

Reliability and the Future of Wind Energy

*Reliability Workshop
U. S. Department of Energy
&
Sandia National Laboratories*

Jim Walker
Vice Chairman, enXco
Past President, American Wind Energy Association

**“It’s tough to make predictions, especially about the future”
Y. Berra, American Philosopher**



First, a word about my sponsor

Installed Capacity : 863 MW
Under Construction : 173.5 MW
Announced Developments : 450 MW
Total Project Development : 1929.5 MW



- | | | | | |
|----------------------------------|----------------------------|---------------|------------------------------------|------------|
| Owner/Developed/Financed/EPC/O&M | Owner/O&M | Developed/EPC | EPC/O&M | Other Role |
| Owner/Developed/EPC/O&M | Developed/Financed/EPC/O&M | Developed/O&M | O&M | |
| Owner/EPC/O&M | Developed/EPC/O&M | Developed | In-Development Under EDF-EN Canada | |

enXco Service Corporation

Largest third-party provider of
O&M services in North America

Over 5,200 turbines
representing more than 4,100
MW

Operations Control Center
provides 24/7 remote
monitoring

68 wind projects

300+ wind technicians



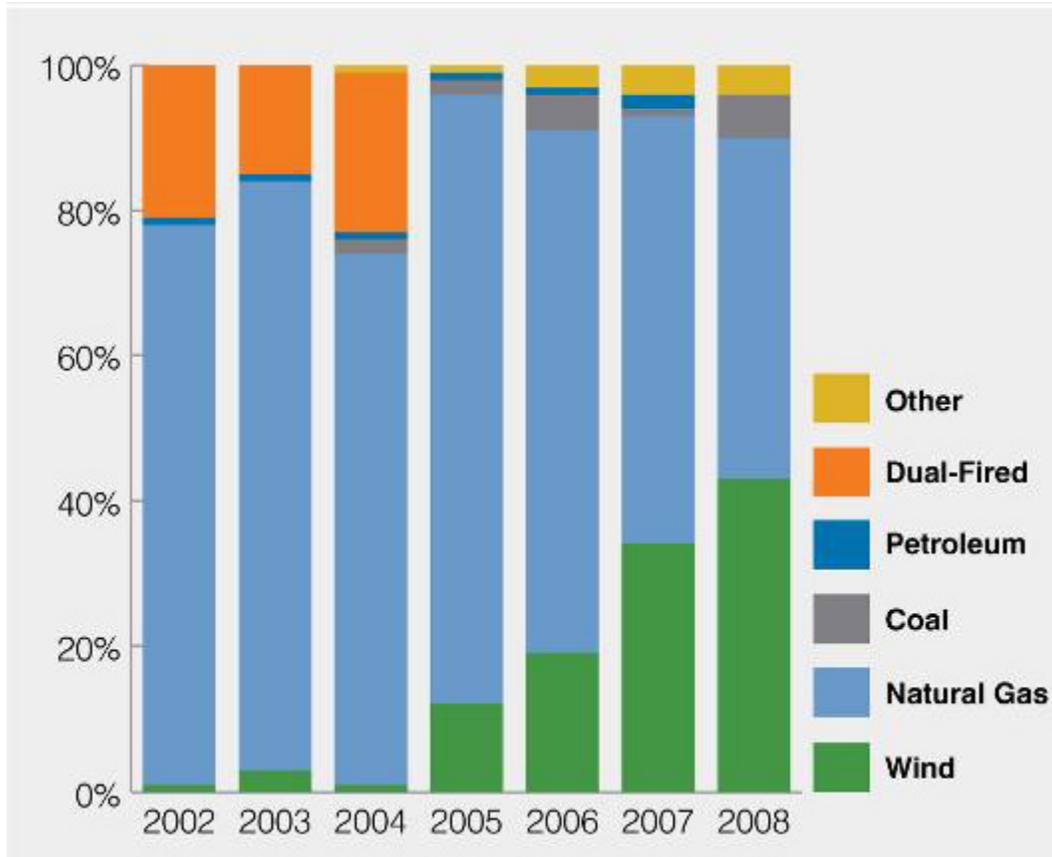


A Banner Year for Wind

- ▶ 9,500 MW installed in the US in the 12 month period from 1 April 2008 to 31 March 2009
- ▶ Investment in wind projects in US grew from \$700M in 2004 to **\$17B** in 2008 (\$48B worldwide)
- ▶ US surpassed Germany as the world leader in new installations, total wind capacity and annual output
- ▶ **35,000 jobs** were added in wind industry in 2008, raising total to 85,000, compared to 82,000 for the coal industry (EIA).



