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Present and Future Wind Energy in the U.S.

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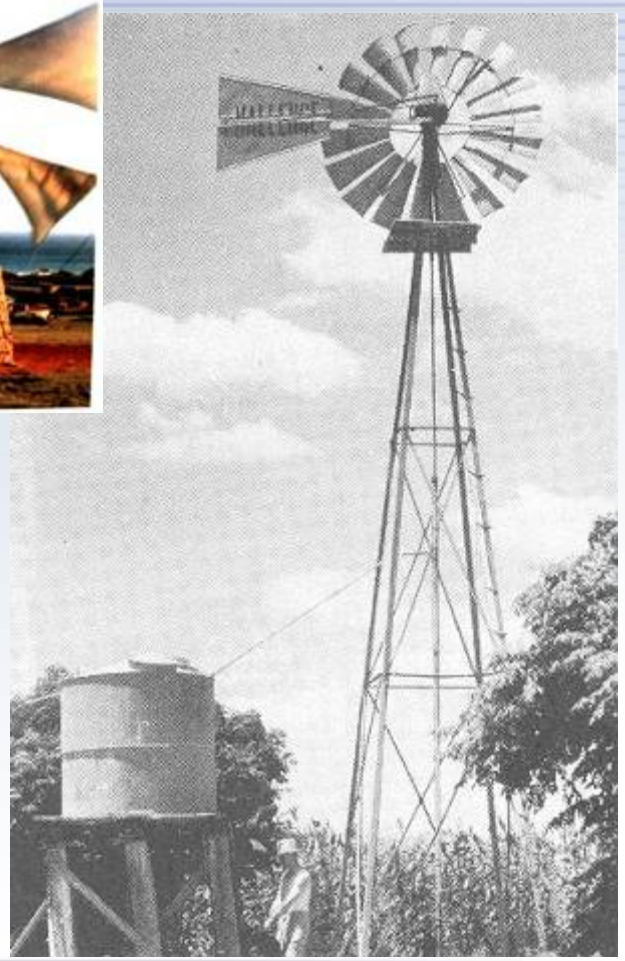
History of Wind Energy

pre - 1970



- Prehistoric – Maritime (Greek, Viking)
- Medieval – Persian, Greek, England
- 20th Century – Great Plains
- First Energy Shortage -- 1974

History of Wind Energy

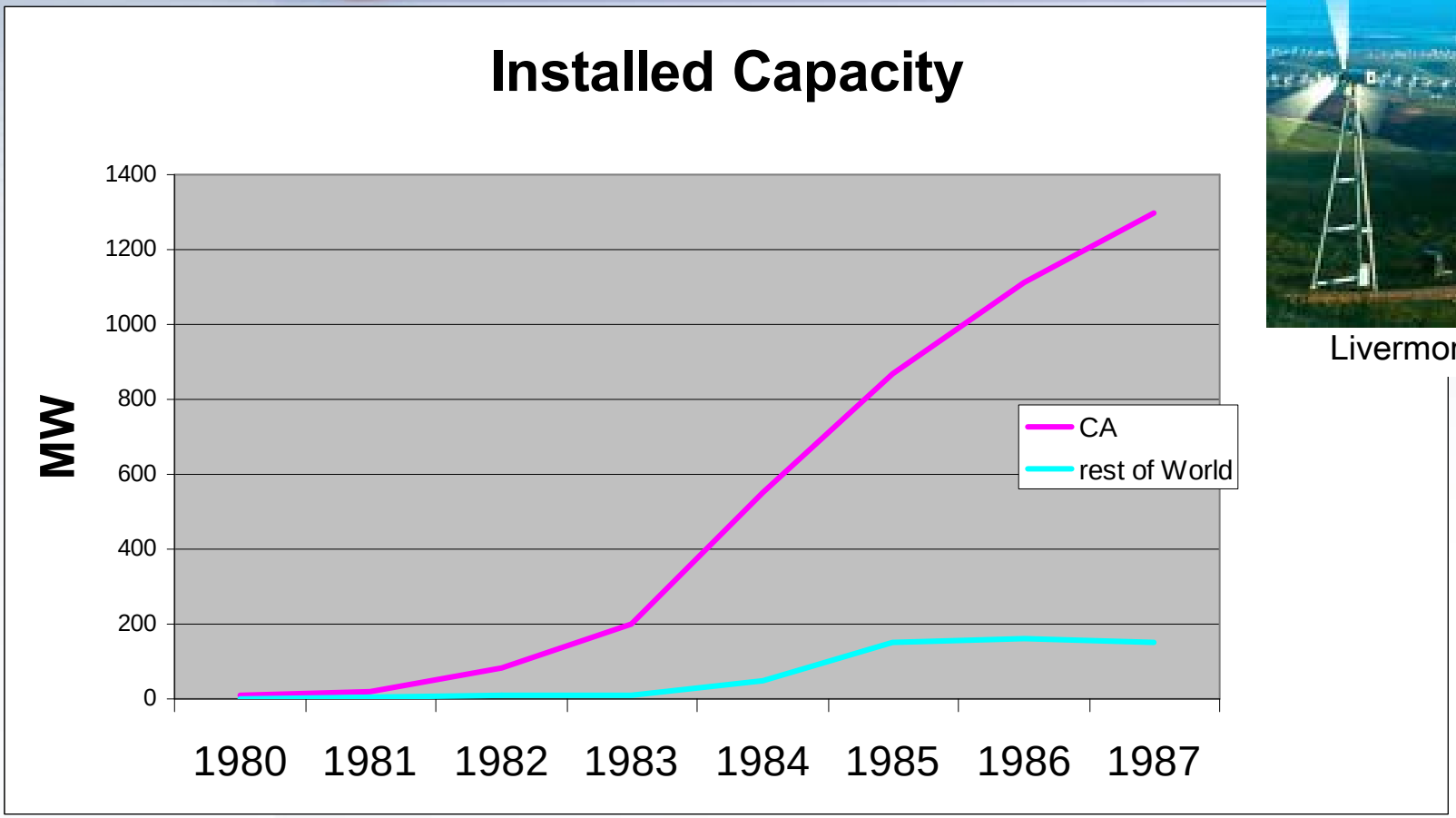
post - 1970

U.S. DOE develops significant research program in response to the energy crisis of 1974

History of Wind Energy

California Boom

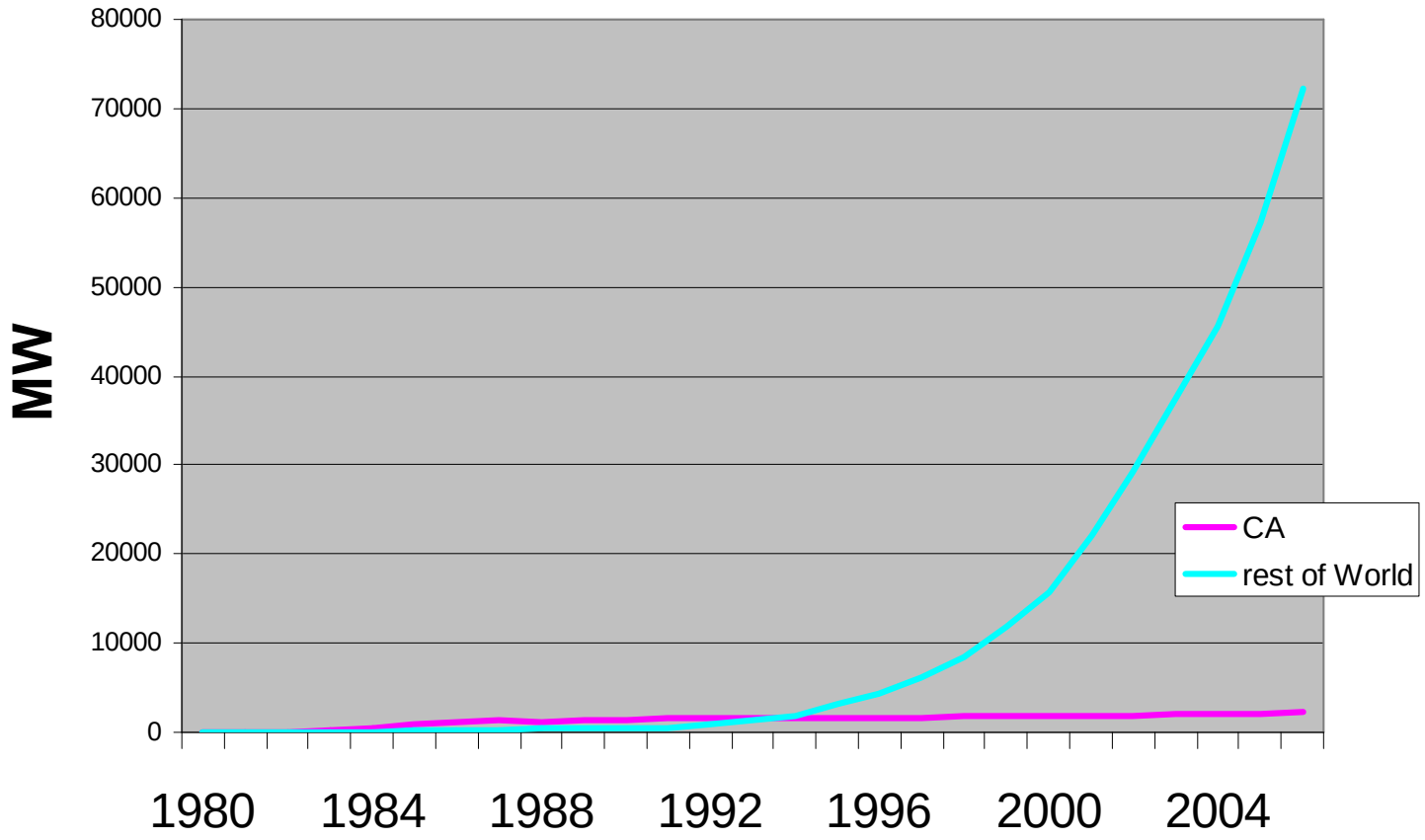
Livermore, CA -1982



AWEA, CEC, Renewable Energy World, Power Engineering, Earth Policy Institute, UC-Irvine

History of Wind Energy

California and World



AWEA, CEC, Renewable Energy World, Power Engineering, Earth Policy Institute, UC-Irvine

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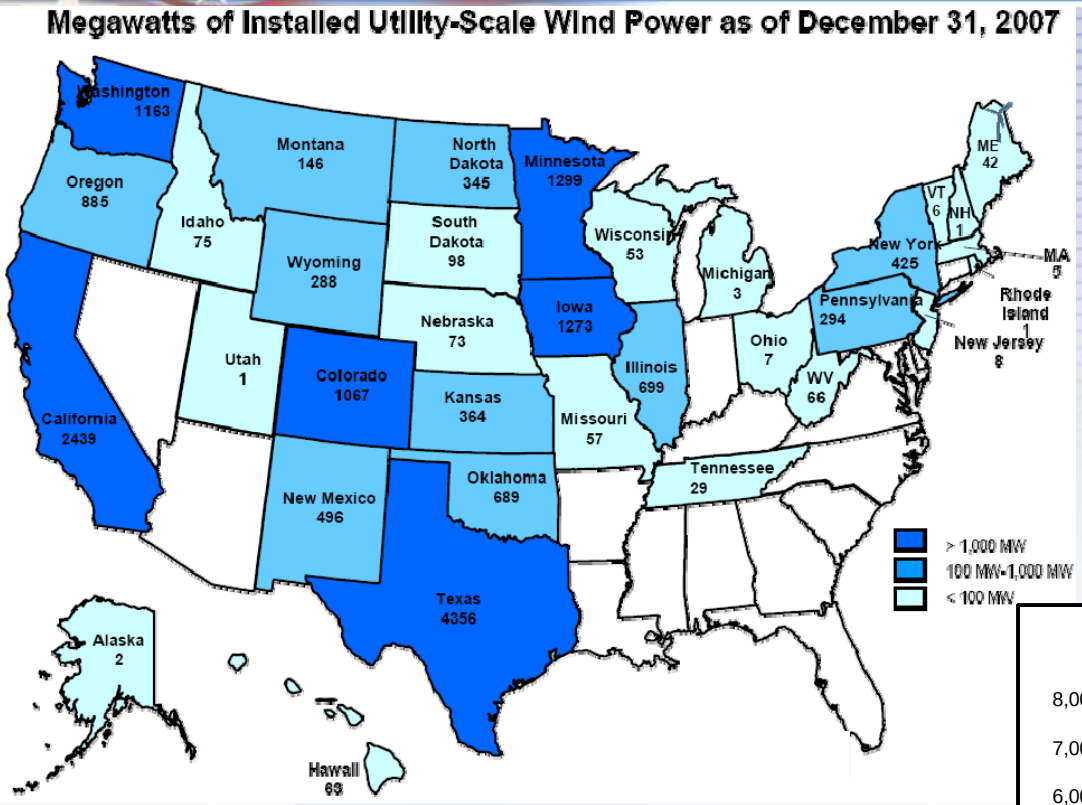
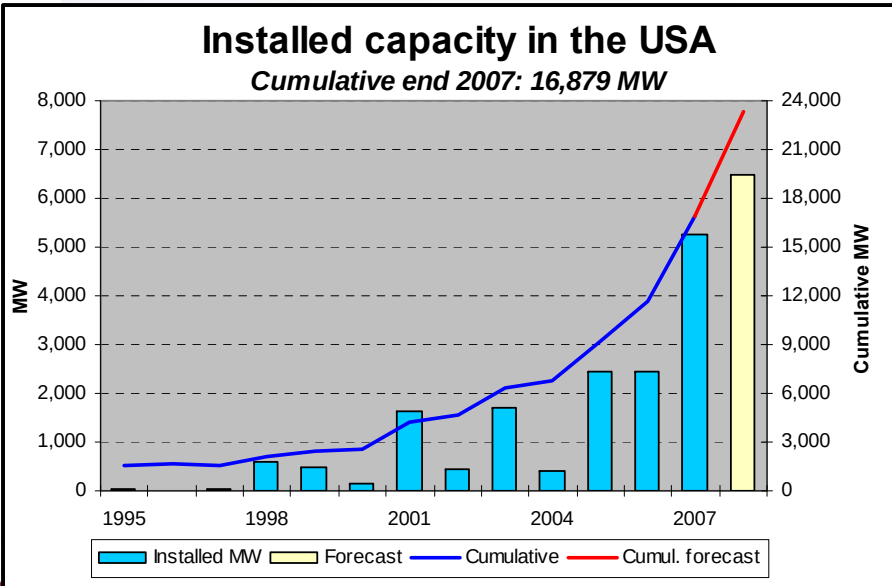
Current U.S. Installation



