IEEE Middle TN Chapter Meeting
Apr. 4, 2007

# Wind Energy: Prospects and Challenges

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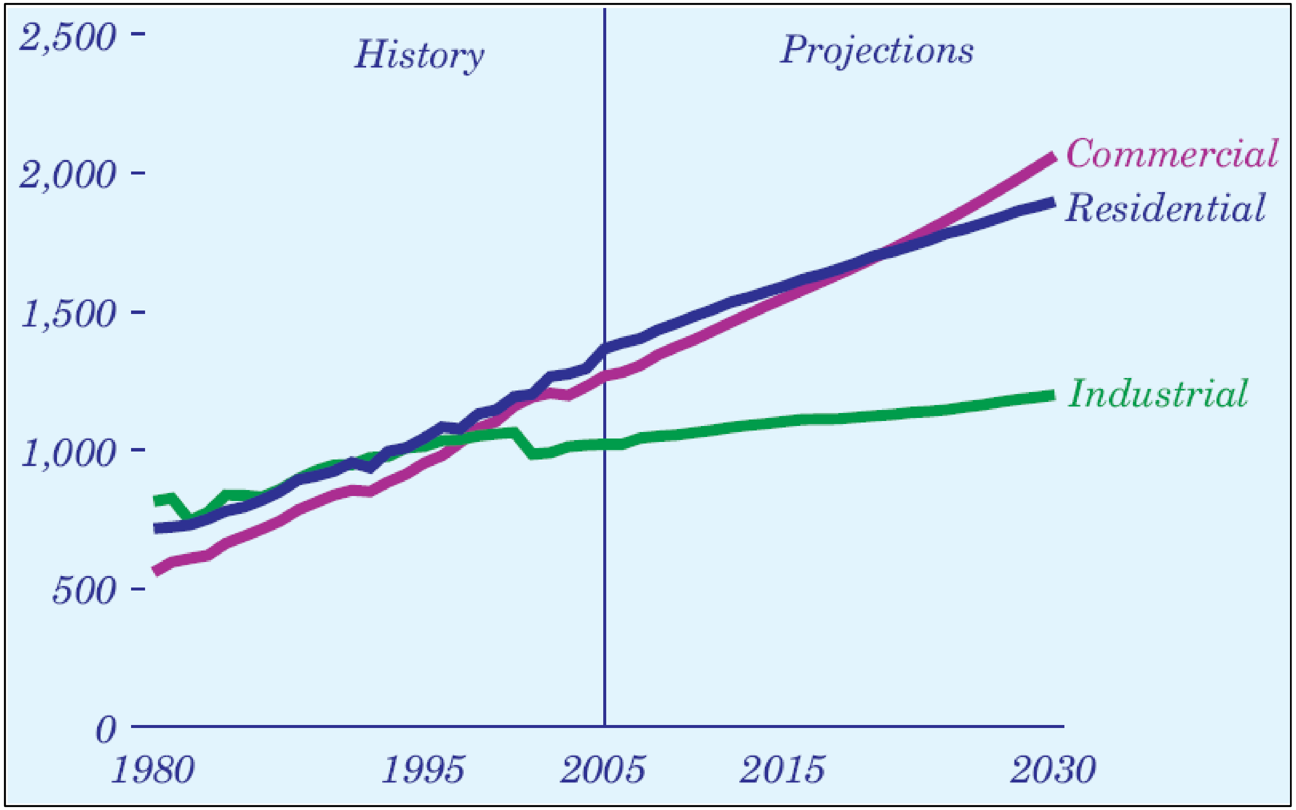
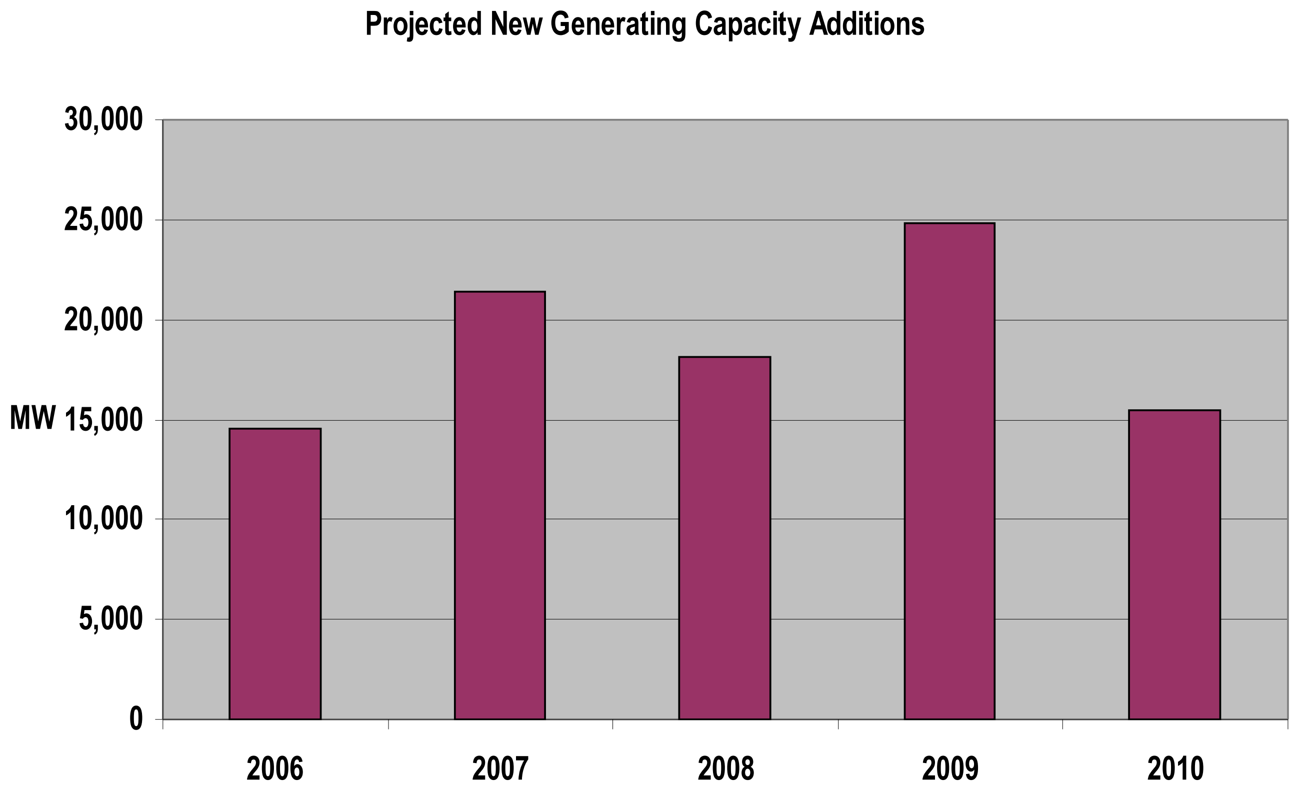
# Electricity Demand Will Continue to Soar

Annual electricity sales by sector, 1980-2030 (billion kWhr)