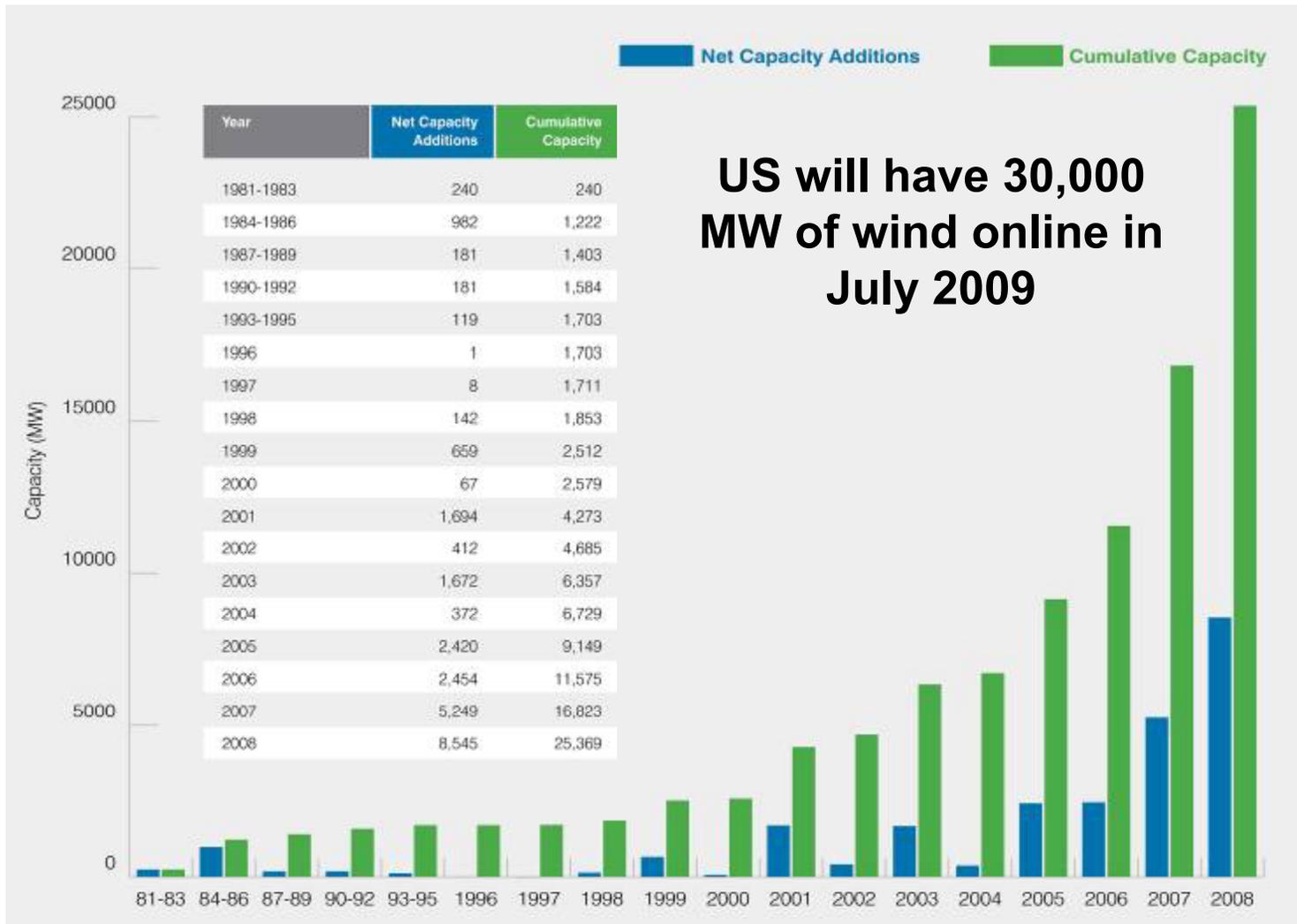
Percentage of Generation Added by Year



42% of all new generating facilities added in 2008 were wind power plants. Wind was second only to natural gas for the fourth year in a row.