- **Wind Energy Today (end of 2007)**
  - **Total installed capacity: 16,879 MW (34 States)**
    - **5,244 MW installed 2007**
    - **45% increase from 2006**
    - **Accounted for 30% of new installed capacity in 2007**
  - **Over 9 billion dollars invested in 2007**
  - **Installed cost: ~5-8¢/kWh**

Almost 5.5 TW Available Resource
(Total U. S. Electric Capacity ≈ 1 TW in 2007)



The 10 Largest Markets by end of 2007

Country	2005	2006	2007	Share %	Cum. Share %
Germany	18,445	20,652	**22,277**	**23.7%**	**24%**
USA	9,181	11,635	**16,879**	**18.0%**	**42%**
Spain	10,027	11,614	**14,714**	**15.7%**	**57%**
India	4,388	6,228	**7,845**	**8.3%**	**66%**
P.R. China	1,264	2,588	**5,875**	**6.2%**	**72%**
Denmark	3,087	3,101	**3,088**	**3.3%**	**75%**
Italy	1,713	2,118	**2,721**	**2.9%**	**78%**
France	775	1,585	**2,471**	**2.6%**	**81%**
UK	1,336	1,967	**2,394**	**2.5%**	**83%**
Portugal	1,087	1,716	**2,150**	**2.3%**	**86%**
Total	**51,303**	**63,203**	**80,415**		
Percent of World	86.4%	85.1%	85.5%		

Source: BTM Consult ApS - March 2008

Germany On-Land Potential ≈ 100,000 MW

USA on-Land Potential > 1,200,000 MW

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Wind Power's Share of World Power Generation

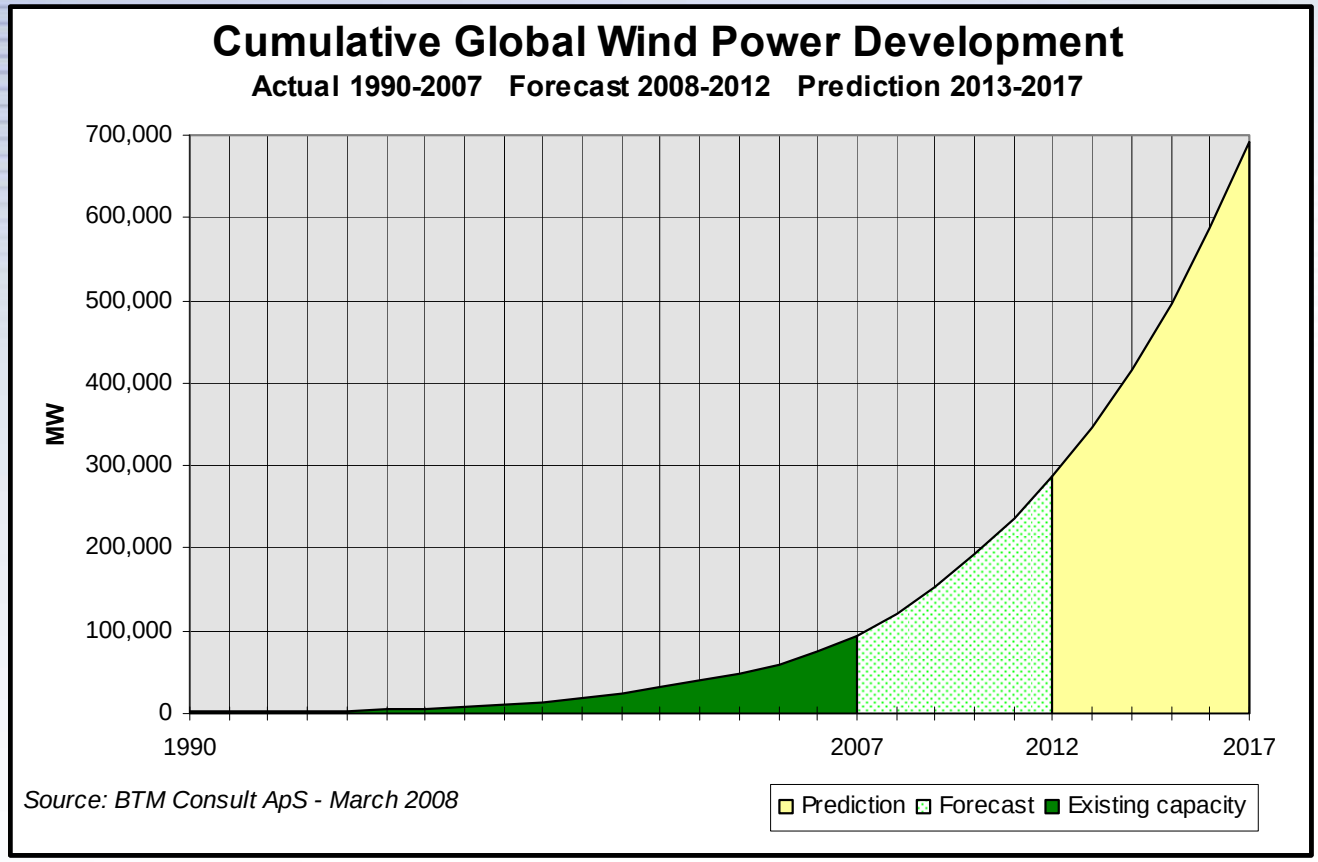
Generation Technology Year:	Electricity gen. by Wind Power (BTM-C) TWh	Electricity from all gen. sources (incl. Wind) IEA TWh	Wind Power's share of the world's electricity generation: %
1996	12.23	13,613	0.09%
1997	15.39	13,949	0.11%
1998	21.25	14,340	0.15%
1999	23.18	14,741	0.16%
2000	37.30	15,153	0.25%
2001	50.27	15,577	0.32%
2002	64.81	16,233	0.40%
2003	82.24	16,671	0.49%
2004	96.50	17,408	0.55%
2005	120.72	17,982	0.67%
2006	152.35	18,576	0.82%
2007	**194.16**	**19,189**	**1.01%**
2012 (forecast)	605.4	22,571	2.68%
2017 (est.)	1573.8	26,549	5.93%

Source: BTM Consult ApS - March 2008 ; World Figures: IEA World Energy Outlook 2007

Phenomenal Growth

Global Wind Industry

- 25% annual growth rate, 1990-2007 (actual)
- 25% annual growth rate 2008-2012 (BTM)
- 19% annual growth rate 2013-2017 (BTM)

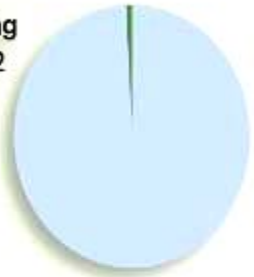


2007 Installed Energy Mix (U.S)

New U.S. Capacity by Energy Source

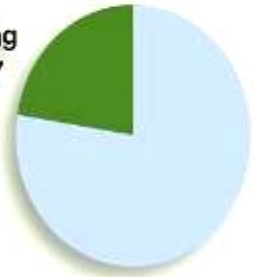
Total Electricity Generating Capacity Installed In 2002

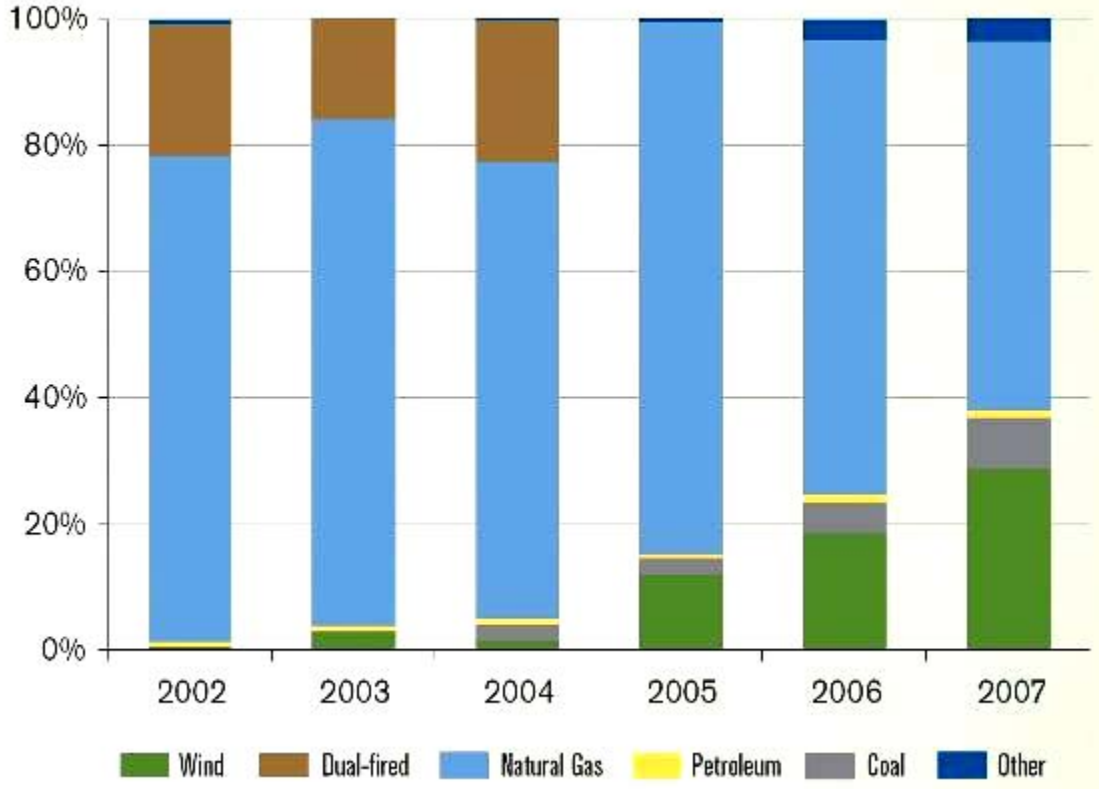
Wind power capacity:
1% of total



Total Electricity Generating Capacity Installed in 2007

Wind power capacity:
30% of total





Sources: US Energy Information Administration, AWEA

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Wind Basics

Wind Power Basics

Air Density — Rotor Area — Wind Speed

$$WindPower = \frac{1}{2}\rho A C_P V_\infty^3$$

Wind Power output is proportional to wind speed cubed.