Source: EIA Annual Energy Outlook 2007

# And new generating capacity must be added to keep up with planned retirements




Source: EIA

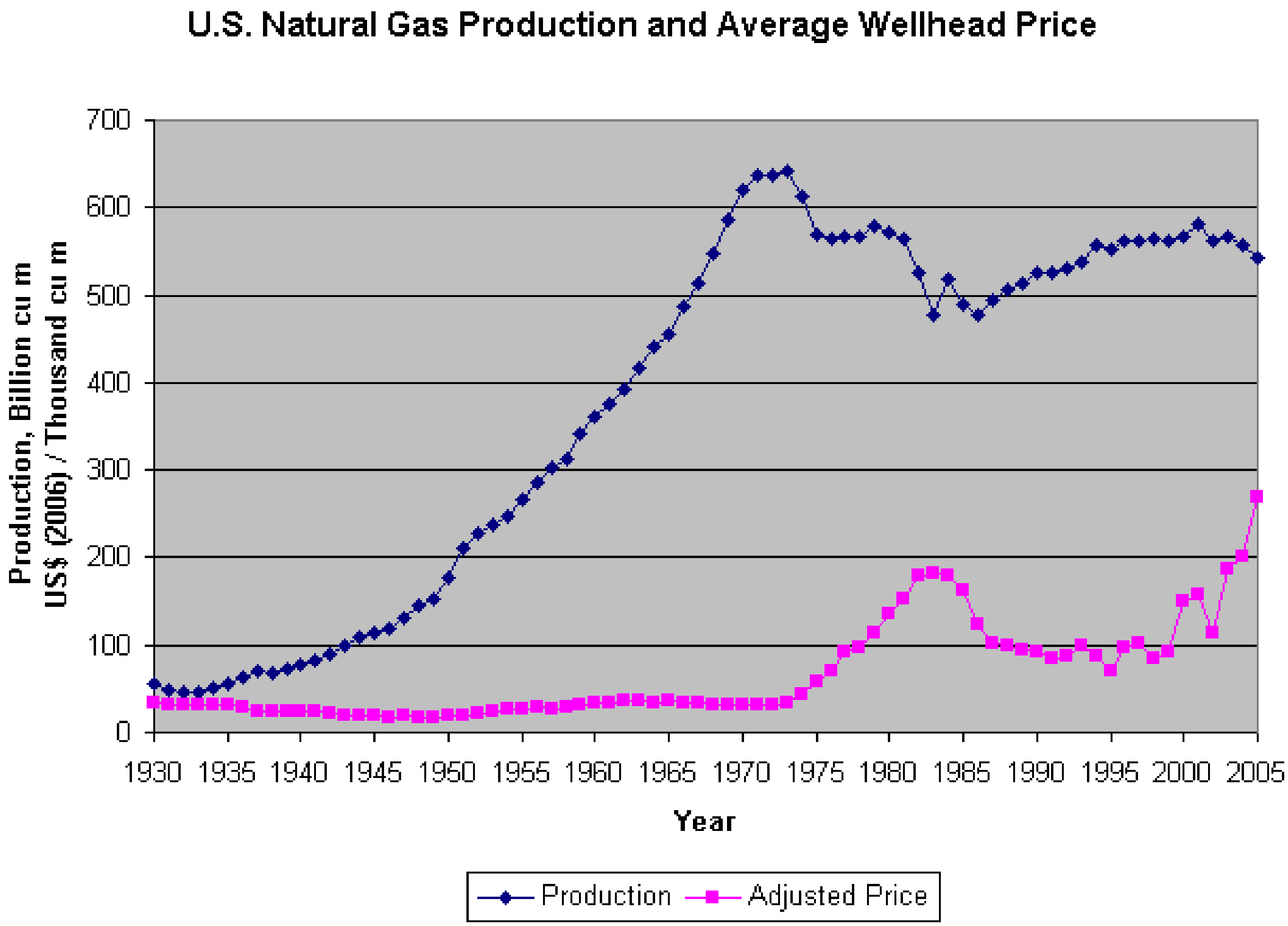
# The Global Warming Threat

- $CO_2$ levels increasing 200X faster than ever occurred naturally
- If half the Greenland ice sheet melted...

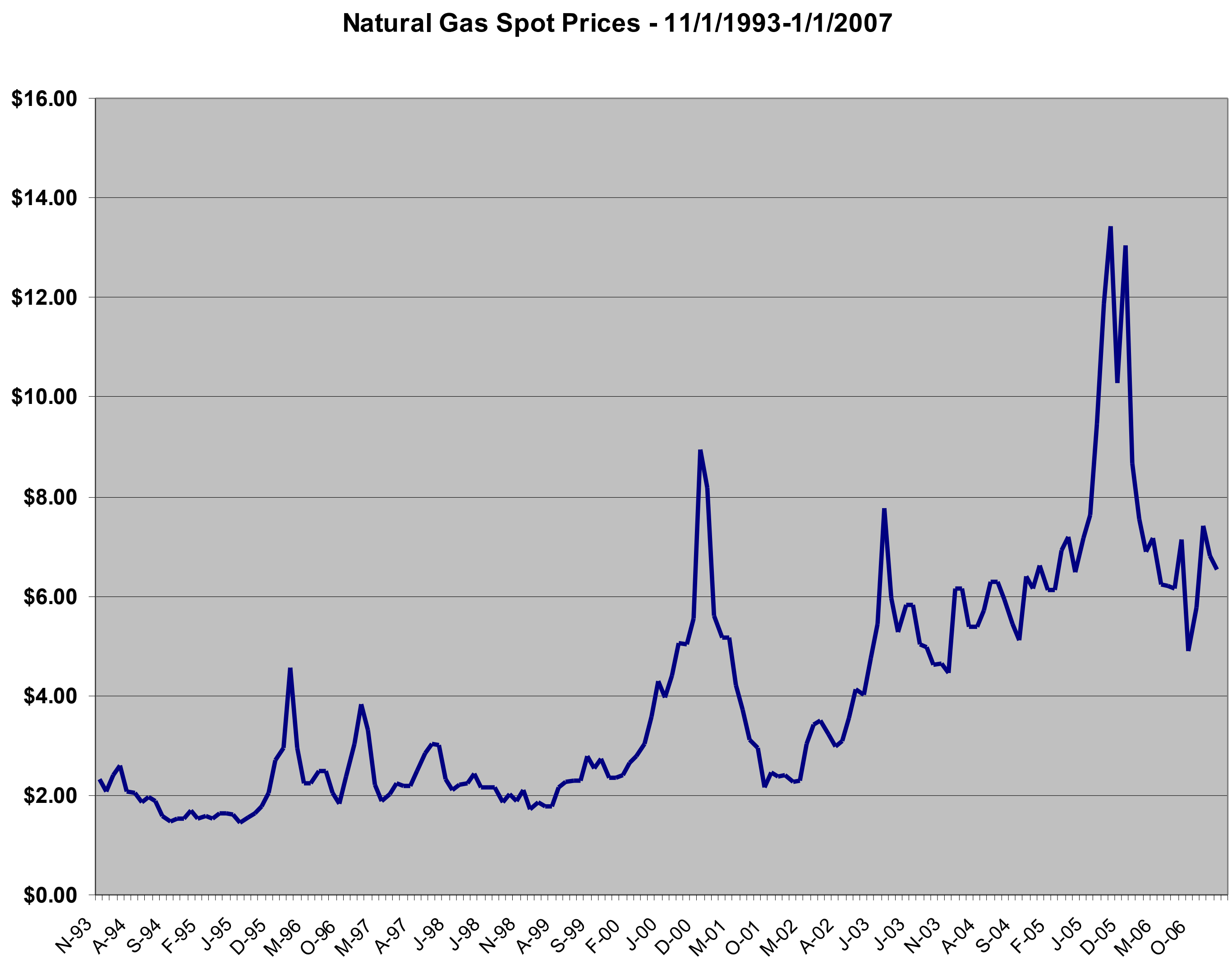

NYC, 2007


NYC, 2107?