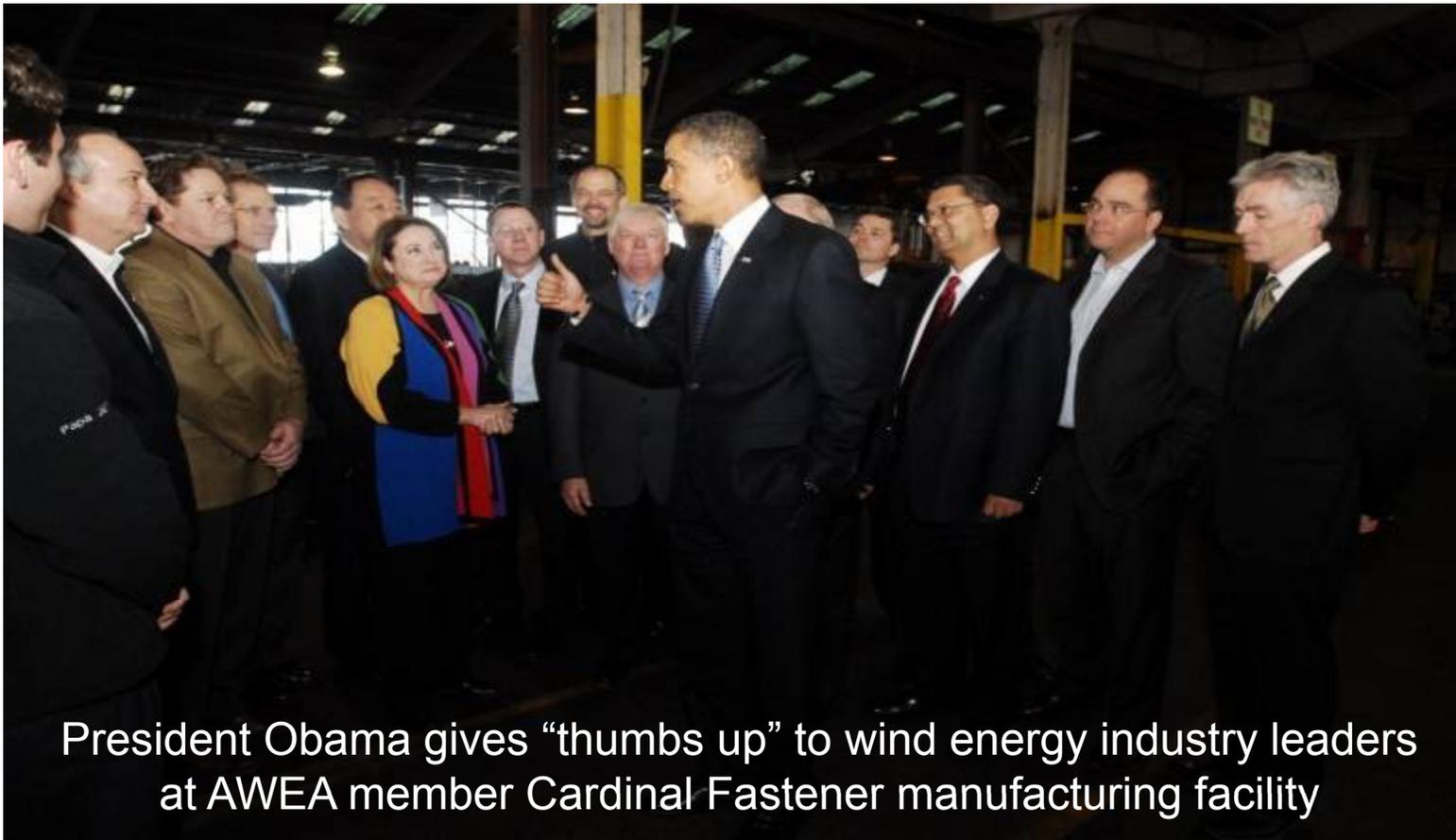
U.S. Wind Project Growth





President Obama has called for the U.S. to double its production