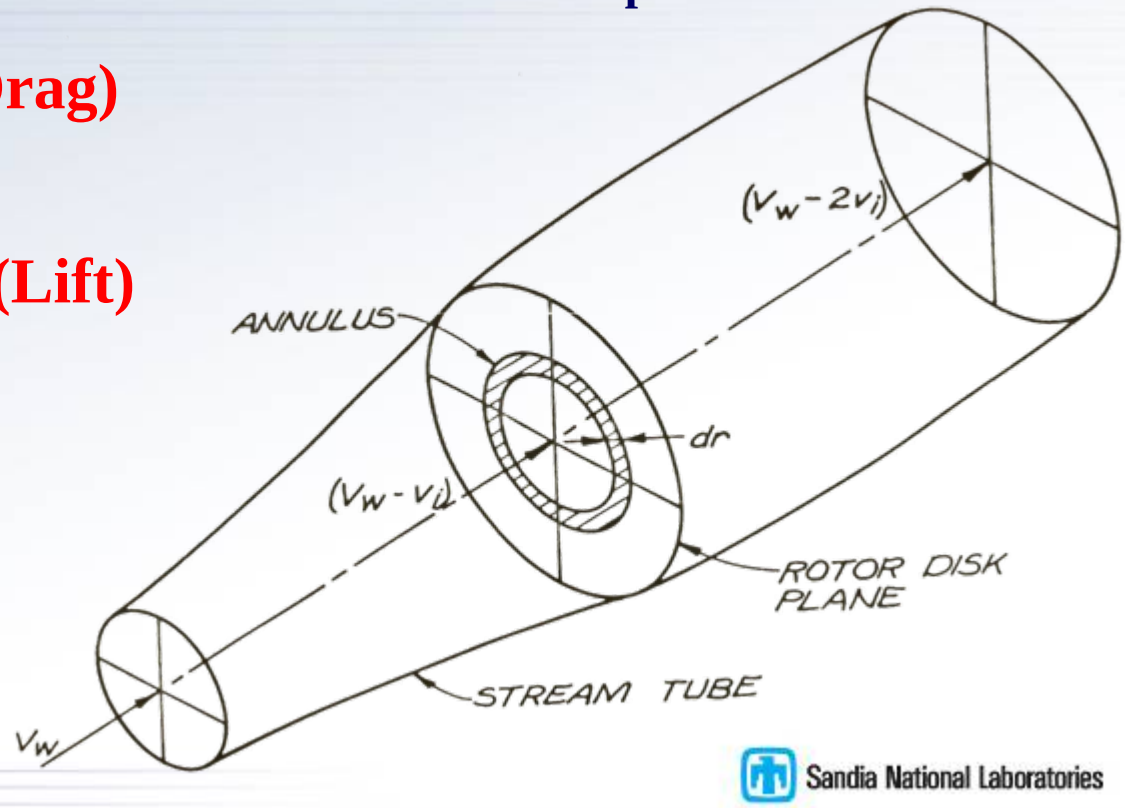
$$C_{P\max} \cong 0.3 \text{ (Drag)}$$

$$C_{P\max} \cong 0.59 \text{ (Lift)}$$

The Betz Limit

$$V_i = \frac{1}{3} V_w$$

$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$



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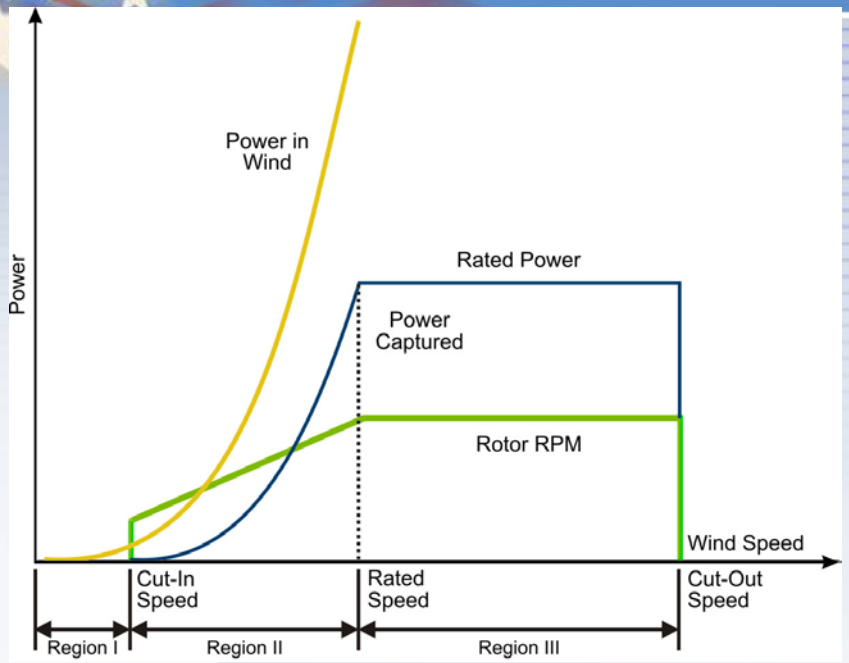
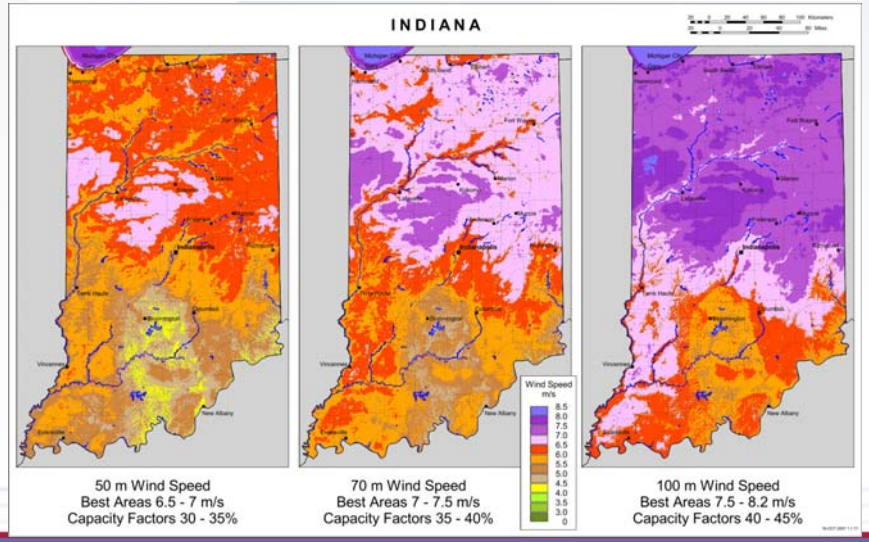
The Physics of the Power Curve Drives Technology Development





Facts about Wind Technology

- Power in the wind is proportional to wind speed cubed
- At best, we can capture 59% (the Betz limit)
- "Rated Power" governs the size and cost of the entire turbine infrastructure
- Energy is power multiplied by the amount of time spent at that power level
- Capacity Factor is the ratio of total output to what would have been generated if always operating at Rated Power – Meaningful metric
- Wind shear puts higher winds at greater elevation

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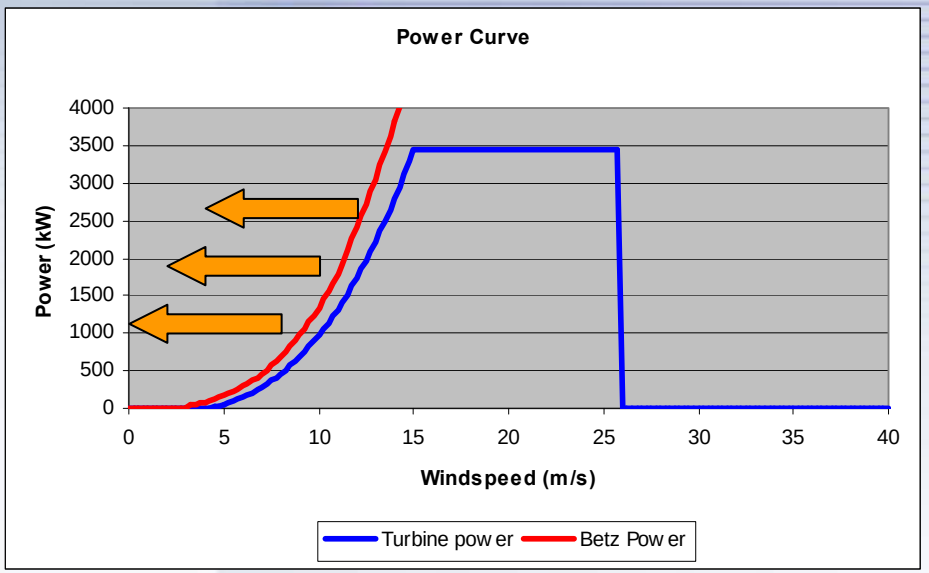
Performance Enhancement Options

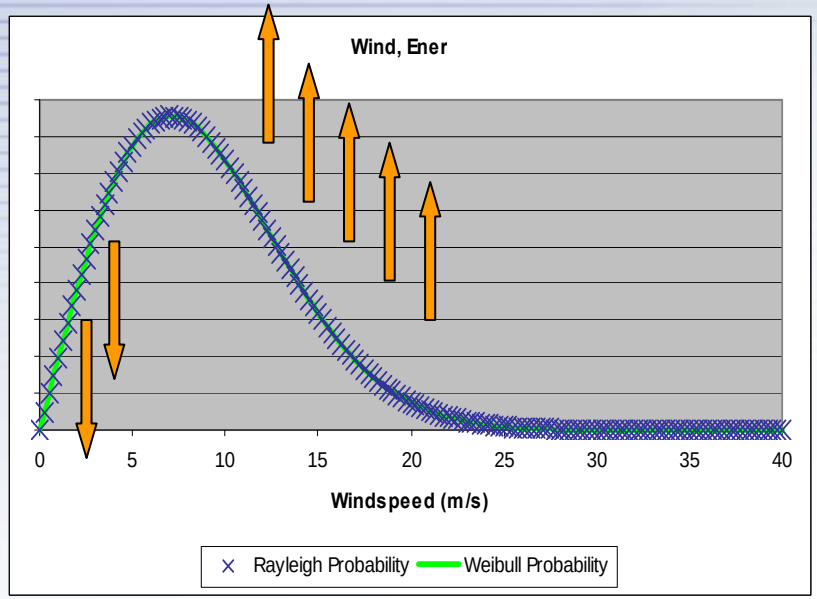
Power



Larger Rotor

Rotor *costs* increase with diameter *cubed,* Rotor *power* grows with the diameter *squared*

Resource

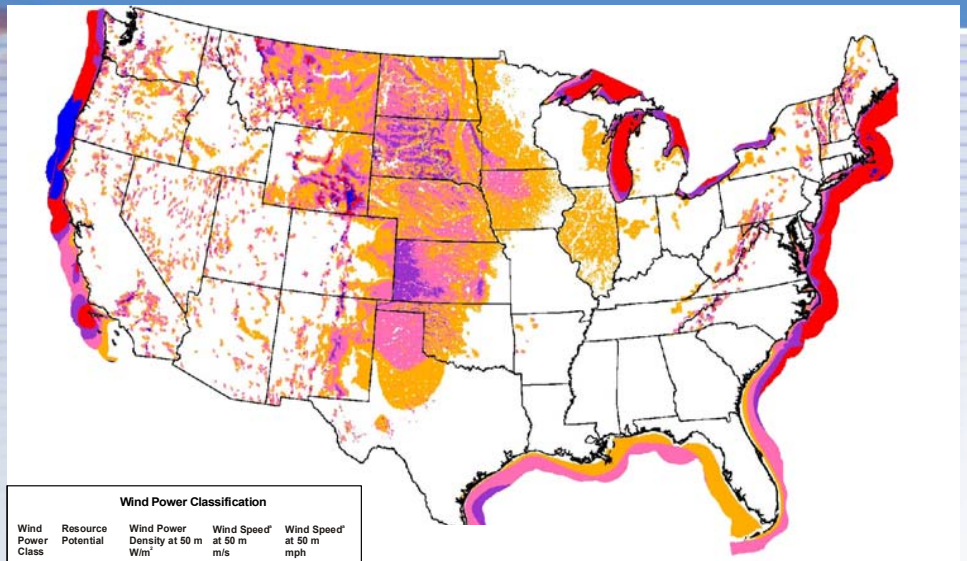


Taller Tower

Tower costs increase with height to the *fourth* power

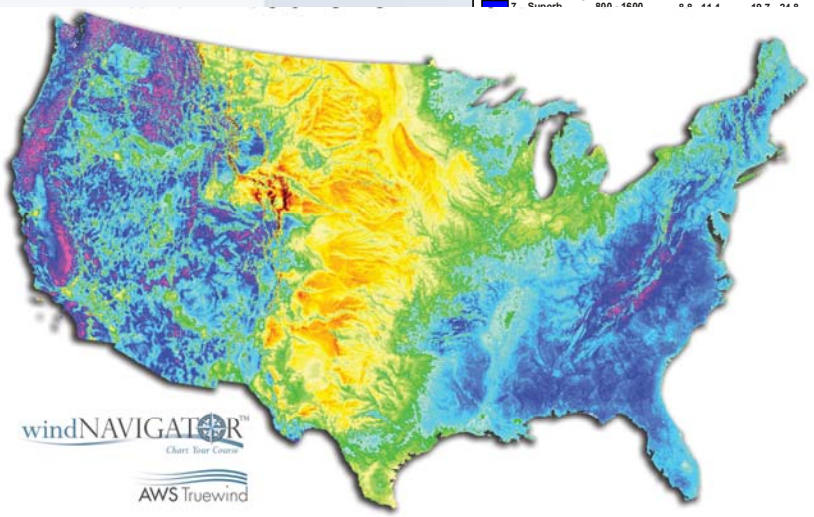
We can only win this battle if we build rotors that are smarter and components that are lighter to beat the squared-cubed law.

