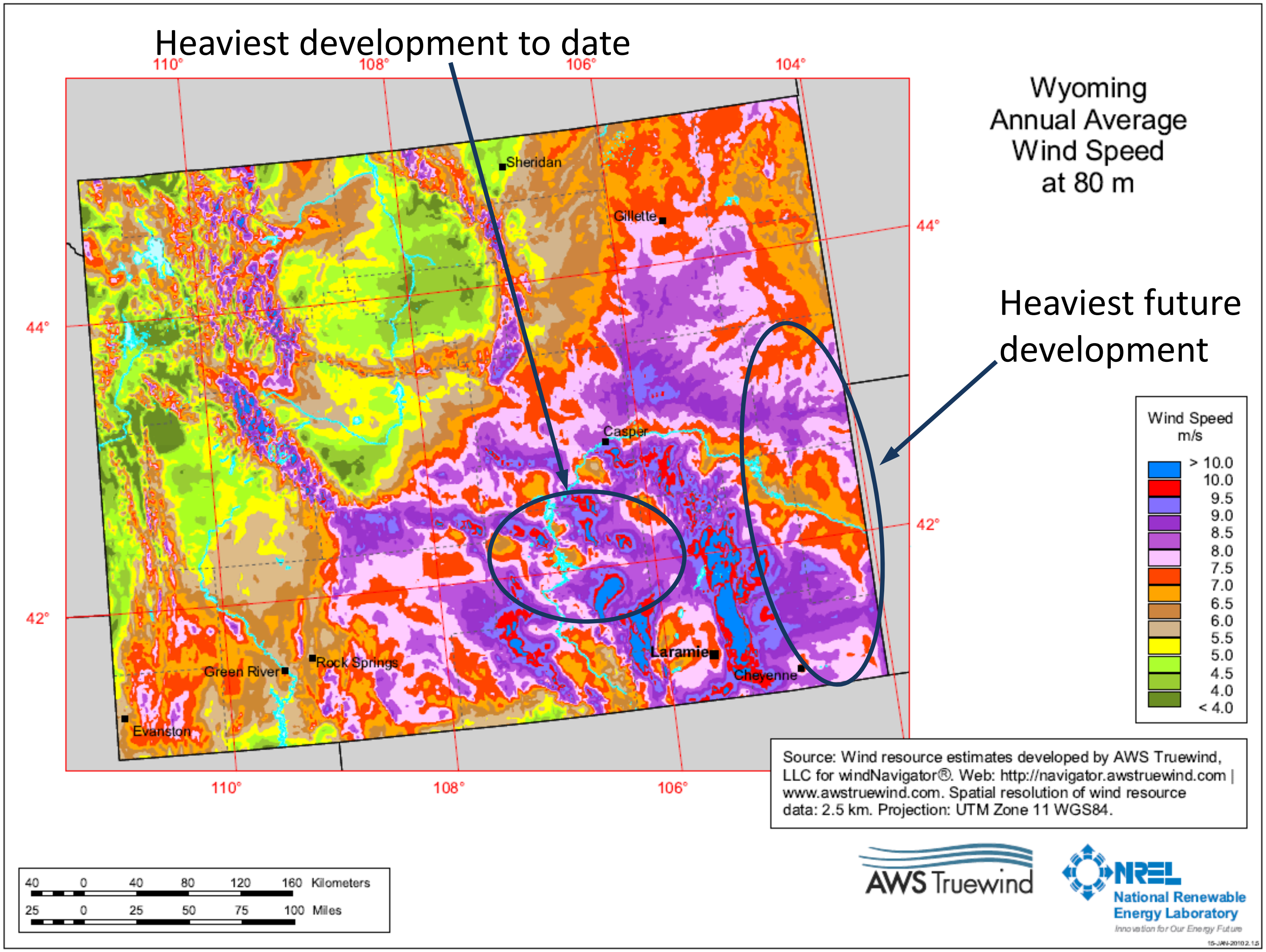
National Grid:
The West's Renewable Energy Future



	Maximum CF	Minimum CF	% of Sites w/ CF ≥ 40%
WY	52.0%	14.7%	43.1%
CA	44.3%	2.0%	6.9%
AZ	38.2%	14.3%	0.1%
NV	38.6%	15.2%	0.1%

$$\text{Capacity Factor} = \frac{\text{Average Annual Power Generated}}{\text{Annual Maximum Possible Power Generated}}$$