of renewable energy in 3 years

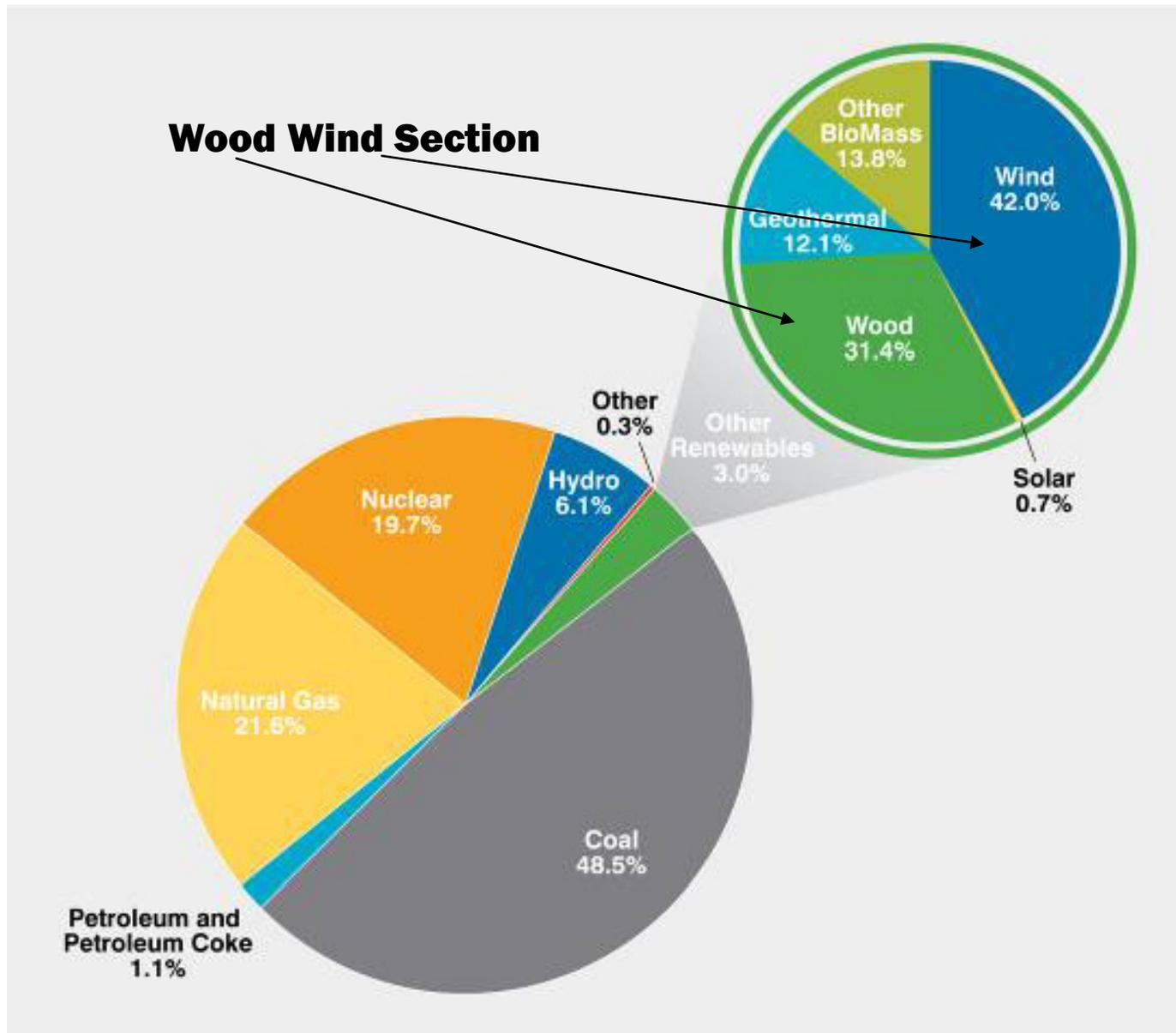
Strong Policy Support from Administration & Congress