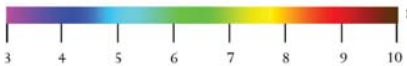
U.S. Wind Resource Maps



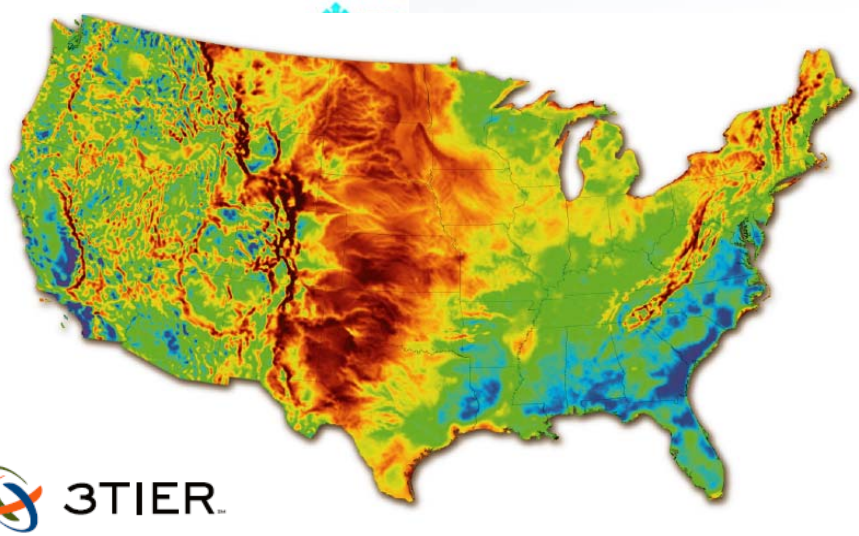
Wind Power Classification

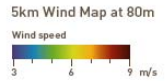
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7



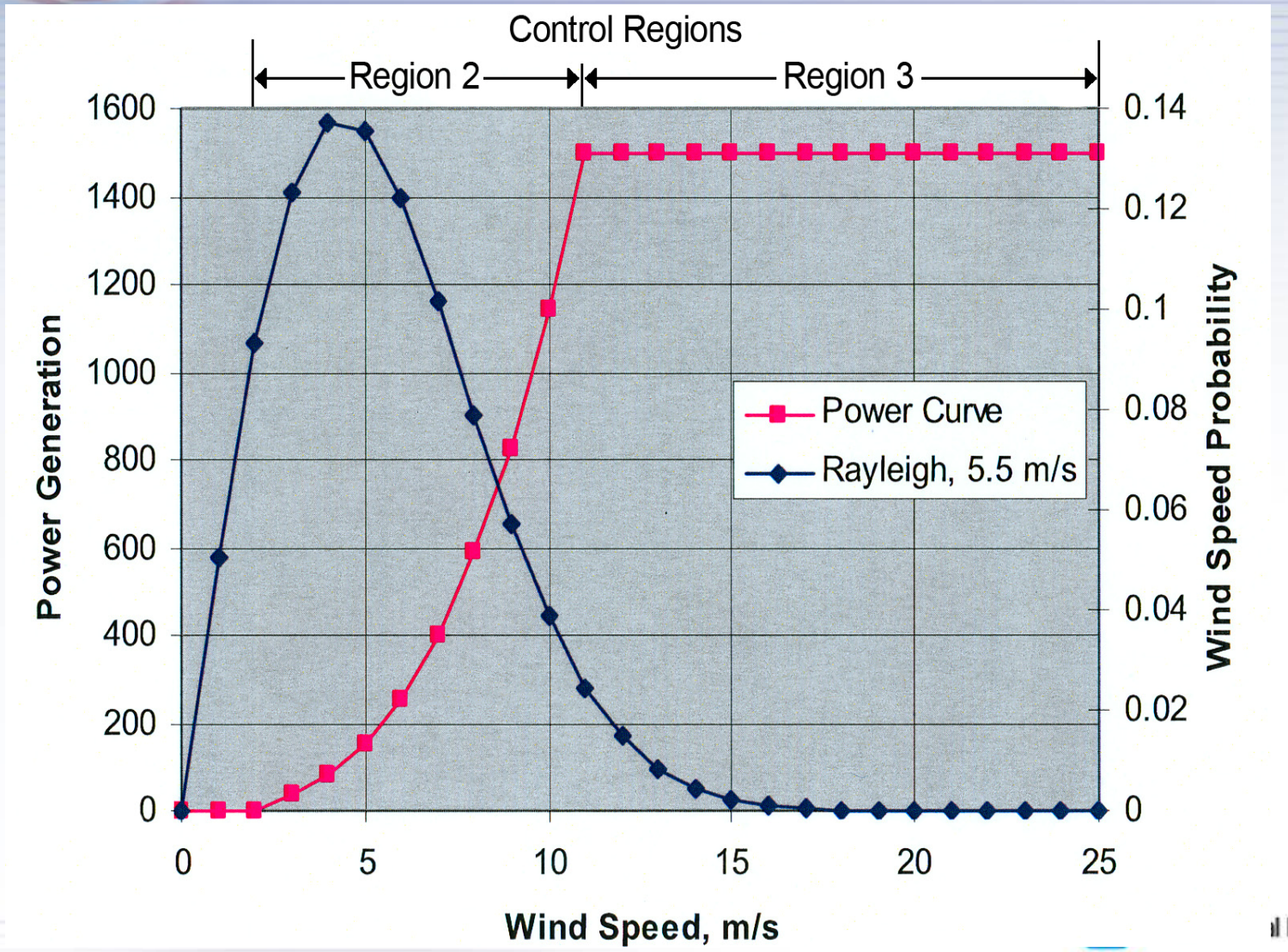


Wind Resource of the United States at 2.5km grid cell resolution.
SOURCE: Data and image developed by AWS Truewind for windNavigator: http://navigator.awstruewind.com





Power Curve and Wind Speed Distribution at Low Wind Site



Current Technology and Energy Cost

Wind Power

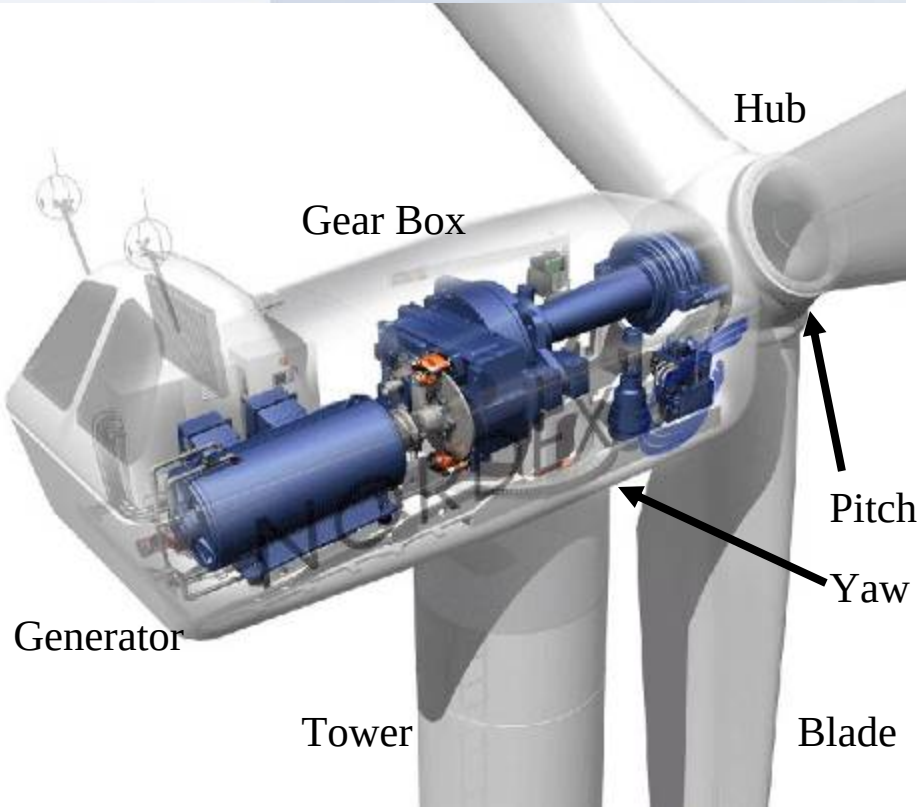
Small Wind
(1-1000 kW)

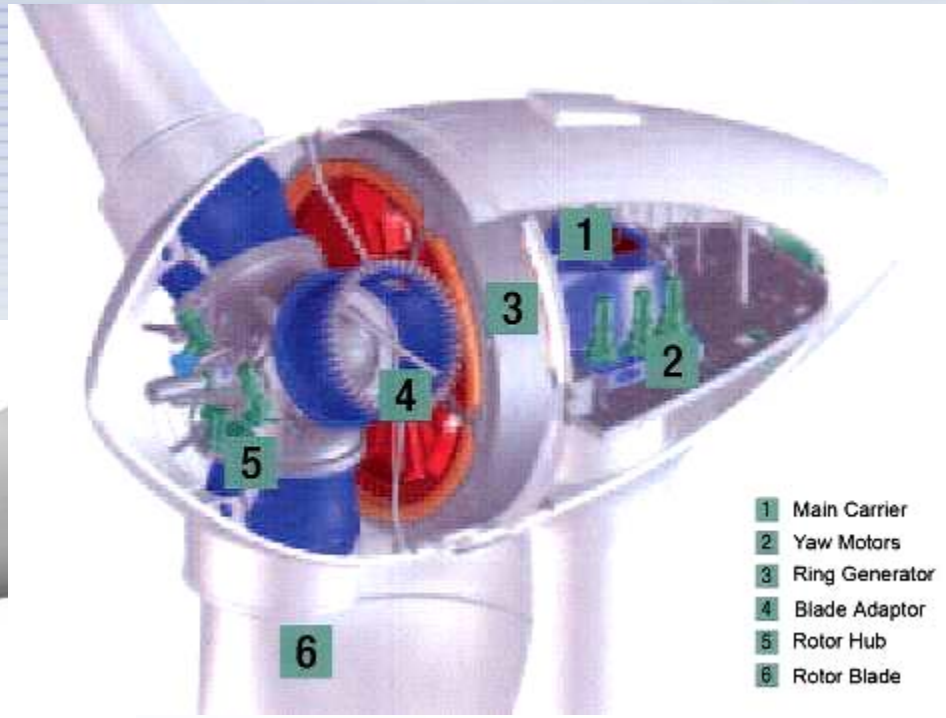
Utility-Scale Wind
(1-5 MW)

American Wind Energy Association
www.awea.org

Current Wind Turbine Systems

Conventional Drive Train





Direct Drive System

Typical Turbine Installation

GE (US)

Gamesa (Spain)

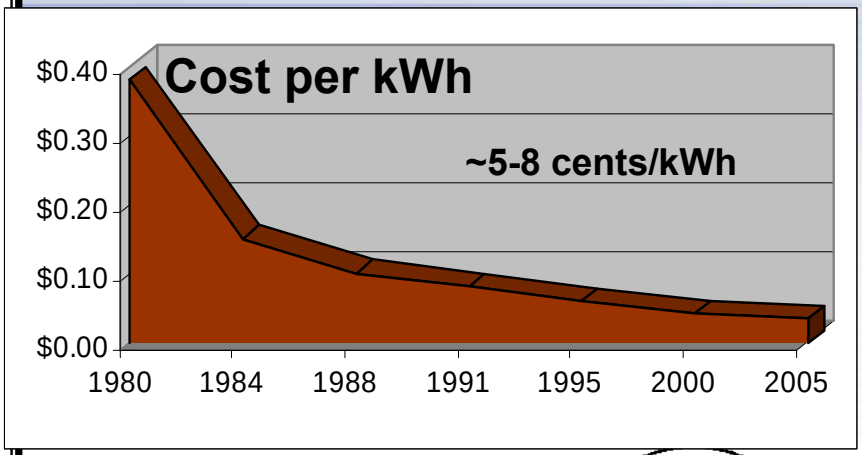
Vestas
(Denmark)