Introduction



Introduction

B. Why Wind Energy Now?

4. Wyoming and Wind Energy

a. Favorable Characteristics

- Transmission Capability
  - » Ability to transmit the power from the site where it is produced to where it might be used
- Proximity to a Load Center
  - » The closer to where the energy is going to be used, the cheaper the transmission and the lower the losses
- Availability of Land
- Economics and State Incentives
  - » Production tax credits for companies producing wind energy
  - » Sales tax rebate for wind plant construction

Introduction

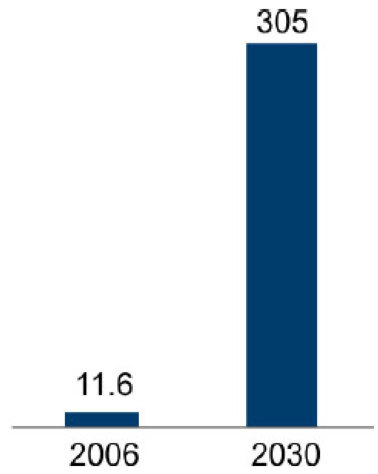
B. Why Wind Energy Now?

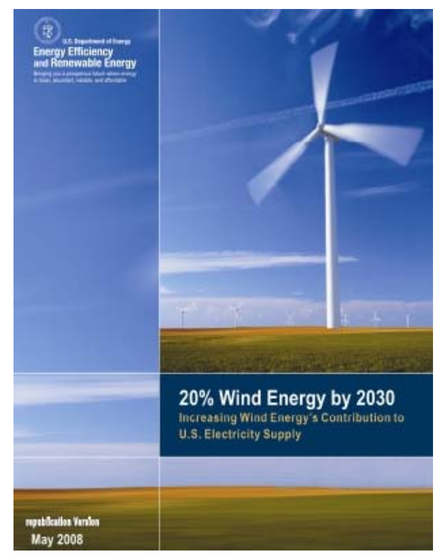
5. Where is the industry going?

a. Predicted US Electrical Consumption in 2030
- 39% growth from 2005 to 2030
- 5.8 billion megawatt hours in 2030

b. Wind Energy
- 20% of electricity – 300,000 MW of wind power capacity
- 241,00 GW land based turbines
- Consider 2.5 MW as the standard turbine size
- Nearly 100,000 turbines would be installed

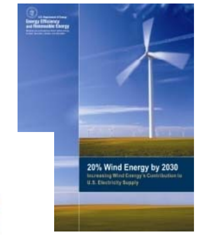
c. Is This Possible?
- 10,000 MW installed in 2009 alone
- Increased total capacity to 35,000 MW
- Exceeded 1.80% of U.S. electrical generation
- Detailed study performed by DOE – their answer is yes





Introduction

765 kV lines shown



B. Why Wind Energy Now?

5. Where is the industry going?

d. What are the challenges?

- Transmission
- Load balancing
- Manufacturing
- Wind Turbine Technology
- Workforce
- Siting