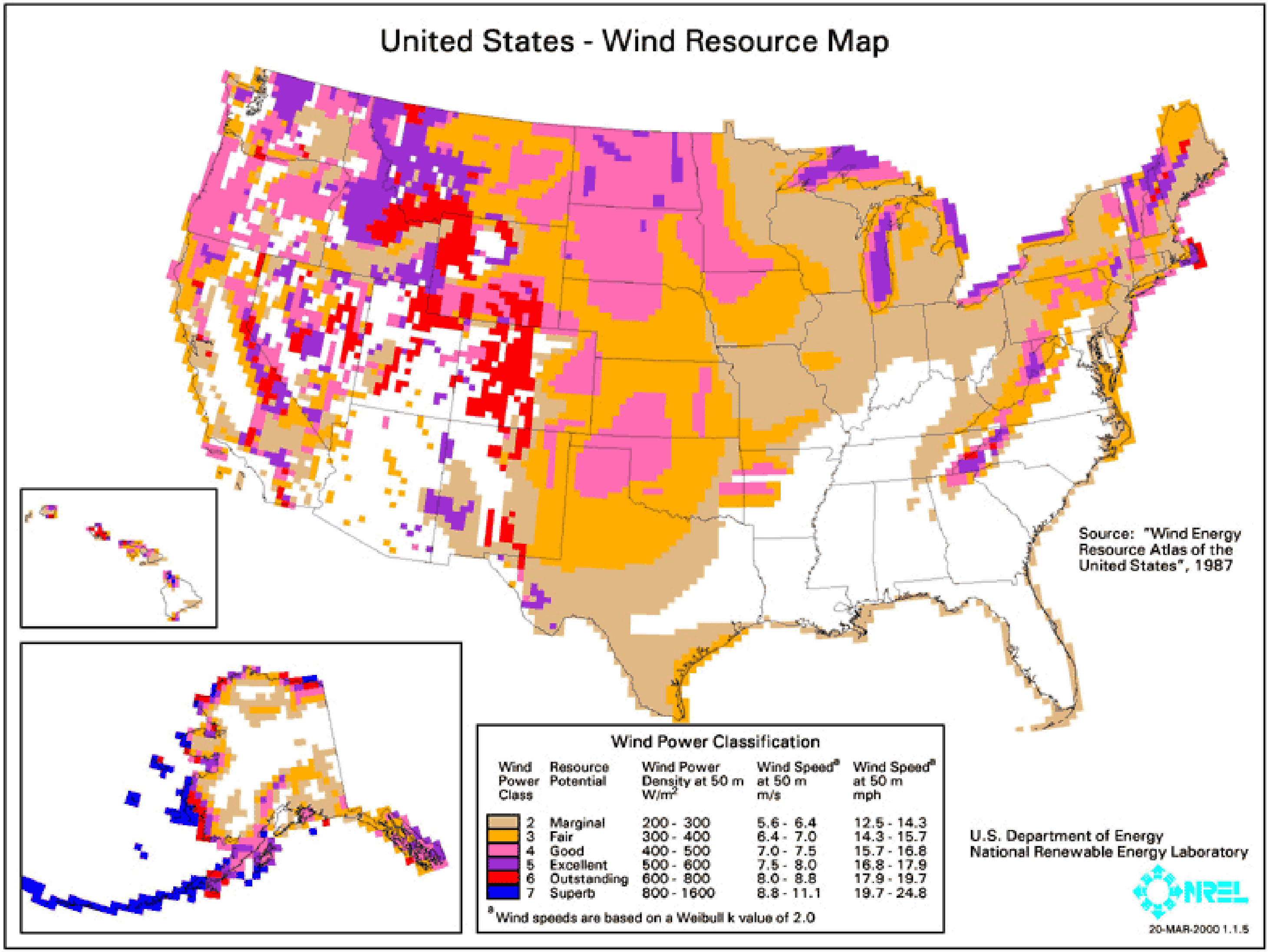
# Wind – a hedge against uncertain natural gas supplies