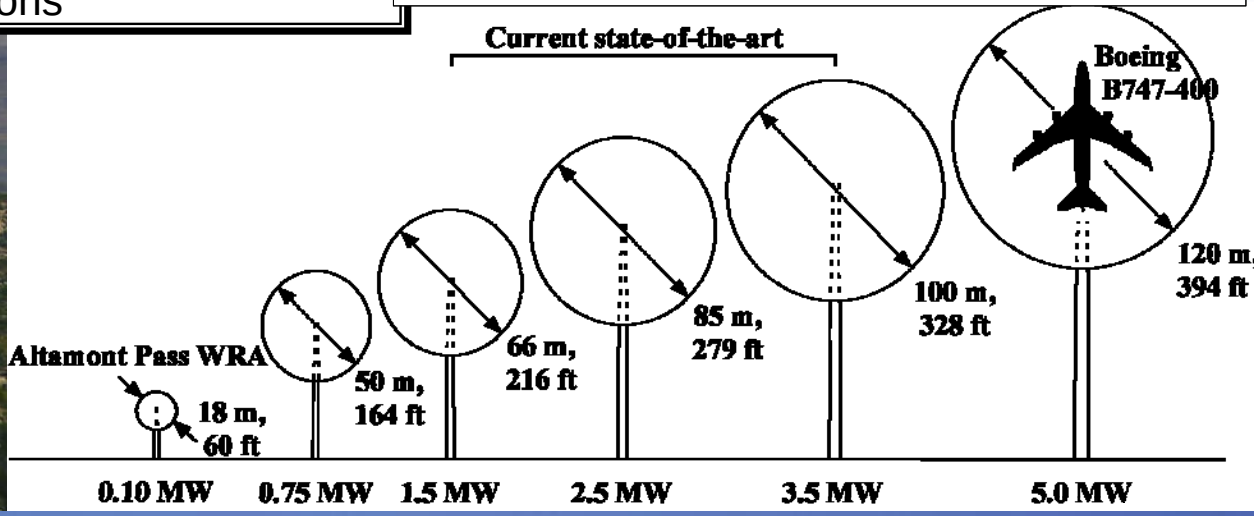
Enercon
(Germany)

Wind Industry Trends & Costs

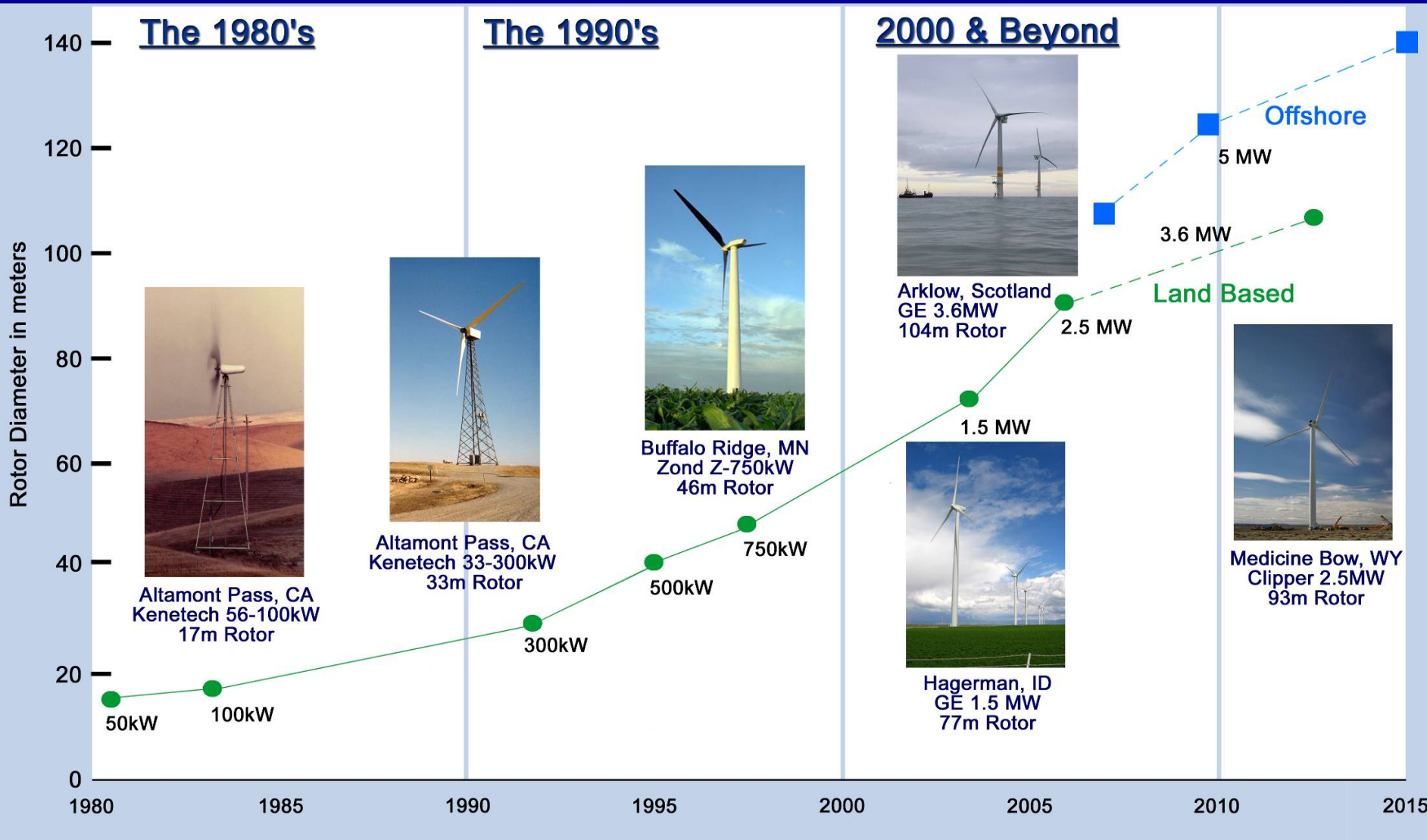
Size

- 1.5-5.0 MW
- Towers: 65-100 meters
- Blades: 34-60 meters
- Weight: 150-500 tons





Evolution of U.S. Commercial Wind Technology



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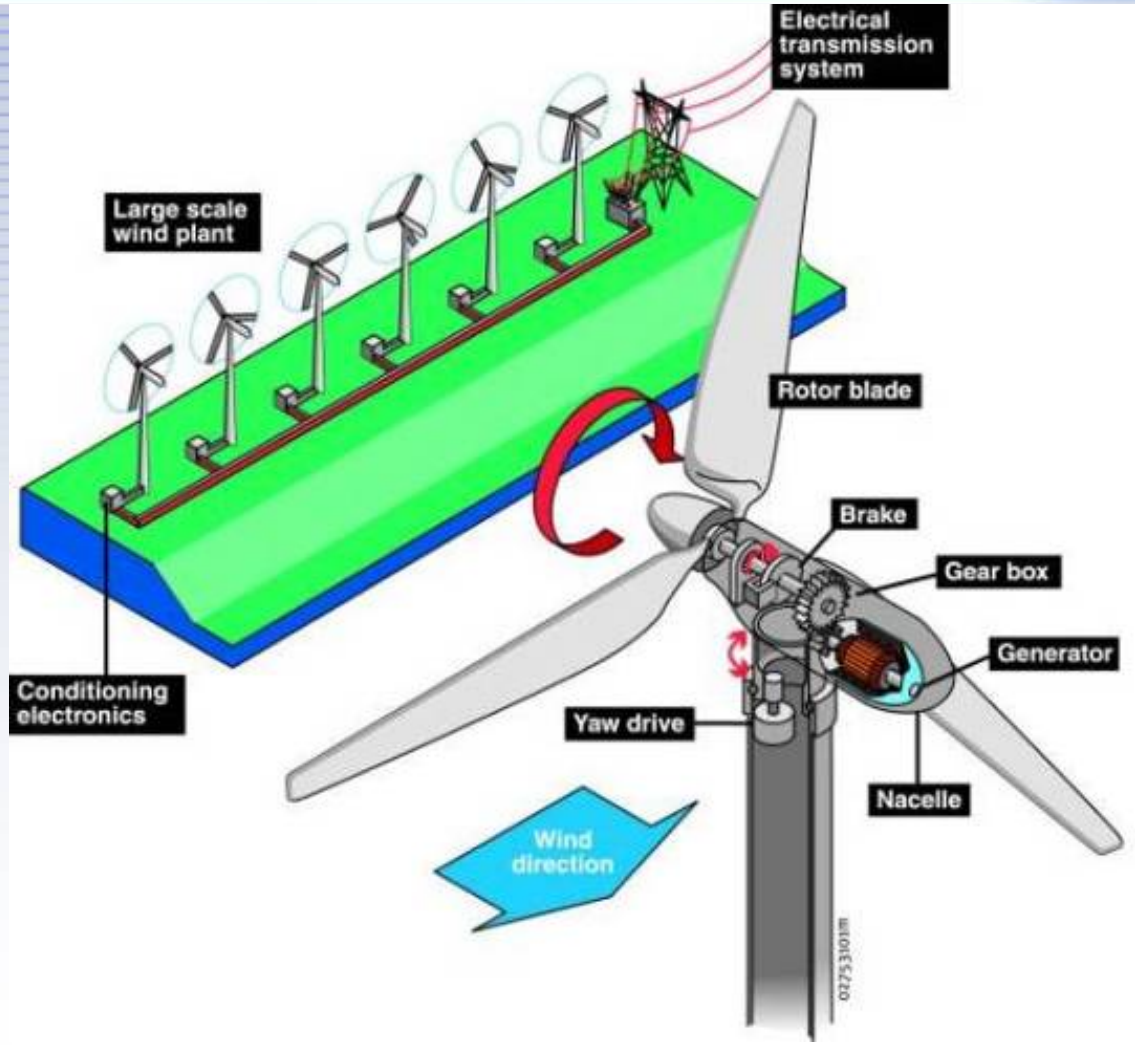
Typical Wind Farm Components

- Turbine
- Foundations
- Electrical collection system
- Power quality conditioning
- Substation
- SCADA
- Roads
- Maintenance facilities



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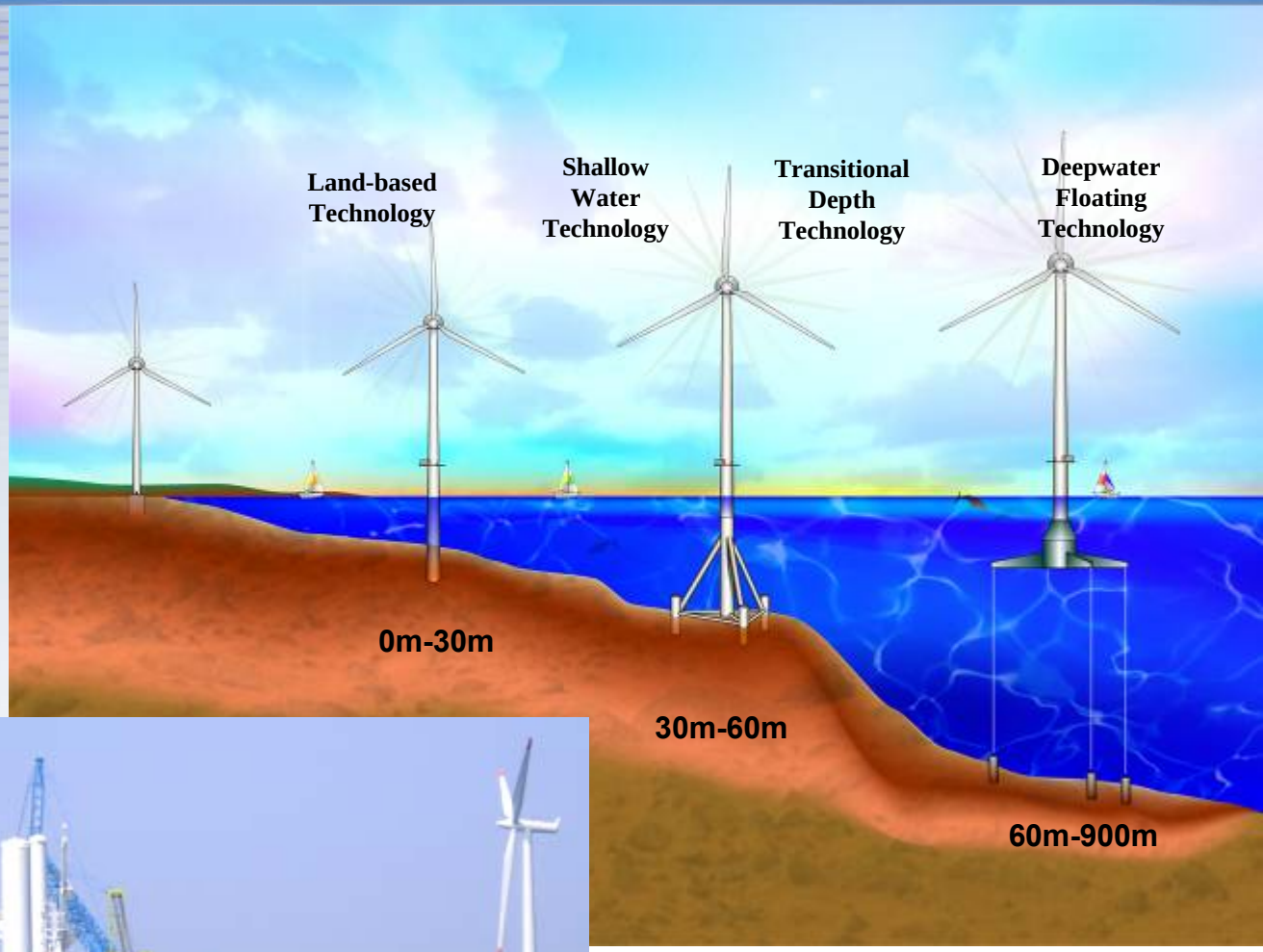
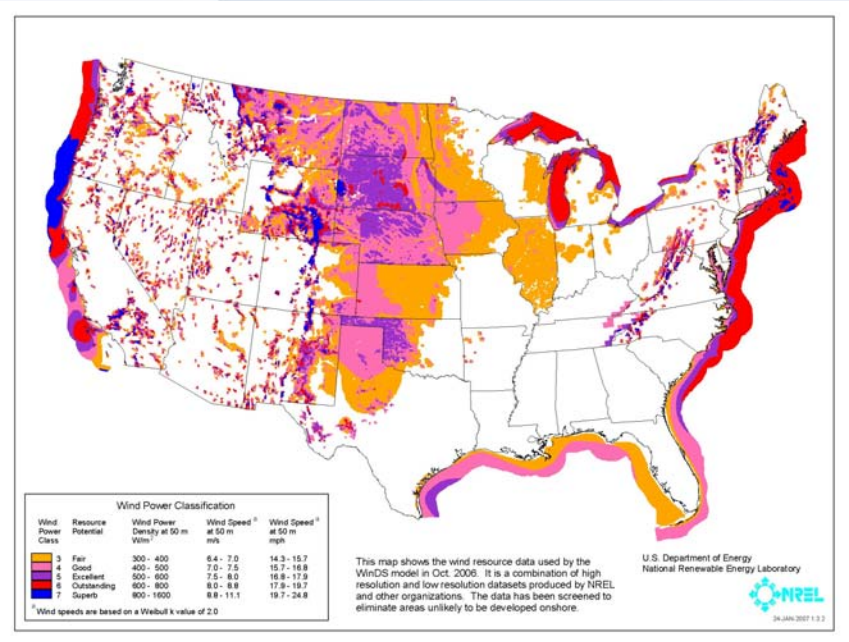
Offshore Wind Background