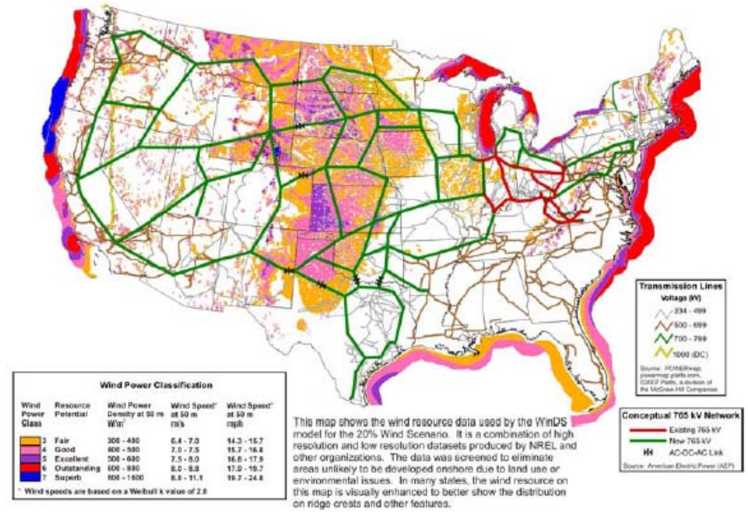
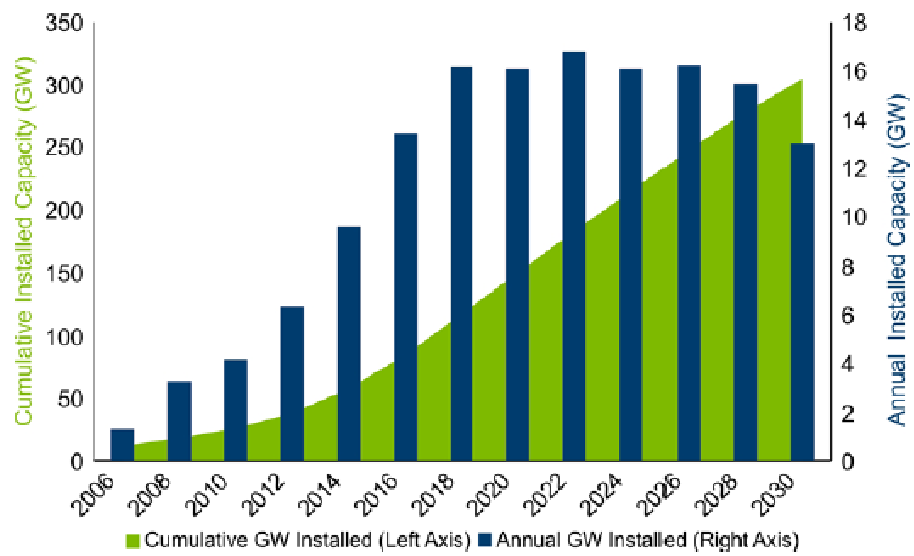


Figure 1-4. Annual and cumulative wind installations by 2030



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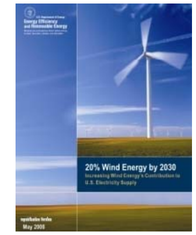


B. Why Wind Energy Now?

5. Where is the industry going?

   e. What are the benefits

      - Environmental
      - Water savings
      - Energy security
      - Price stabilization
      - New revenue sources
      - Well paying jobs
      - Growth of U.S. industry

Figure 1-13. CO_2 emissions from the electricity sector

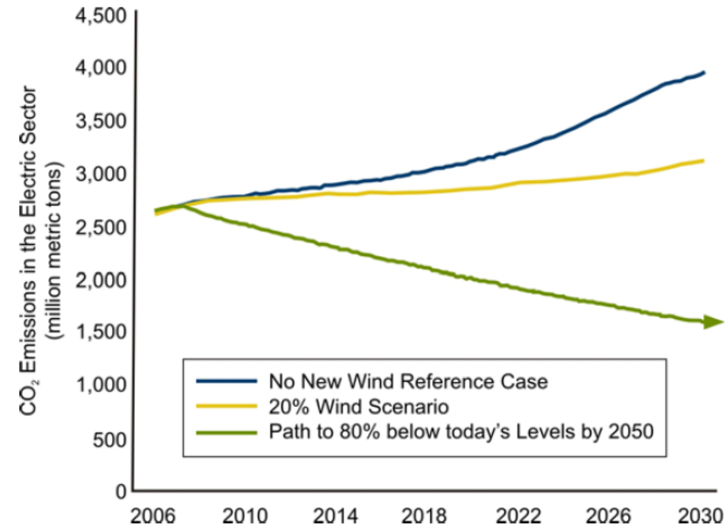
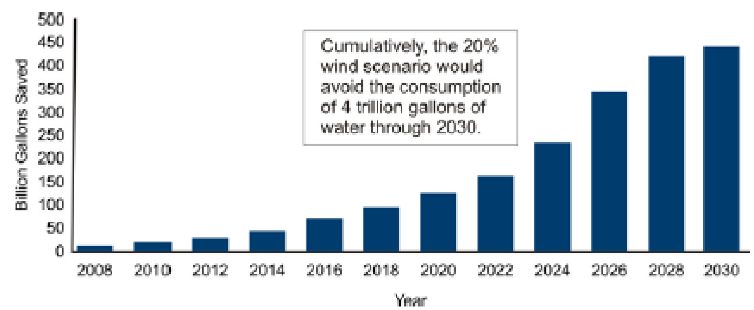