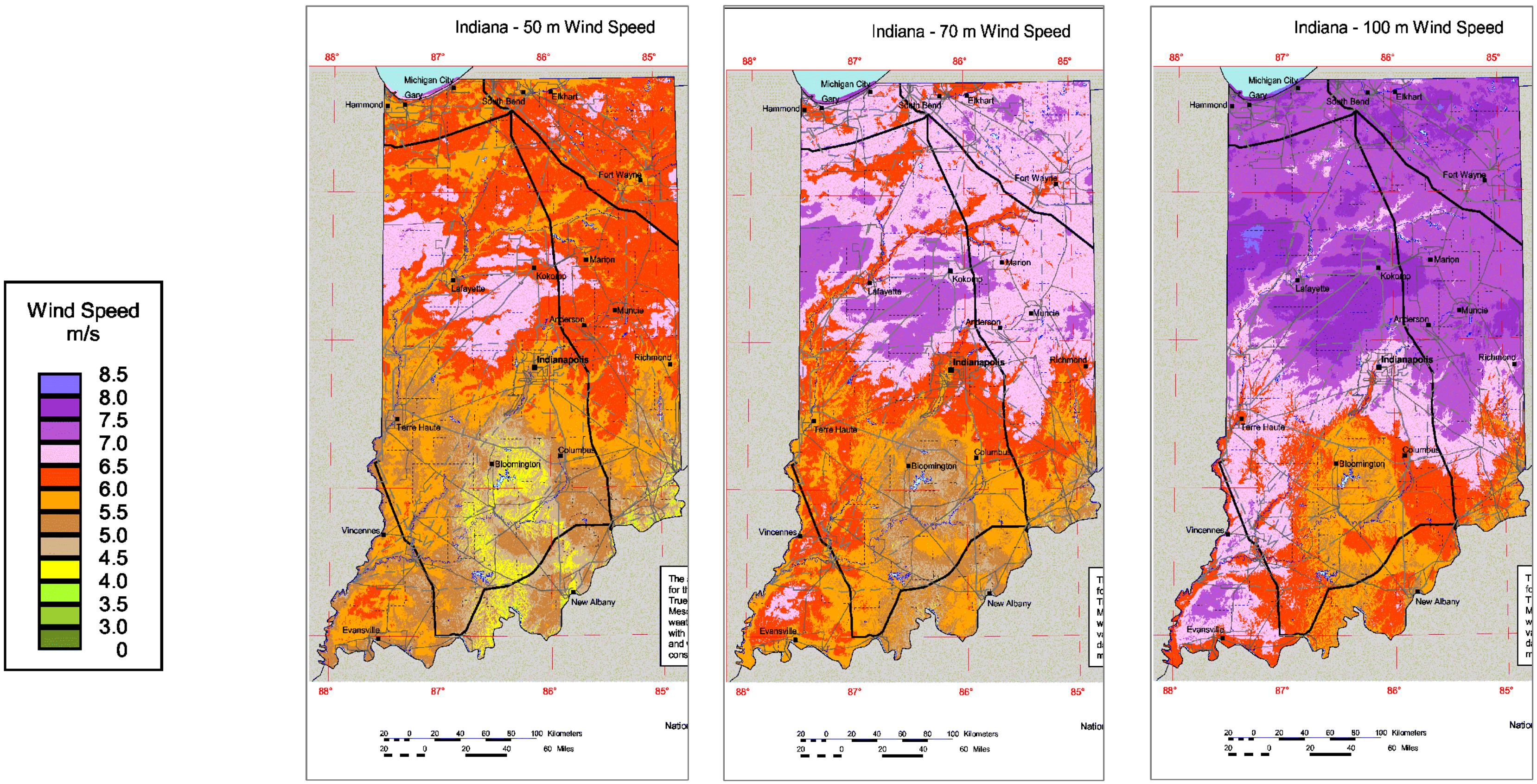
# ... and price volatility



# The Potential Wind Resource: 4.4 trillion kWh (1.5x energy consumption in 1990)



# Impact of Increased Hub Height on Wind Resource




Best areas 6.5-7 m/s
Capacity factors 30-35%

Best areas 7-7.5 m/s
Capacity factors 35-40%

Best areas 7.5-8.2 m/s
Capacity factors 40-45%

Energy produced is function of *cube* of wind speed

Economic impact - Increases Scale (i.e., utility) -Dependence

# A Brief History

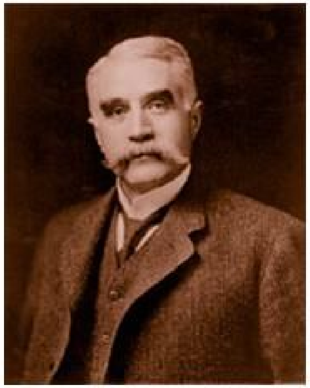
Poul La Cour


First Journal of Wind Electricity 1905

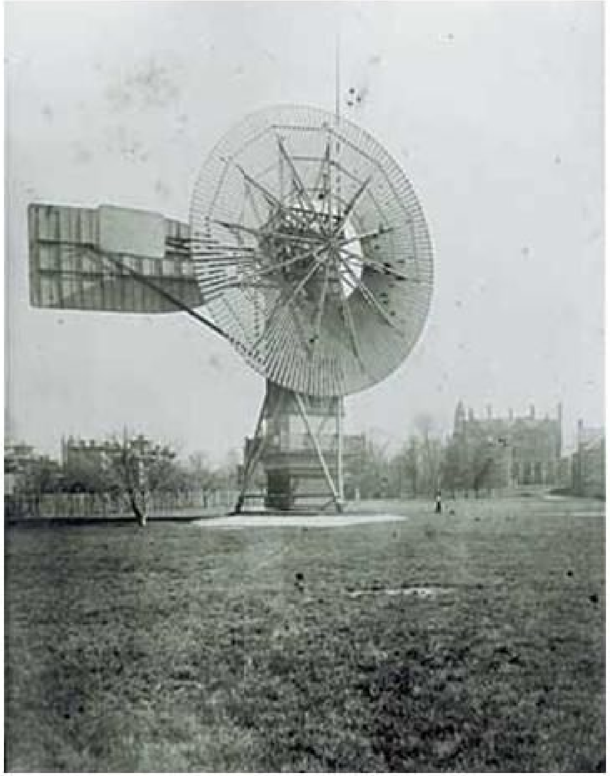
Two of his test wind turbines in 1897 at Askov Folk High School, Askov, Denmark

Poul La Cour, Danish pioneer of electricity generation from wind energy- used electricity for electrolysis of water to produce hydrogen for gas lamps.

# A Brief History



Charles Brush
(1887-1888, Cleveland, Ohio)
1st Automatically Operating
Wind Turbine Generator
12kW, 17m Rotor Diameter
Ran for 20 Years To Charge
Batteries in Mansion Cellar
www.windpower.org/en/pictures/brush.htm



Charles F. Brush (1849-1929), one of the founders of the US electrical industry. His Brush Electric Company in Cleveland, Ohio, was a forerunner to the General Electric (GE) Company.

# Origins of the Current Generation

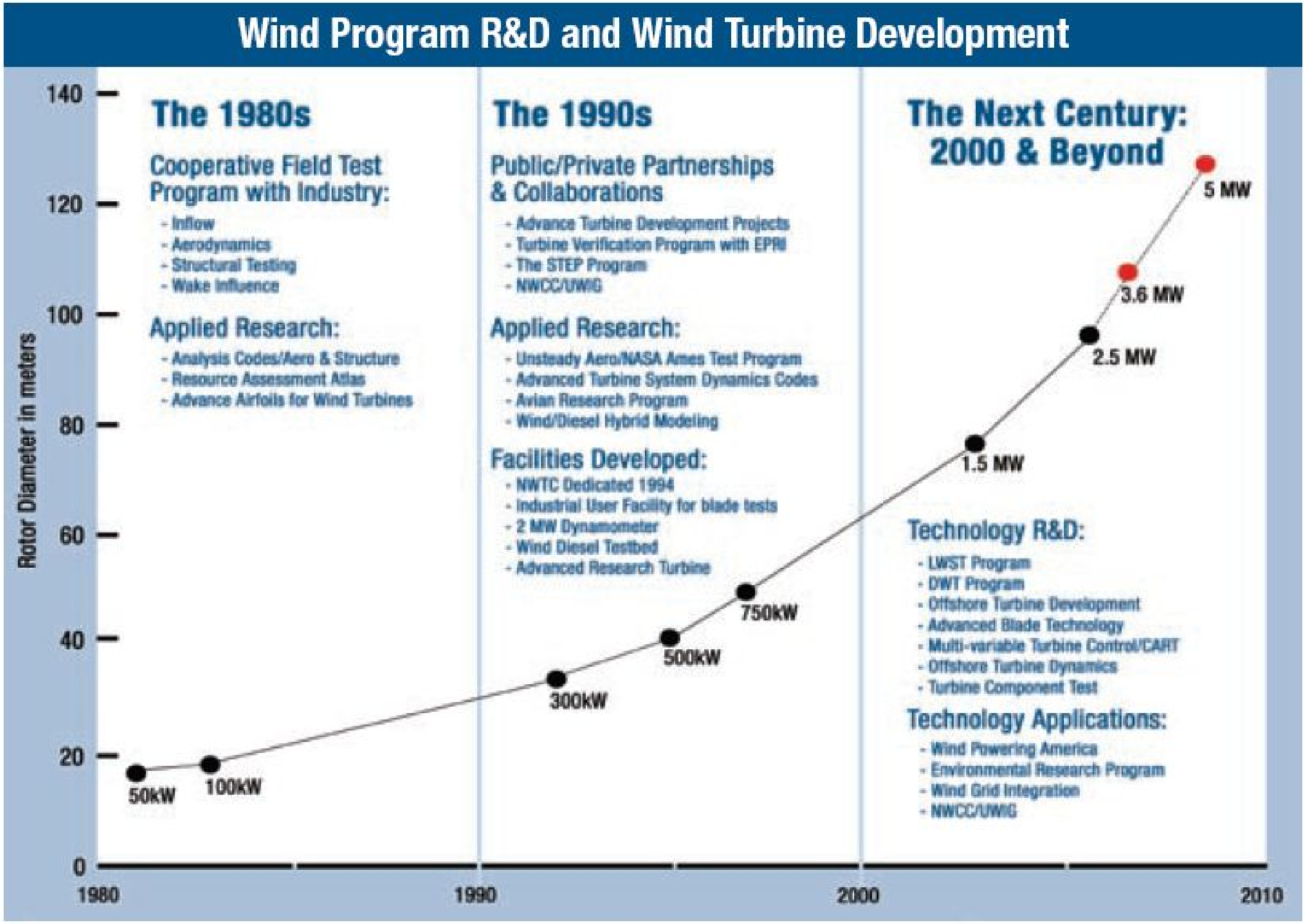
In the seven years between 1974 and 1981, NASA in Cleveland led the U.S. Wind Energy Program for large wind horizontal-axis turbines (the predominant systems used today). NASA constructed and operated its first Experimental 100-kilowatt wind turbine at the Plum Brook facility in Sandusky, Ohio.