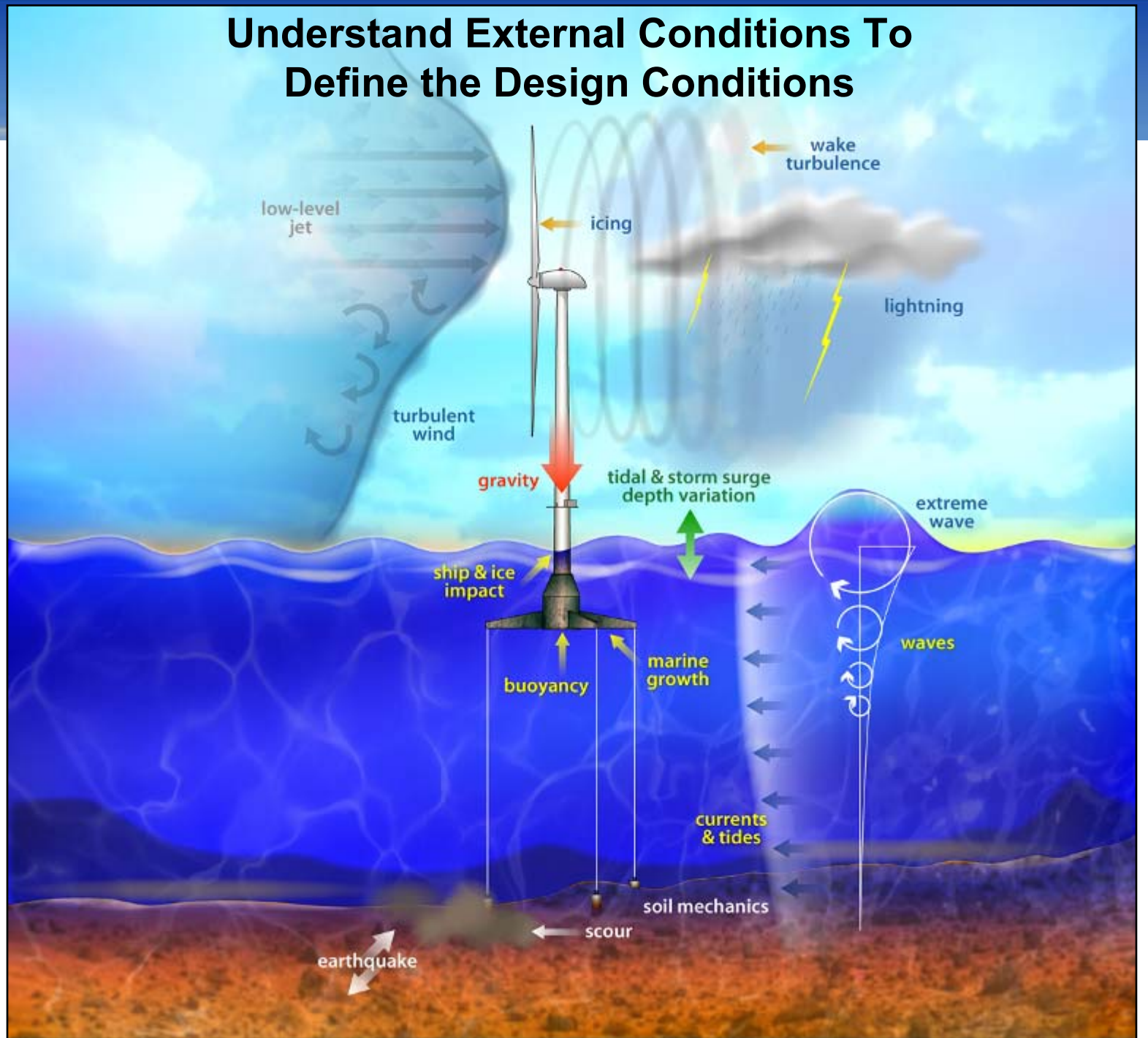


Offshore Wind

- Technical challenges, higher costs
- Close to load centers
- 1000 MW installed in Europe
- Limited shallow depths in U.S.
- Proposals in U.S.
  - Cape Cod (Cape Wind)
  - Long Island (LIPA)



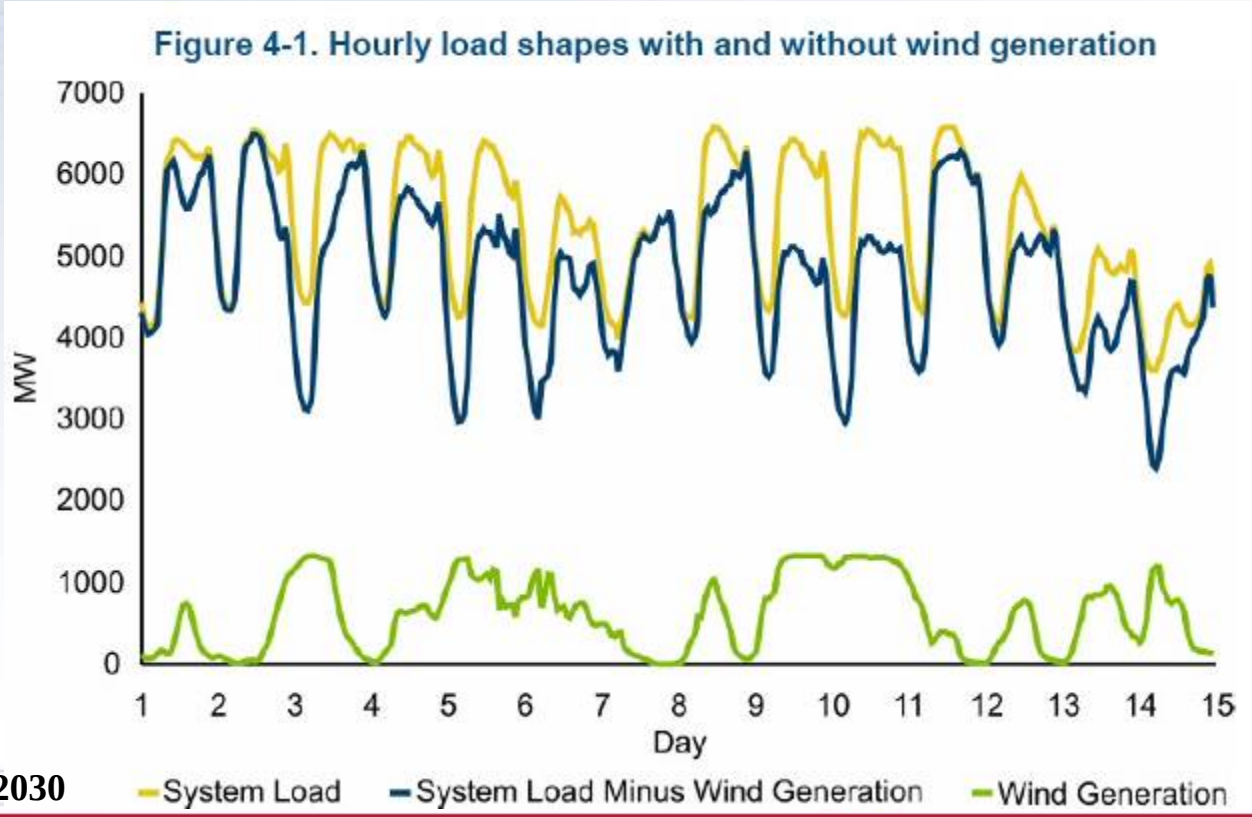
Understand External Conditions To Define the Design Conditions



Problems and “Problems”

Production Fluctuates

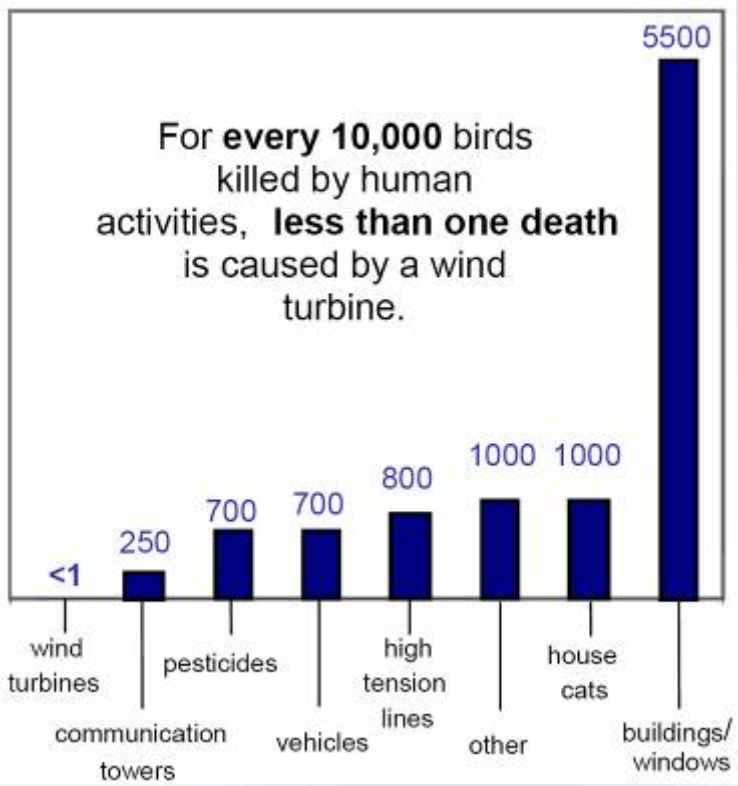
- Load fluctuates significantly
- Even an all-fossil power system must ramp up and down to follow the load
- Day-ahead wind forecasting
- Wind is a "negative load"
- Effects ramp rates