Figure 1-14. National water savings from the 20% Wind Scenario



Introduction

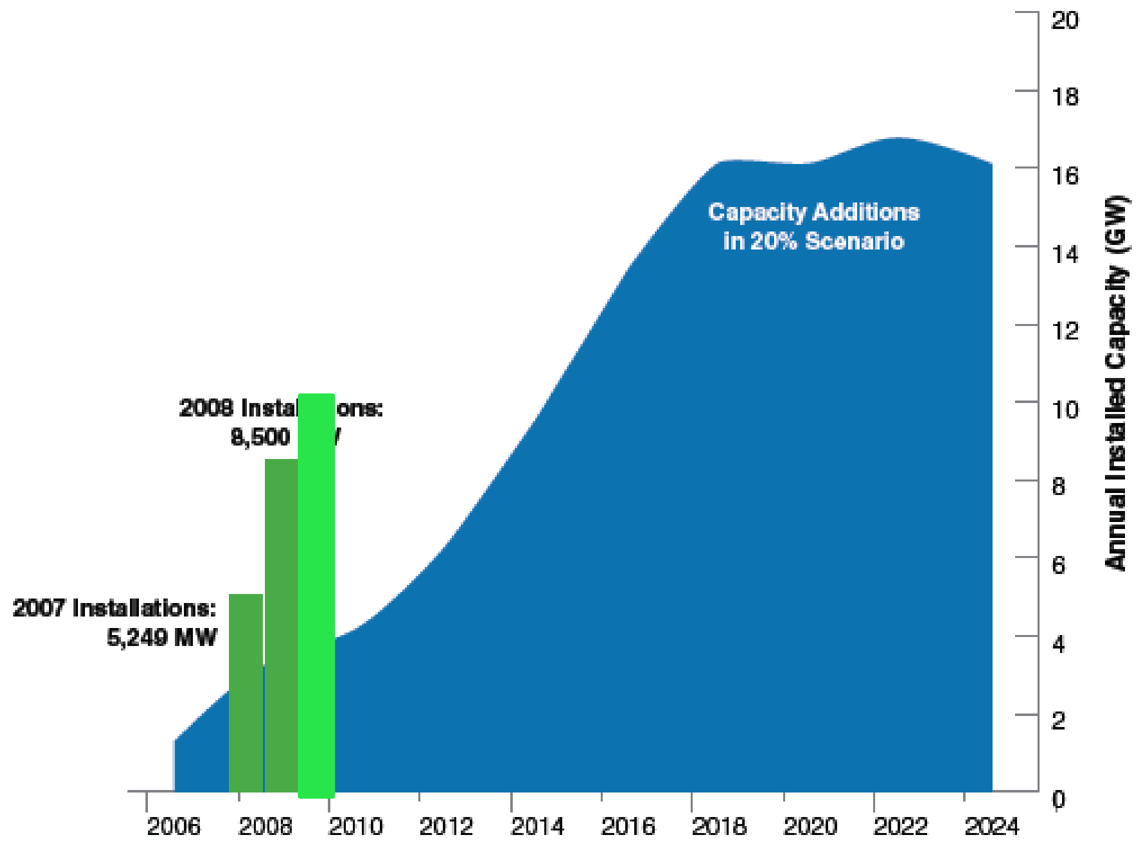
AWEA 20 Percent Report Card, 2009

B. Why Wind Energy Now?

5. Where is the industry going?

   e. How are we doing?

      - 2008-2010 – well above growth anticipated in 20% by 2030
      - Easy to develop sites are becoming more difficult to find