President Obama gives “thumbs up” to wind energy industry leaders at AWEA member Cardinal Fastener manufacturing facility



Non-Hydro Renewables Still only 3% of U.S. Electricity Generation, but Growing Fast



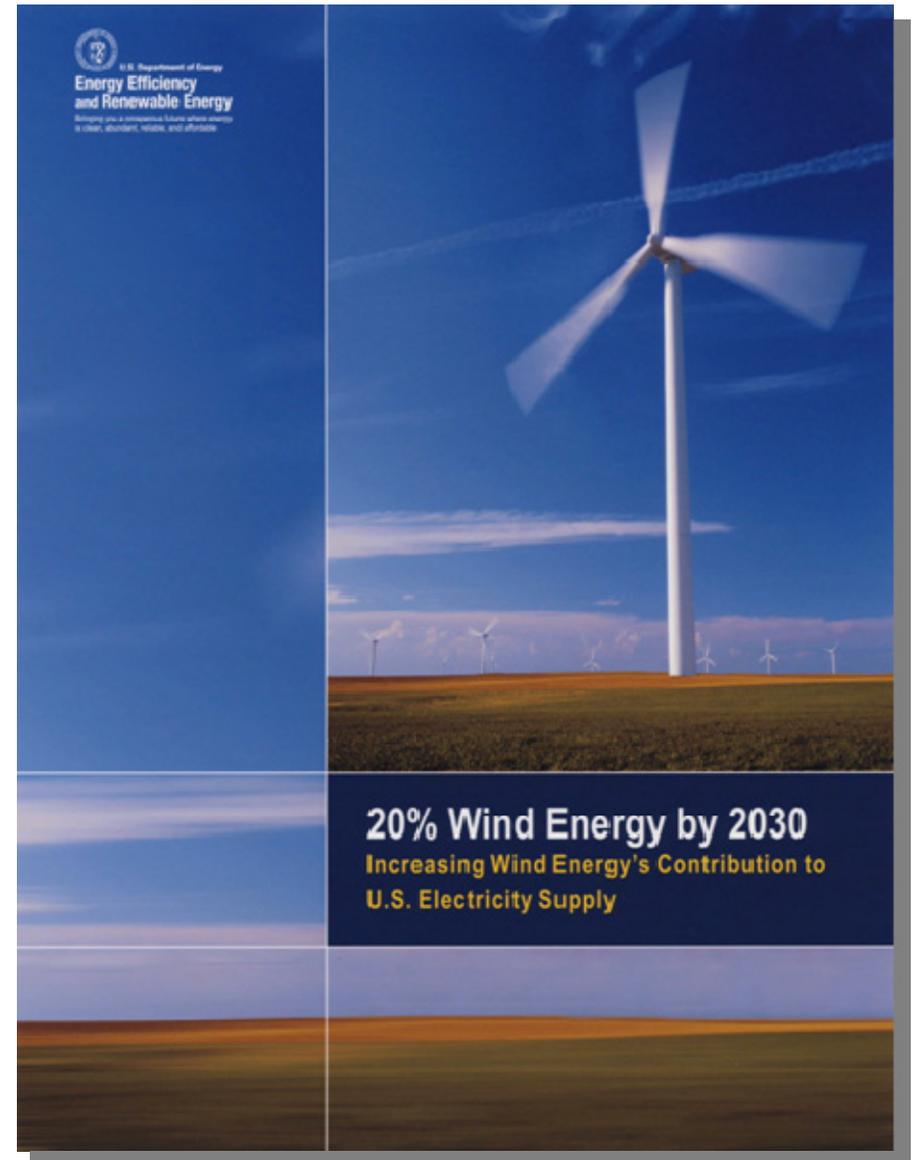


Biomass on the way to market near Lubumbashi, Democratic Republic of Congo

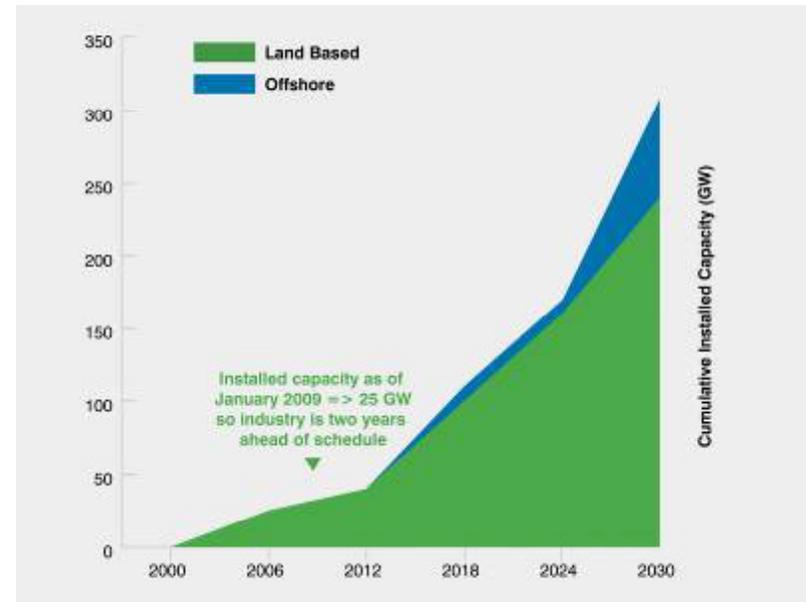