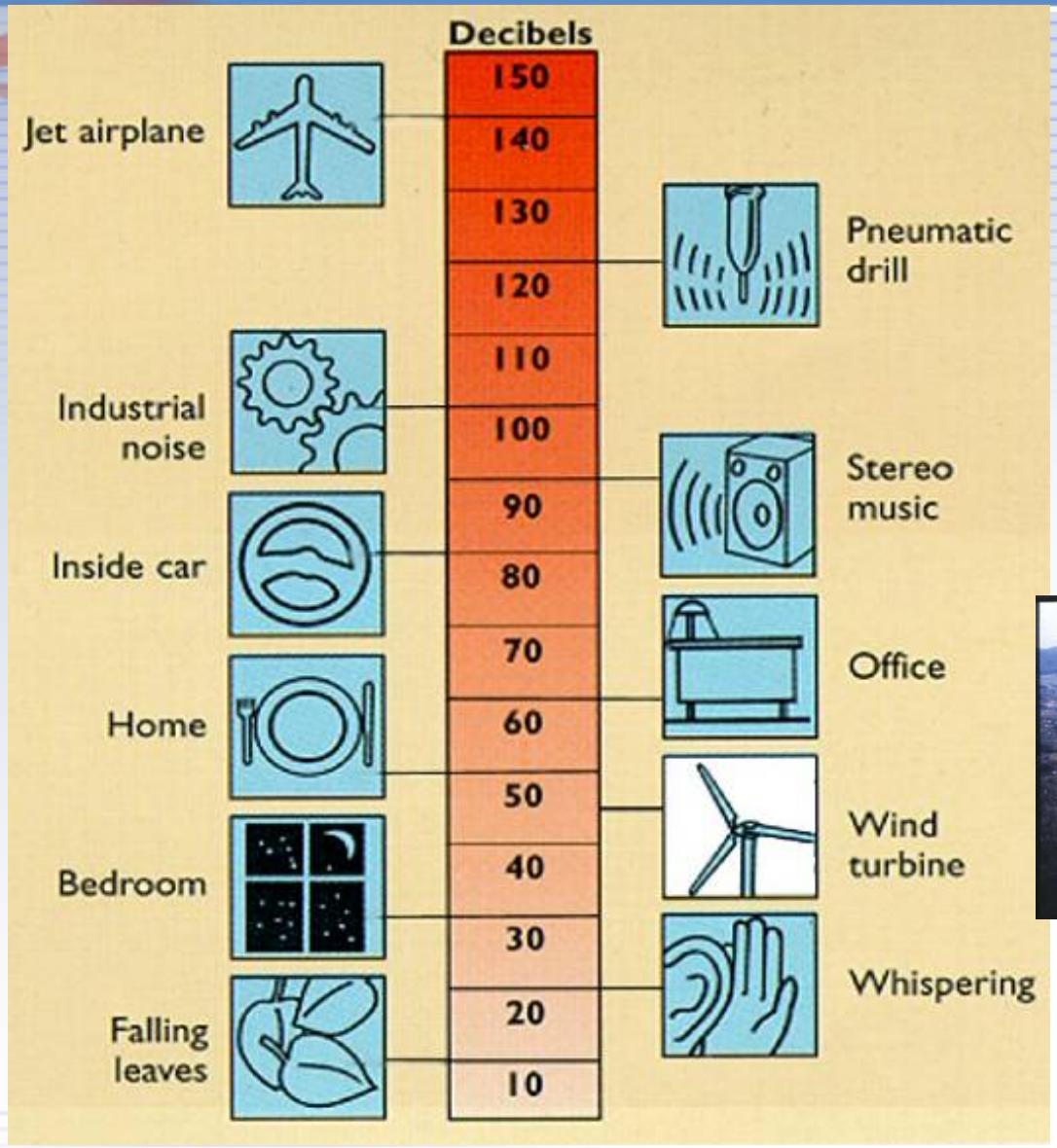
EIA: 20% Wind Energy by 2030

Bird Collisions & Mortality

- **Problem documented in Altamont Pass**
  - **One of nation's largest concentrations of federally-protected raptors**
  - **Abundant prey base (migration path)**
  - **Heavy year-round raptor use**



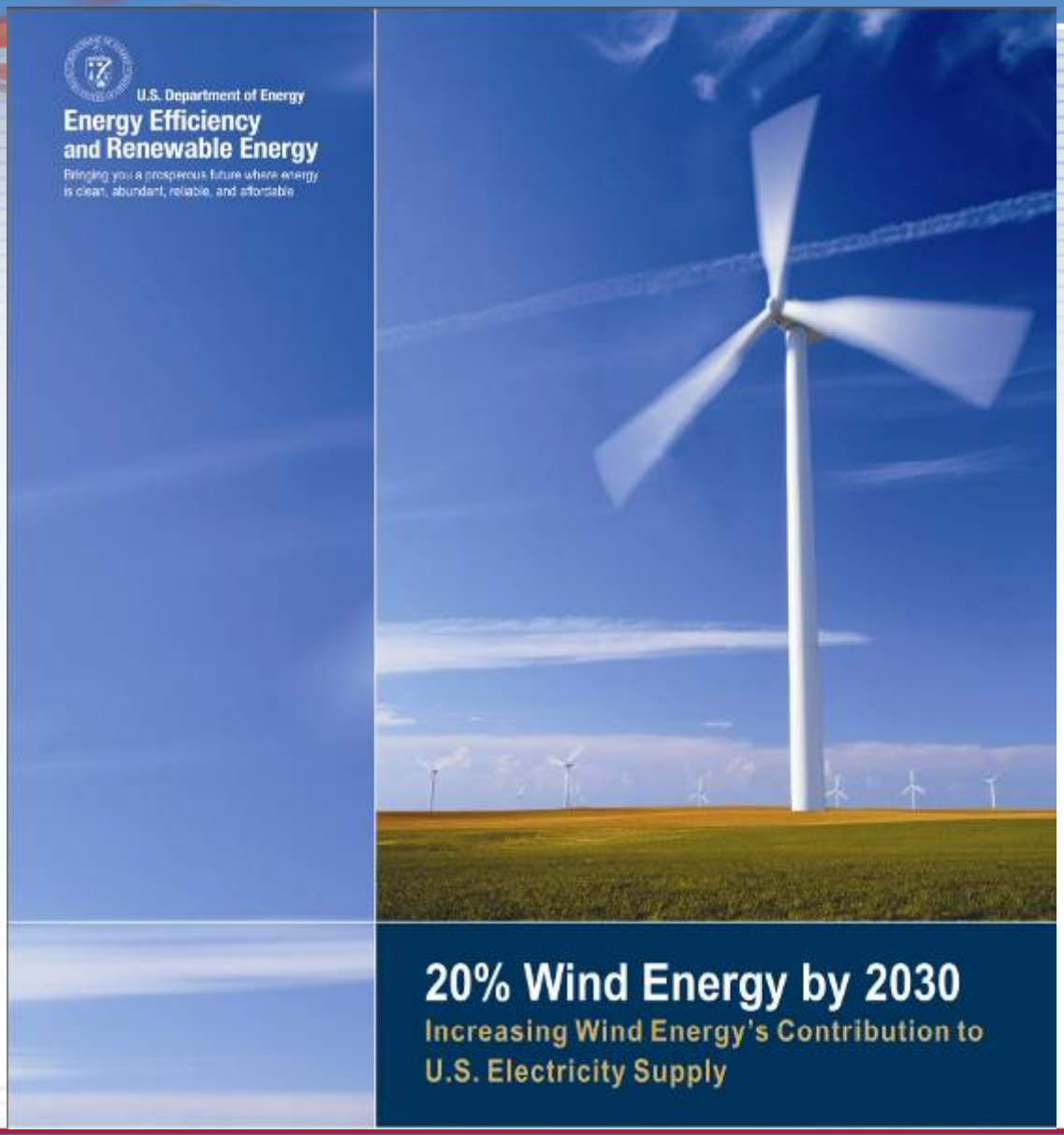
Acoustic Emission -Noise



Mod 1
Boone, NC

20% Wind Energy

U.S. DOE Report, May 2008



Addresses Scalability

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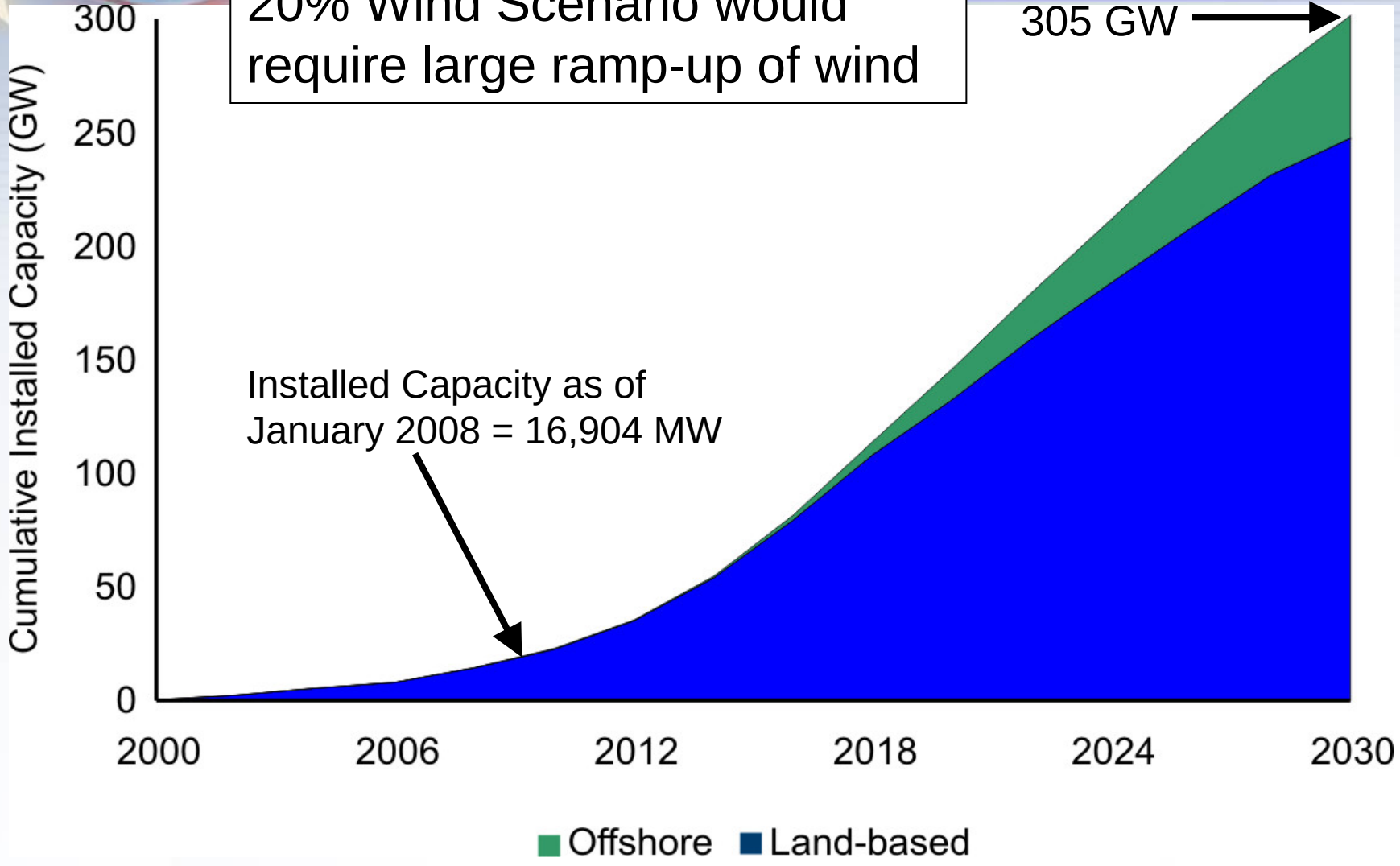
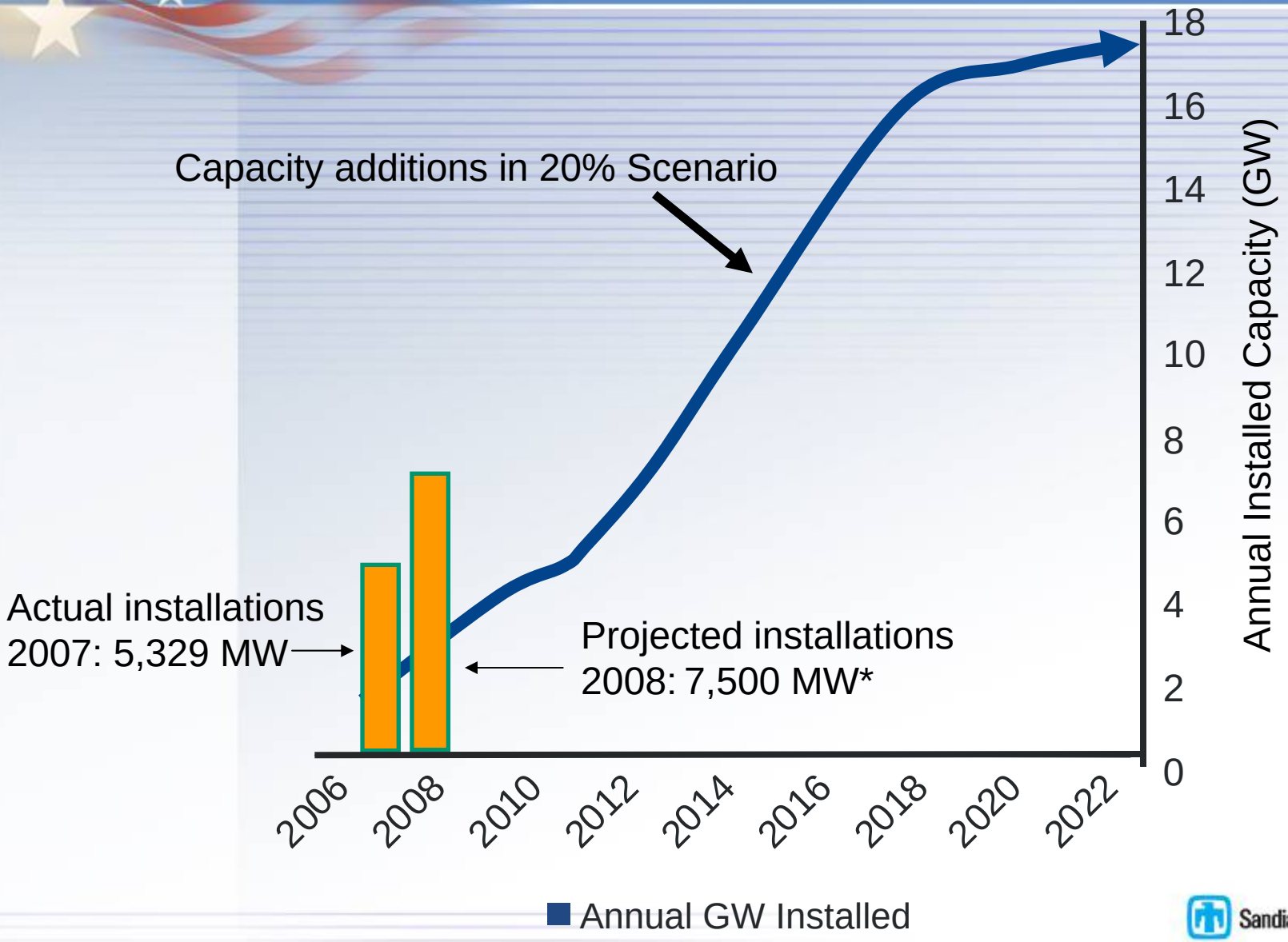
20% Wind Scenario