Introduction

C. Wind Turbine – An Overview

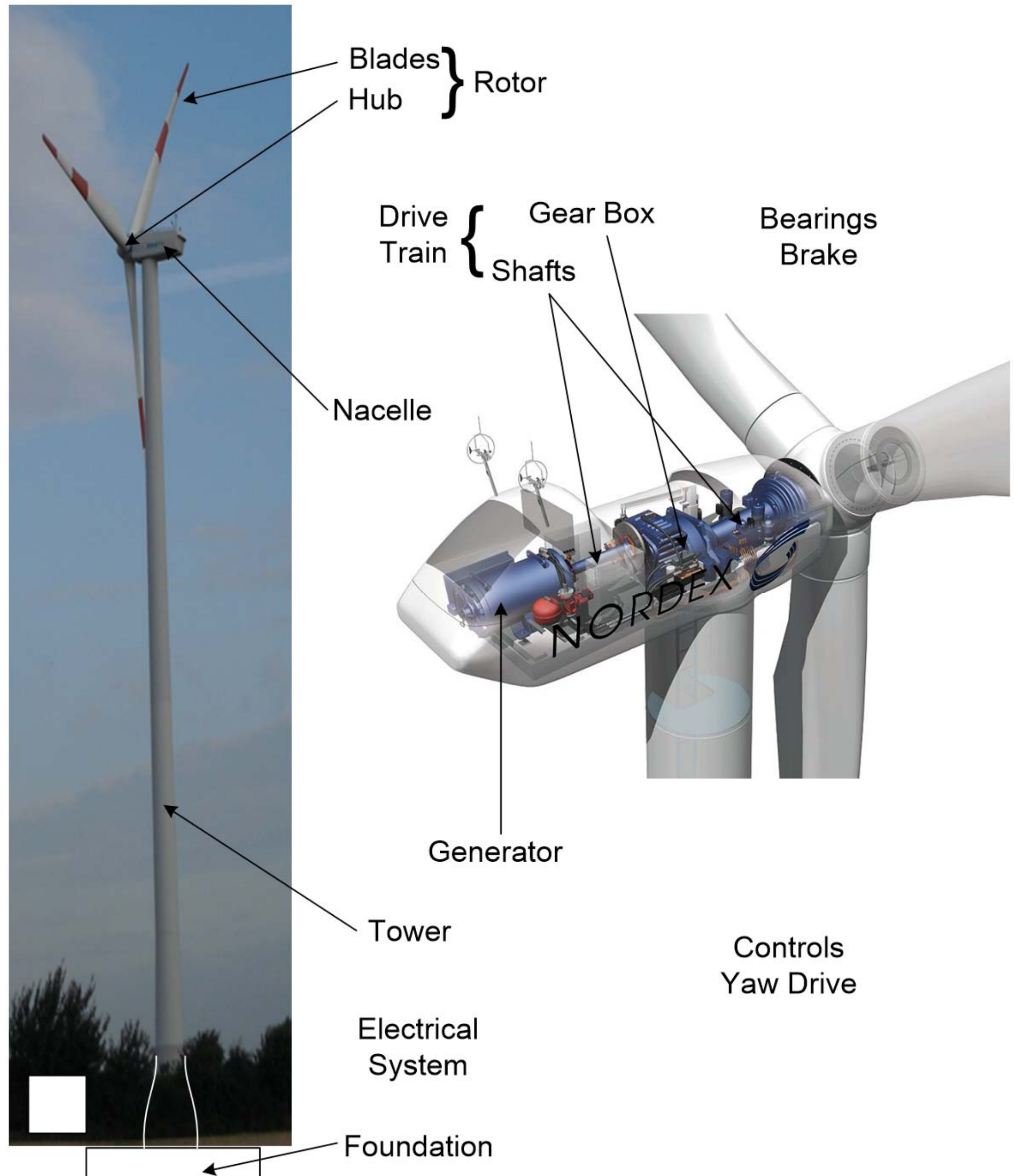
1. Multi-Disciplinary Problem

   - Wind turbine research and development involves many traditional disciplines
     - Atmospheric Science
     - Civil Engineering
     - Electrical Engineering
     - Mechanical Engineering
   - Wind turbines are a system of systems
     - Highly integrated
     - Experts from different fields must be able to communicate

Introduction

C. Wind Turbine – An Overview

2. Parts of a Turbine
   - Very large systems
   - 1.5 MW turbine
     - Nacelle 70 tons
     - Tower up to 100 m
     - Blade lengths up to 40 m