http://www.greenenergyohio.org/page.cfm?pageId=952

Mod-0 100kW Experimental Wind Turbine in Sandusky, Ohio

The first oil shock 1973-74

# Accelerating Progress on Power Output



# The New Frontier: Offshore Wind Energy

GE’s 3.6 MW Turbine
Arklow Ireland, 7 x 3.6 = 25.2 MW

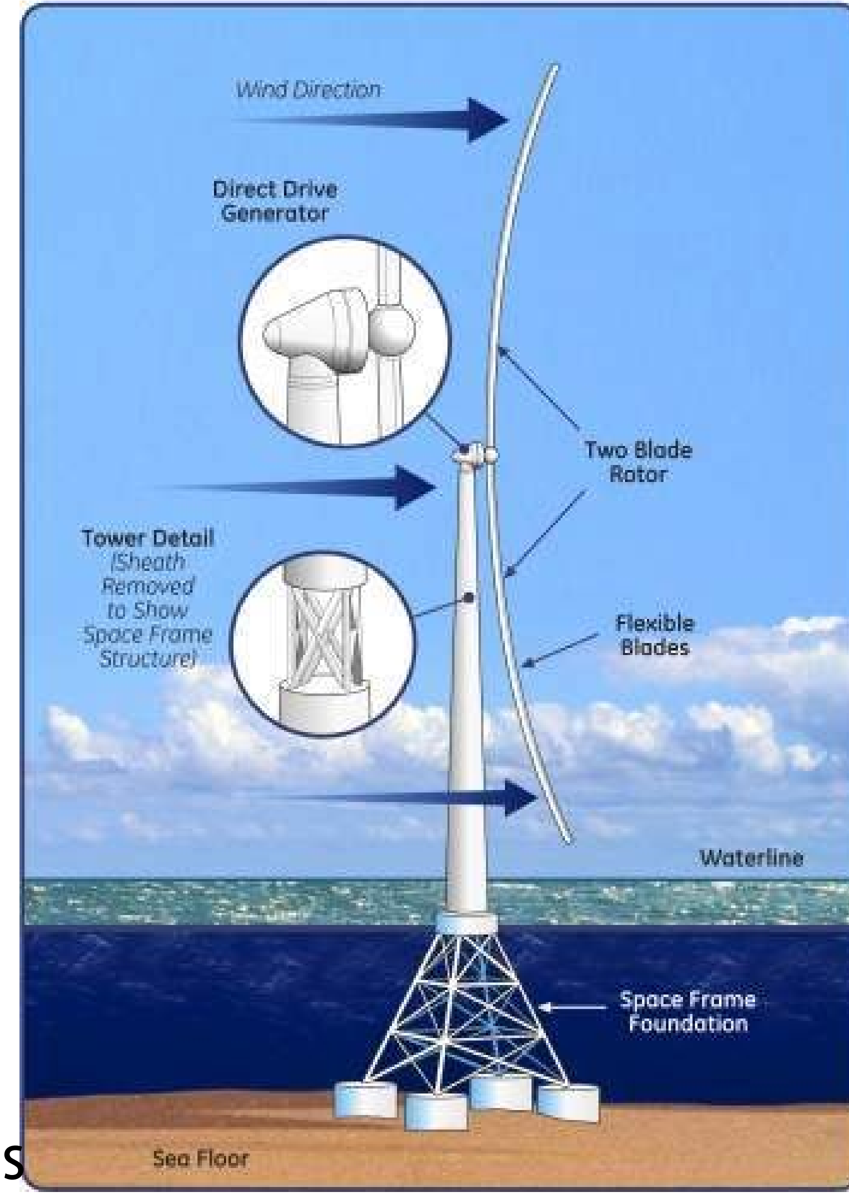
# Challenges

- Technology
- Economics
- Politics

# Decades-long progression of cost, power, operational efficiency may be reaching maturity

# Proposed 10 MW turbine

- 180 m rotor diameter
- Downwind 2 blade machine
- Flexible compliant blades
- High rpm/tip velocity > 100 m/s
- Gearless direct drive
- Space frame structure
- Multivariable damping controls
- 40 m water depth foundation
- Hurricane ride-thru capability




Cost/kWhr: about 2x land turbines
Can the economics work?

# The grid – one of the great technological feats of human history

Unlike oil and gas pipelines, acts as a single device

# But is the grid up to the challenge?

Northeast Blackout of Aug. ‘03

- Exposed lapses in quality, regulatory oversight

People walking in NYC (Wikipedia)

Satellite image of Northeast before and during blackout
Source: NOAA, 8/15/03

# Some grid fundamentals... Loads are variable and unpredictable

- Utility response
  - Add generating capacity to match peak load
    - e.g., combined cycle gas turbine
  - Has made grid highly reliable under extraordinary demand
    - Massive blackouts are *rare!*

# But conventional energy sources are predictable

- Coal, hydro, nuclear, gas are dispatchable *when needed*
  - at predictable levels and reliability

# What happens when you add a variable power source?

- Grid *not* designed for intermittent power sources ("negative load")
  - Sudden capacity increase requires either adding load or shedding capacity elsewhere (*not easy!*)
  - Gas turbines can be easily stopped and restarted, but only operate under peak loads
  - Coal plants can't be quickly stopped/started
    - High economic and operational penalties

# Now add wind to the mix

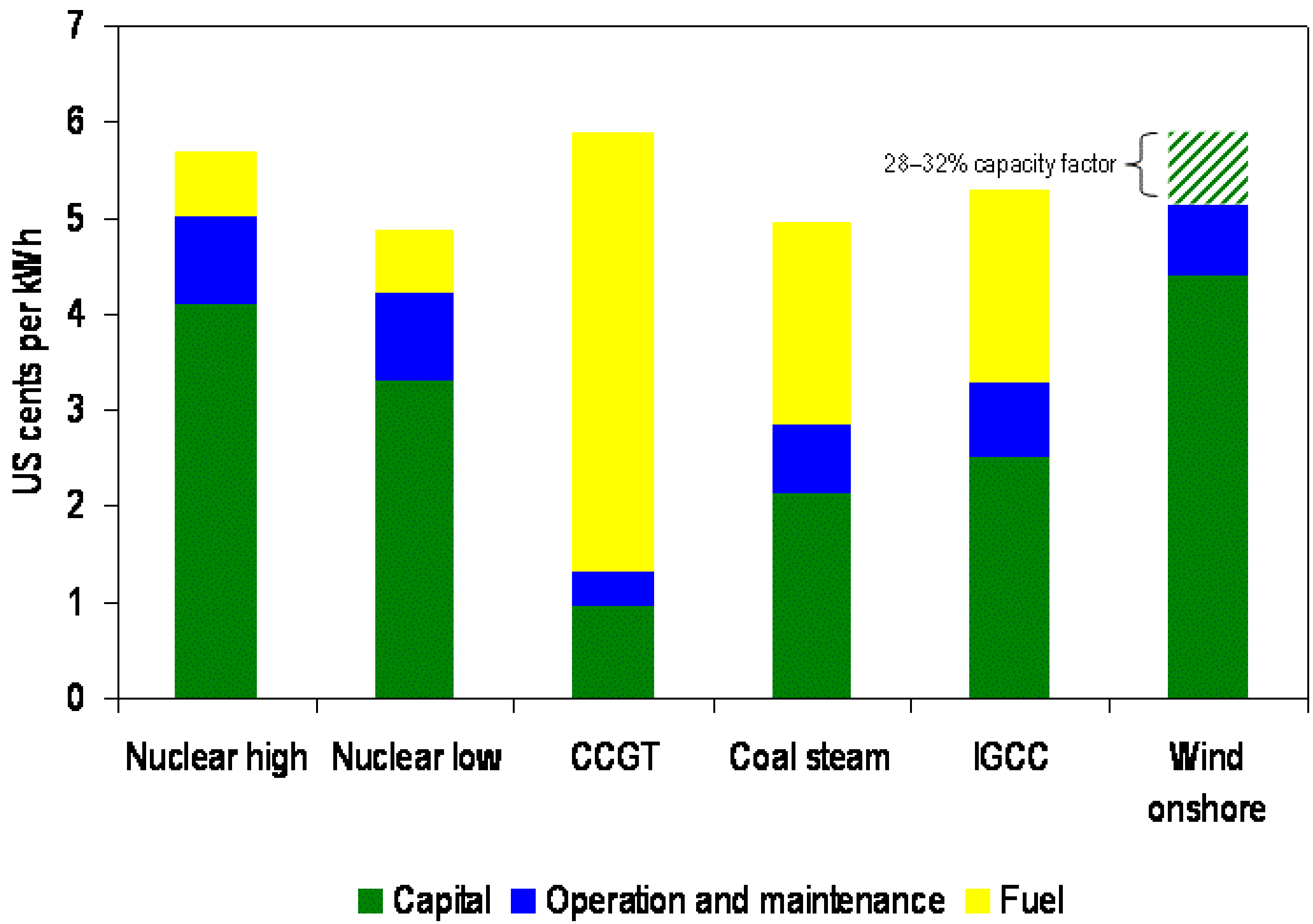
**“2 Saudi Arabias” of Wind in US, *but***