20% Wind Scenario would require large ramp-up of wind



Scenario Installed Capacity vs. Current Installed Capacity



Source*: AWEA, 2008

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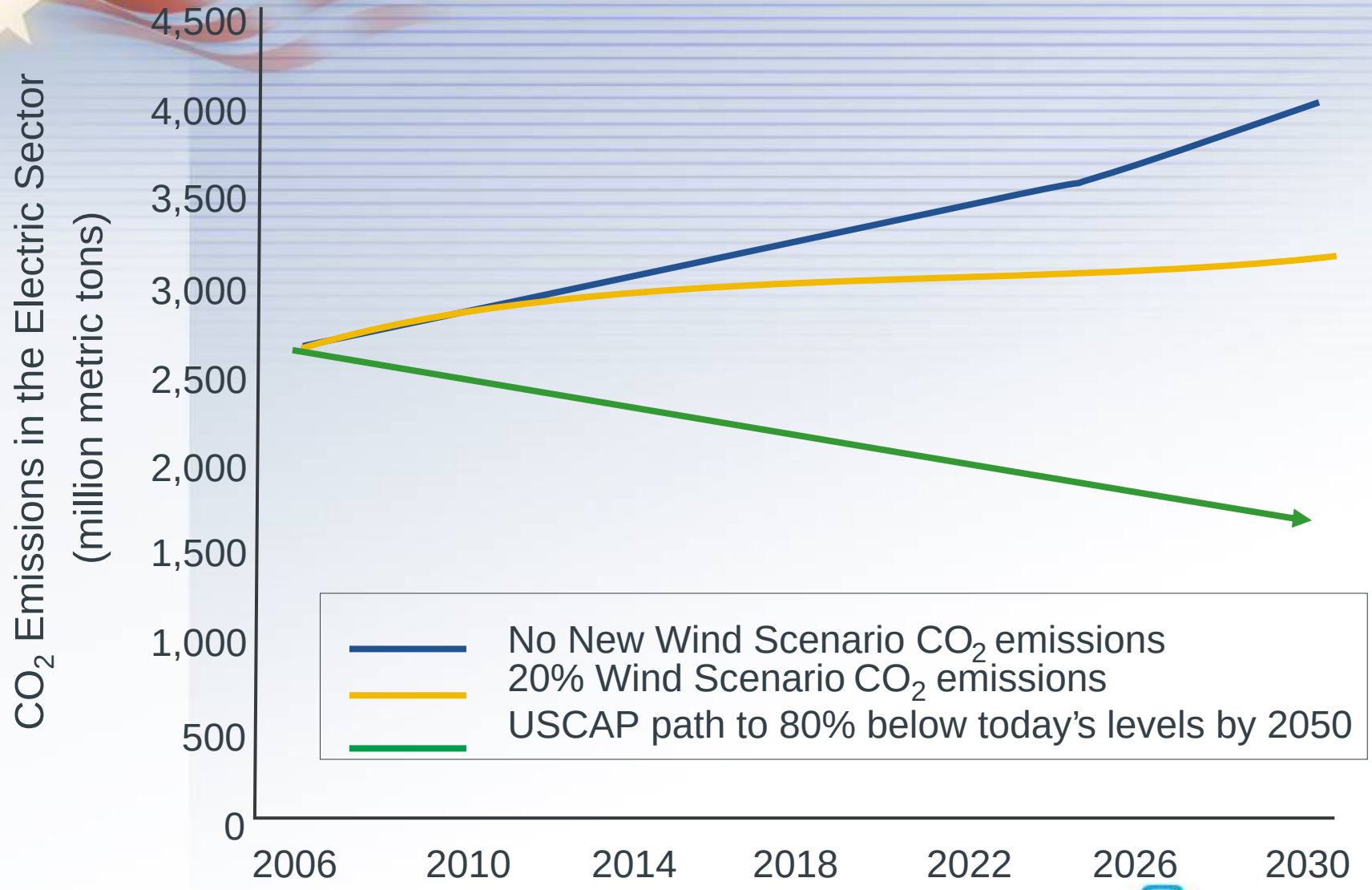
CO_2 Emissions from the Electricity Sector



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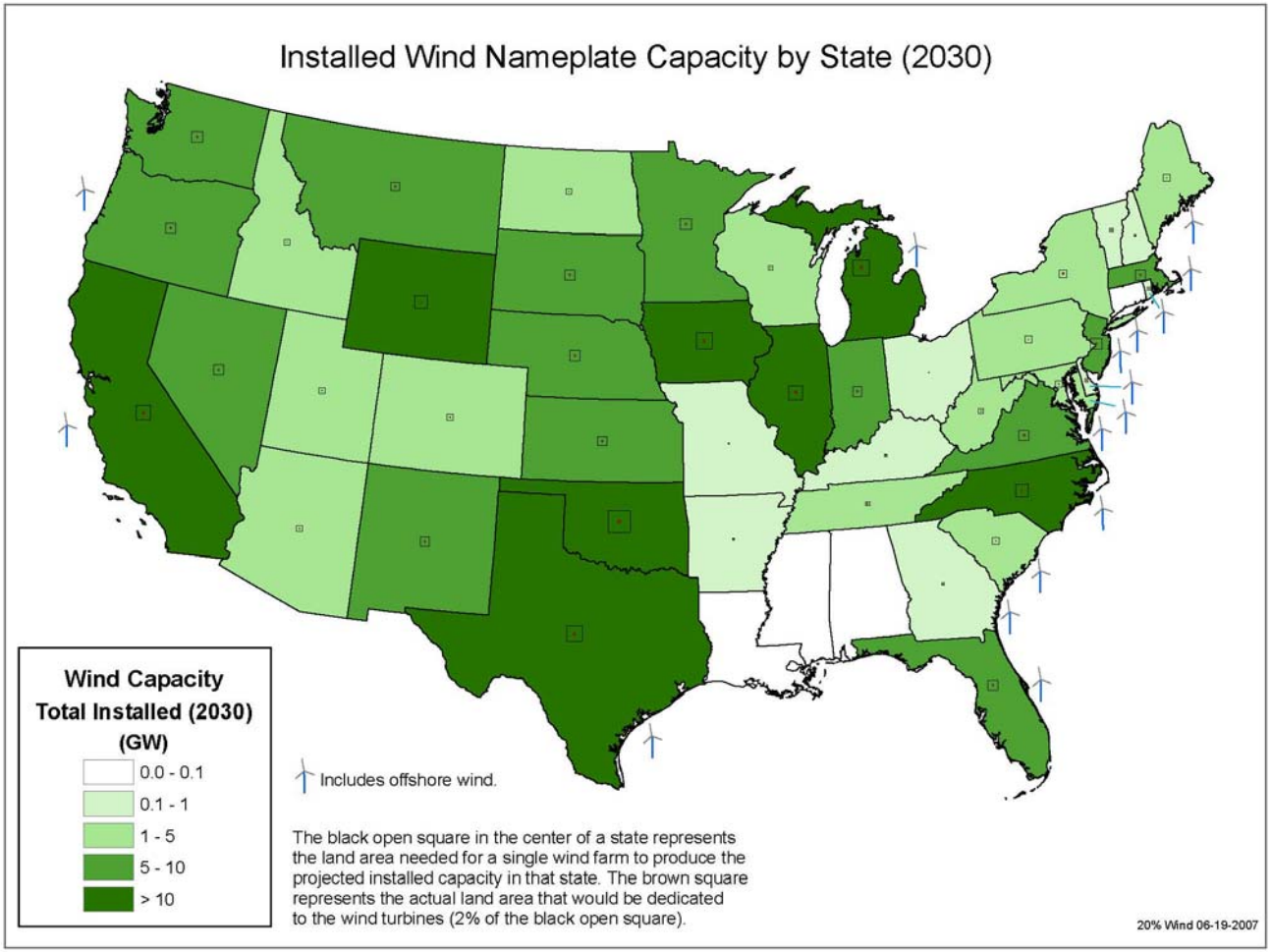
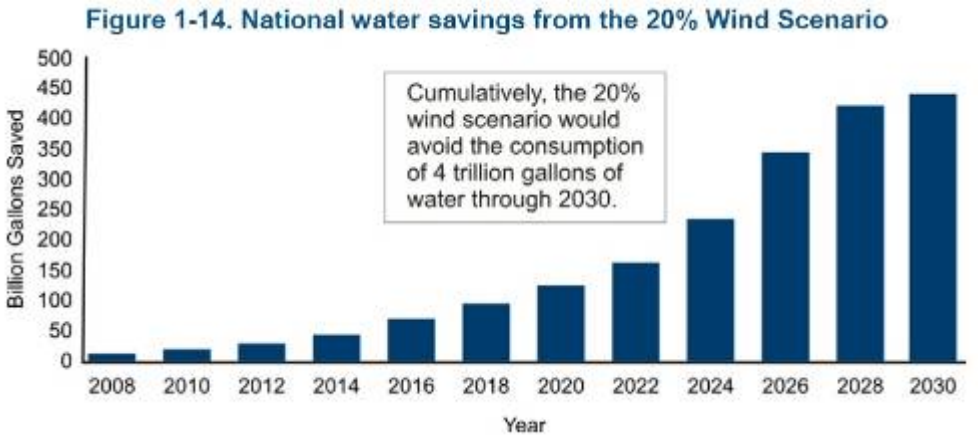
Challenges for Technology from the Analysis Results



- **Massive growth in installations**
  - **~12GW in 2006**
  - **over 300GW in 2030**
- **Widely distributed across the nation**
  - **Many high wind sites**
  - **Substantial installation in moderate resource areas**
  - **Some offshore is needed**
- **Performance is critical**
  - **Capital cost**
  - **Capacity Factor**
  - **O&M**

Benefits of Wind Power

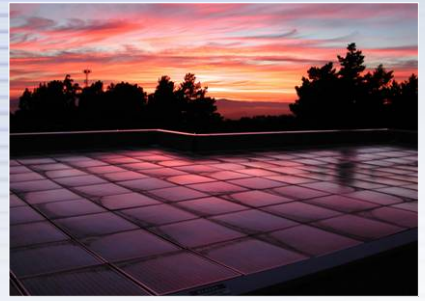
- **Economic Development**
  - Lease payments, tax revenue
- **Cost Stability**
- **Resource Diversity**
  - Domestic, inexhaustible, reduced risk
- **Environmental**
  - no CO_2, SO_2, NO_x, mercury
  - no mining or drilling
  - no waste
  - no water use



EIA: 20% Wind Energy by 2030

World-Wide Growth in Energy Demand Will Require all Available Energy Technology Options Integrated into a System




- A complete portfolio of supply options: renewables, fossil, nuclear
- Highly efficient and environmentally benign technologies
- Fault-tolerant, self-healing infrastructures
- Enhance physical and cyber security and safety

"…we could generate up to 20% of our electricity needs through wind…"

President George W. Bush - February 21, 2006

Thank You!!!

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