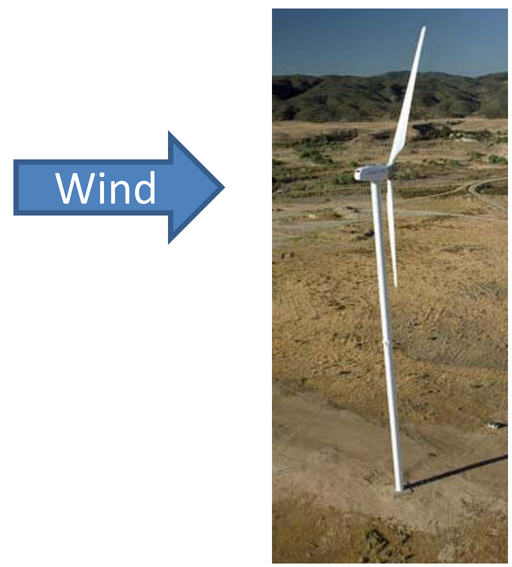
Introduction

C. Wind Turbine – An Overview

3. Wind Turbine Classifications

a. Upwind and Downwind

- Upwind – blades rotate upwind of the tower
    - No tower interference
    - Turbine must be actively turned into the wind
    - Blades bend toward tower under load
- Downwind – blades rotate downwind of the tower
    - Tower wake effects
    - Turbine turns itself into the wind
    - Blades bend away from tower under load



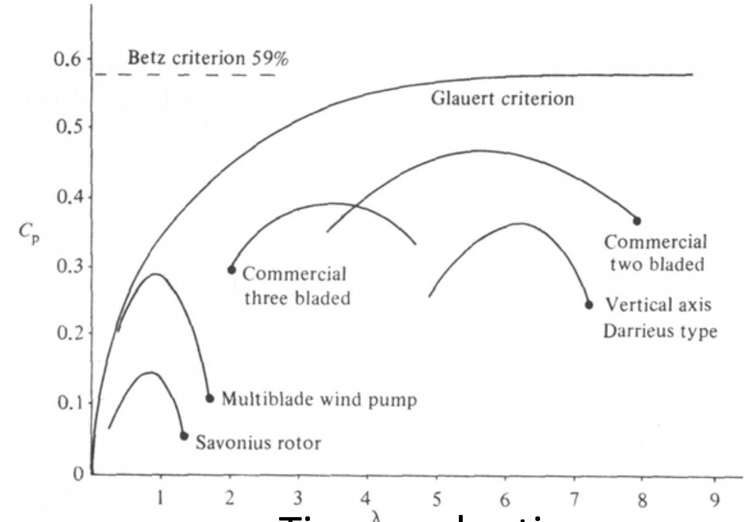
Introduction

C. Wind Turbine – An Overview

3. Wind Turbine Classifications

b. Number of Blades

- More is not better!



Tip speed ratio

2 blade

Multi-blade

3 blade

Introduction

C. Wind Turbine – An Overview

3. Wind Turbine Classifications

c. Yaw Control

Passive Control

Downwind

Tail or Guide Vane

Active Control

Yaw control motors steer turbine into the wind

Introduction

C. Wind Turbine – An Overview

3. Wind Turbine Classifications

d. Blade Load Control

Blades designed to stall as wind speed increases

Results in loss of lift and reduction in load

Pitch Control

Blade pitch varied to control load

Similar to an airplane varying the angle of attack to control lift

Stall Control

Introduction

C. Wind Turbine – An Overview

3. Wind Turbine Classifications

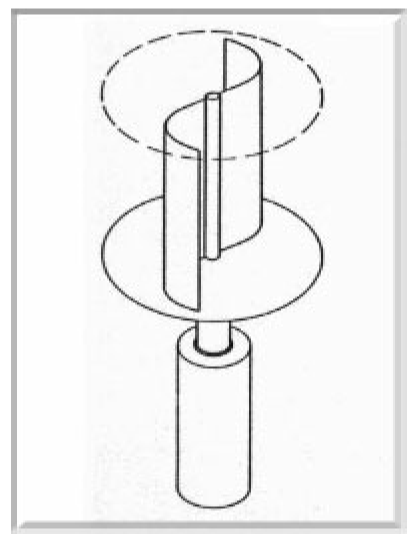
d. Lift or Drag Design

Lift is the primary force generating torque

Lift is much more efficient than drag

A simple aerodynamic analysis can show this, yet many drag based machines are proposed every year

Drag is the primary force generating torque



Introduction

C. Wind Turbine – An Overview
   3. Wind Turbine Classifications
      e. Other
         - Hub designs
           - Rigid, hinged, teetering
         - Blade rotation speed
           - Fixed, variable
         - Generator type
           - Synchronous, induction, permanent magnet
         - Drive train
           - Gearbox, direct drive
         - Rotation Axis
           - Horizontal Axis Wind Turbine (HAWT)
           - Vertical Axis Wind Turbine (VAWT)

Introduction

C. Wind Turbine – An Overview

4. Wind Turbine Power Rating