- **Intermittent**
- **Blows when you least need it**
  - **10% of wind capacity available during peak periods**
- **Far from major load centers**
  - **90% starts in Rockies, blows through Great Plains**
    - **Most sparsely populated region**
    - **Lowest grid capacity**

# The Economics of Wind Energy

- It's *case-by-case*
  - Cost vs. natural gas, coal, etc.
  - Wind resource and pattern
  - Local capital construction costs
    - Includes material (steel, concrete), transportation
    - Installed cost up 40-50% since 2001
  - Access to transmission infrastructure
  - State PUC regulatory policy

# Electricity Generating Costs




World Energy Outlook 2006

INTERNATIONAL ENERGY AGENCY

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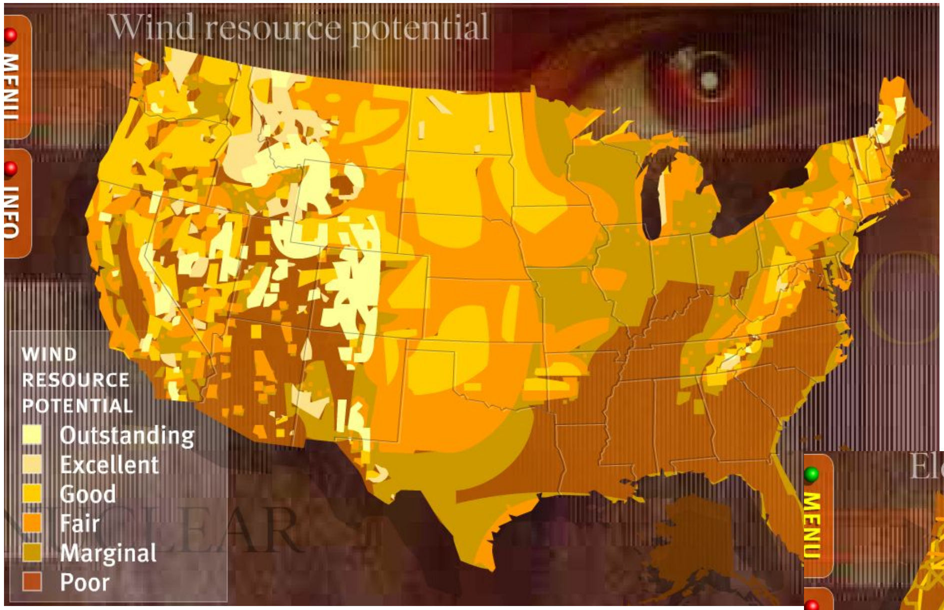
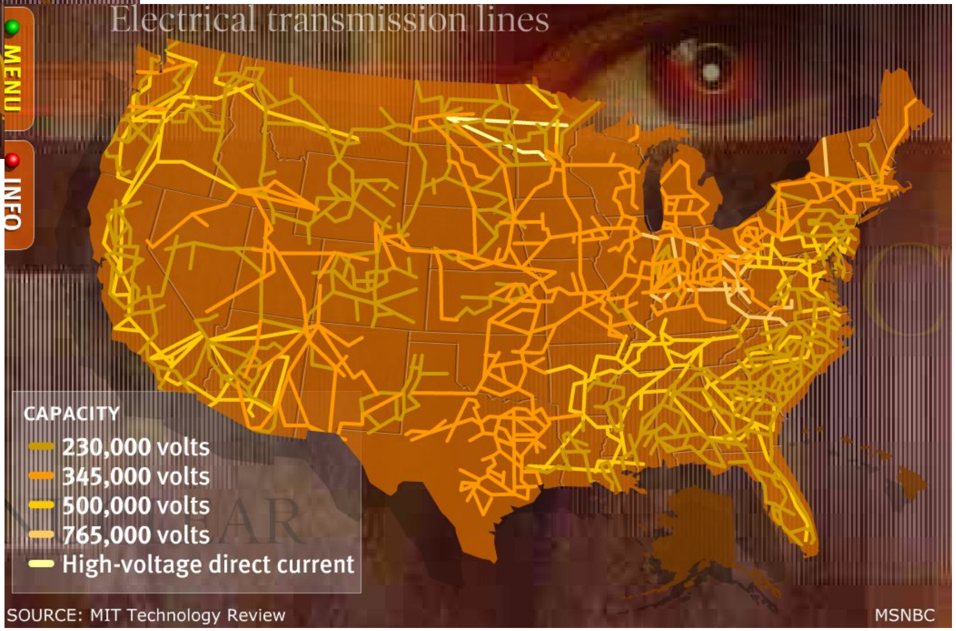
# Mismatch: Wind Resource vs. Transmission Infrastructure

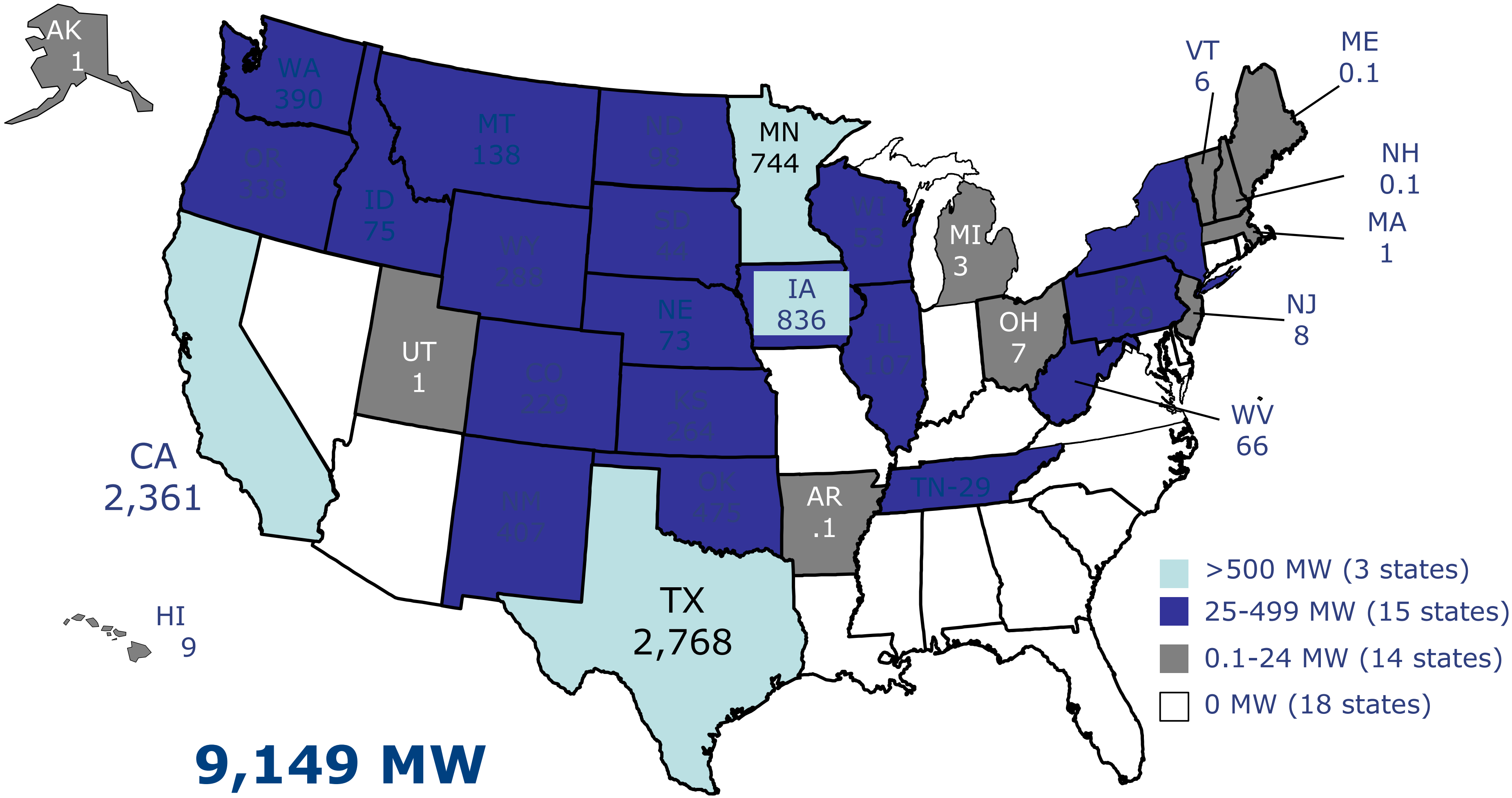



US Wind Resource Map




US Electricity Transmission Grid

# Current Installed Wind Capacity (MW)




**9,149 MW**
**as of 12/31/06**

*Source: American Wind Energy Association*

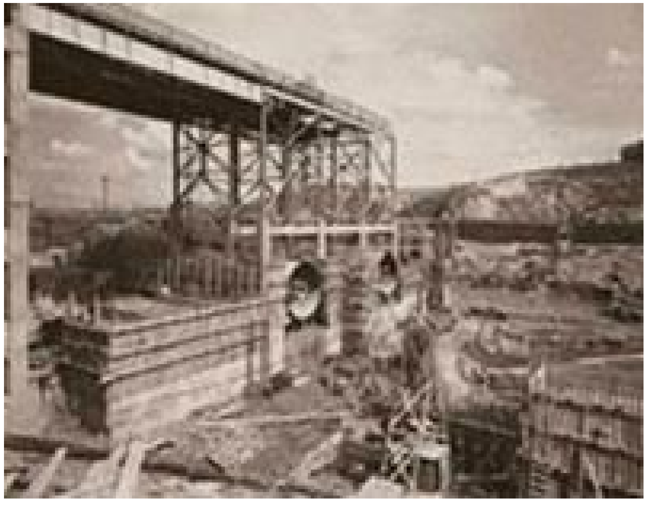
# Economic Challenges
# The Utility Perspective

- Replace aging generating capacity
  - Coal, nuclear plants approaching retirement – a looming crisis
- Maximize load factor (generation & transmission)
  - Best time to wheel excess power – at night
- Comply with utility commission
  - Choose least-cost generation alternative
- Make a profit
  - Be allowed to pass on any higher costs
    (Business vs. charitable mission)
- Act in economic self-interest
  - Goes beyond compliance
    - e.g., US Climate Action Partnership

# Enter the Policy Arena

Government-driven innovation…

- Can achieve what private markets cannot
- Has made US a pioneer and world leader
  - commercial aerospace
  - interstate highway system
  - rural electrification
  - biotechnology/medicine
  - Internet -> WWW



Early TVA dam construction ~ 1942

# Policy Tools

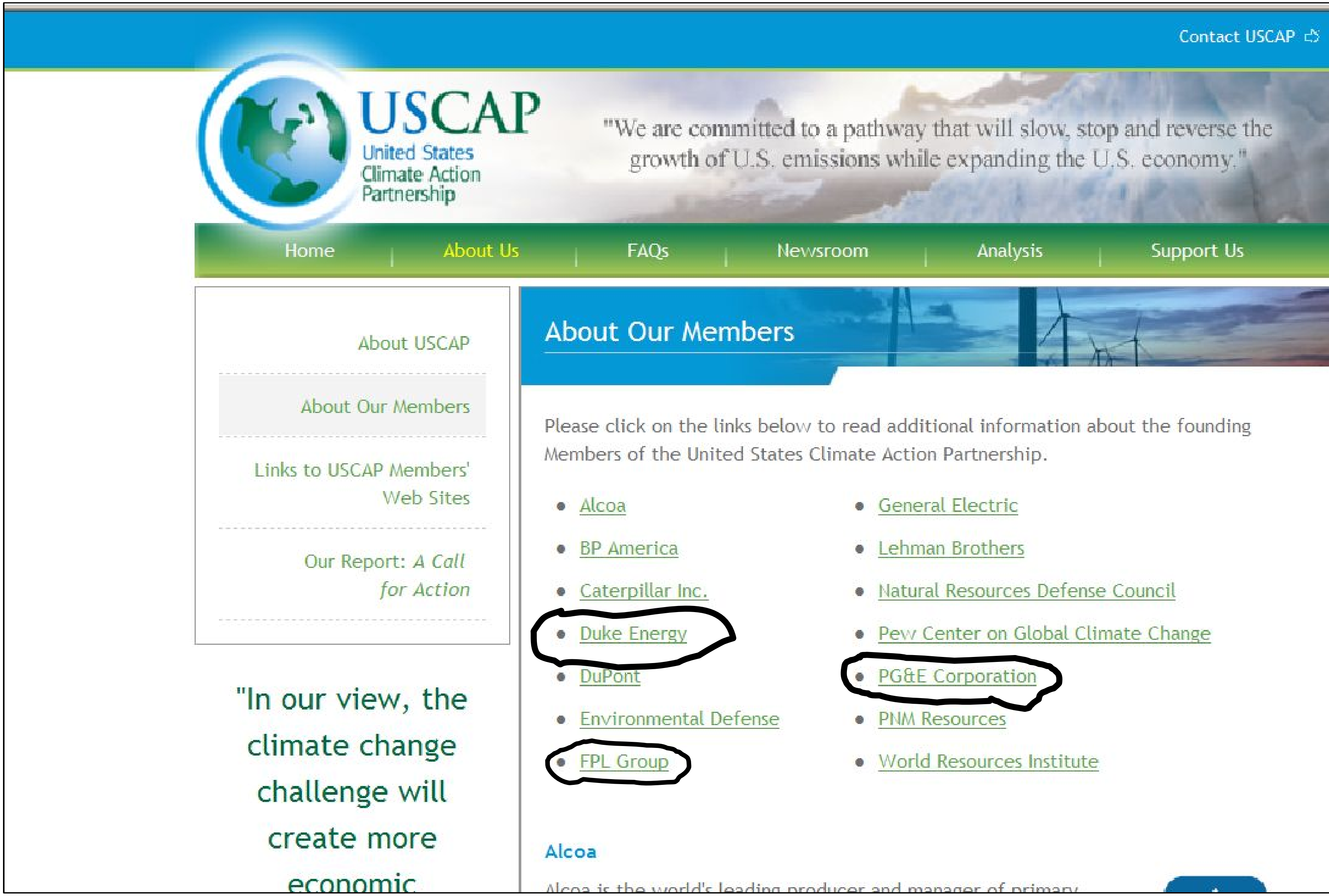
- Sticks
  - Renewable Portfolio Standard
  - Carbon tax
- Carrots
  - US Production Tax Credit (1.9 ¢/kWhr)
  - Some states have additional PTC
  - Emissions trading systems (“green tags”)
  - Subsidized loans (CREB’s)

# Most Powerful Policy Tool: the Renewable Portfolio Standard

- State government mandates that a proportion of all utility-produced power be from alternative/renewable energy sources

- As of 11/06, 20 states have some form of RPF
- Because a utility can meet its RPF by buying as well as producing, a green energy *market* is created.

# Who's keeping company with whom?



# The Danish Experience
# A Strong, Steady Government Hand

- **Wind produces ~25% of Denmark's electricity – world's highest penetration**
  - **On track toward 50% goal by 2030**

- **Kicked off by 1973 energy crisis**

- **Low quality wind resource and limited available land**

- **Government was the driver**
  - **Incentives, subsidies to farmers, small wind developers**
  - **Mandate to utilities to upgrade grid and interconnect.**

- **By 1998 – stalled out (no more land, NIMBY factor) ->**
  - **Brought in utilities to replace with large turbines (>1 MW)**
  - **Most new capacity from *off-shore* (Denmark is world-leader**

World's Largest Offshore Wind Farm, Nysted, Denmark

# The Texas Experience - Triumph of the Market

- “Perfect calm” of positive market forces
  - Enormous wind resource
  - Natural gas (not coal) is the major competing fuel
  - Lots of inexpensive, undeveloped, rural range land
  - Soaring demand
  - Low construction cost
  - Entrepreneurial, risk-taking business culture
  - Overwhelmingly popular support

Trent Mesa Wind Project under construction

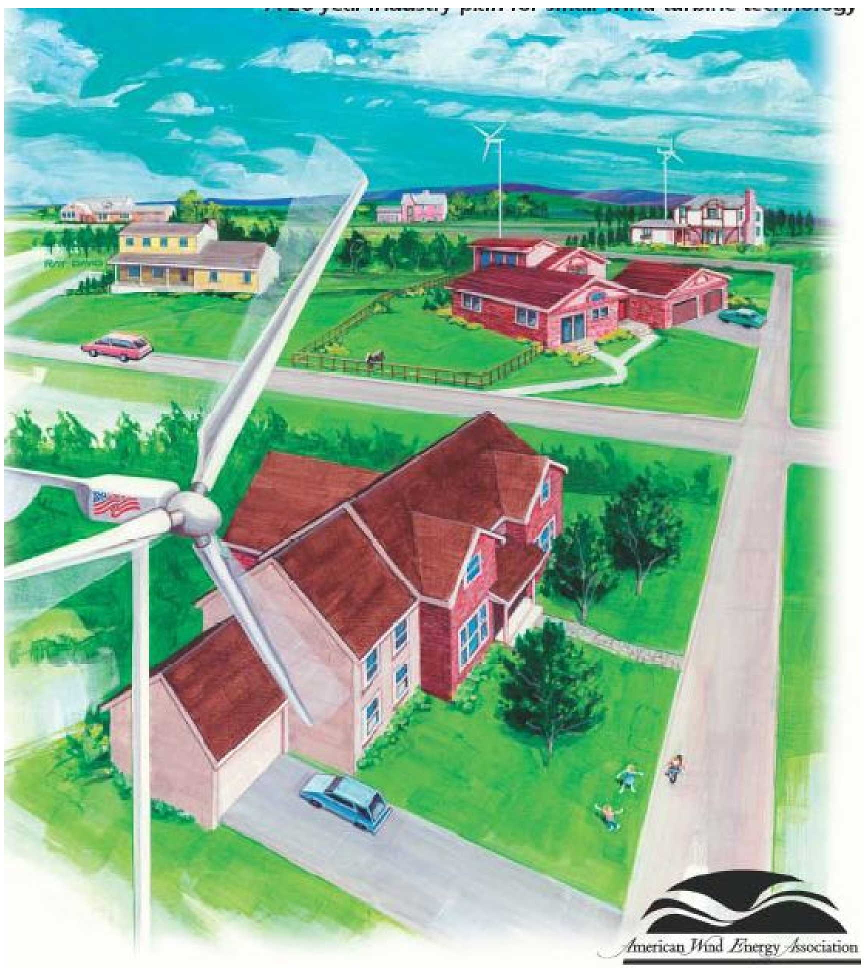
# The Land Constraint: Shell's Proposed Wind Farm – Briscoe County, TX

- One of windiest locations in the US
- Several x larger than any wind farm in the world
  - A 120 sq. mi. farm (5x the area of Manhattan) will generate about as much electricity as *one* coal-fired plant

# New Research Priorities...

- Next wave of innovation may occur at the systems level
  - Turbine transportation and construction logistics
    - Every tower section is an oversize load
  - Handling of variable power sources (negative loads)
  - Renovation/transformation of the grid
  - Small/distributed wind
  - Harnessing low wind speeds
  - More accurate wind forecasting
  - Economical energy storage systems

# Distributed (Community) Wind




- "Small Wind" < 100kw rating
- Behind the meter
  - Competes at retail level (12-20¢/kwhr)
- Not scale-dependent
- No interconnection or transmission issues
- Could sell Renewable Energy Credits ("green tags") to utilities

# Community Wind Could Open Vast New Market

Neighborhoods

Industry

Schools

Farms

Small wind developers

# *But commercializing distributed wind requires breakthrough R&D*

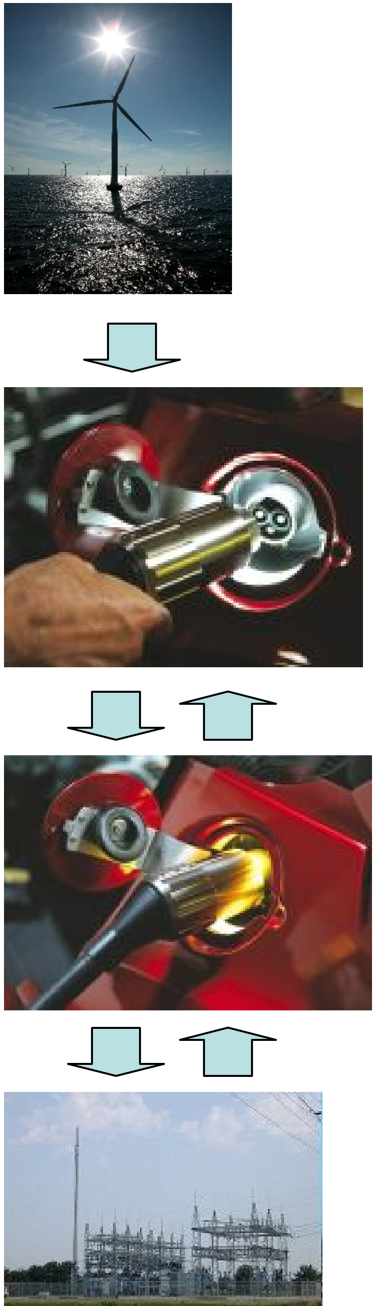
- *small turbines*
- *capturing low wind speeds (<10 mph)*

# The Search for Cost-Effective Energy Storage Options

- Hydro-pumping
- Flywheel
- Battery technologies
- Conversion to chemical fuels ($H_2$, methanol)

*Not cost-effective*

Dedication of Wind to Hydrogen Project at NREL



# An Exciting Storage Option: Vehicle-to-Grid (V2G) Technology

– '000's of plug-in hybrid-electric vehicles (PHEVs) as distributed energy storage device system while parked (90% of time)
– Use wind energy to charge PHEVs at night
  - High wind resource, low load factor on transmission lines
– While parked during day, PHEV owner sells back power to utility to provide grid services
  - Example: frequency regulation
    – Charge/discharge PHEV as needed to provide operating reserves (1.5% of peak power demand required by regulators)
  - Net to PHEV owner: up to $3,500/yr.

Source: Public Utilities Fortnightly, Dec. 2006

# Lessons Learned

- Wind can address some key issues in our energy future
  - Source diversity, global warming
- Wind energy requires a systems perspective
  - integration with network, other energy sources and uses
- Progress in wind energy is primarily crisis- and policy-driven
  - Lead government role is decisive
  - But do we have the political will?
- Utilities are key – they will lead, or it won’t happen!

# Acknowledgments

Special thanks to

- Dale Bradshaw, Manager of Energy Options Development (ret.), Tennessee Valley Authority
- Jay Godfrey, Head of Wind Energy Program, American Electric Power
- Julia Blankenship, Manager, Clean Energy Development and Sustainability AMP-Ohio, Inc.
- John Dismukes, Professor of Chemical and Environmental Engineering, Director, International Accelerated Radical Innovation (ARI) Institute, University of Toledo
- Aleksey Dubrovensky and Kathryn Jennings, undergraduate research assistance, Vanderbilt University School of Engineering

# Discussion Questions

- Do you believe that wind has a place in our energy future?
- What do you see as the greatest challenges facing the deployment of wind energy?
- How would you address them?

# Thank you!