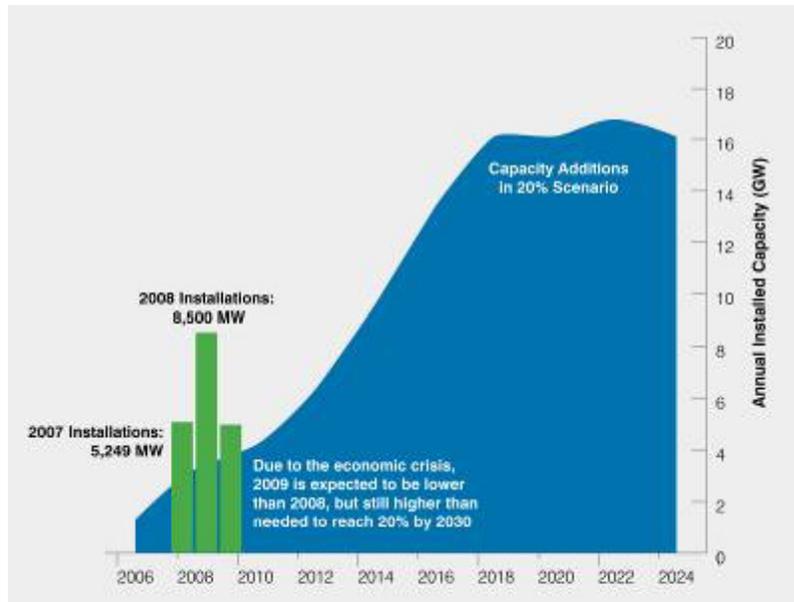
20% Wind Study - US DOE May 2008

- Showed it is technically feasible to get as much of our electricity from wind by 2030 as we now get from nuclear (20%)
- Showed this would have significant positive economic benefits
- Identified key challenges to achieving such a goal

www.20percentwind.org



20% by 2030 Report Card



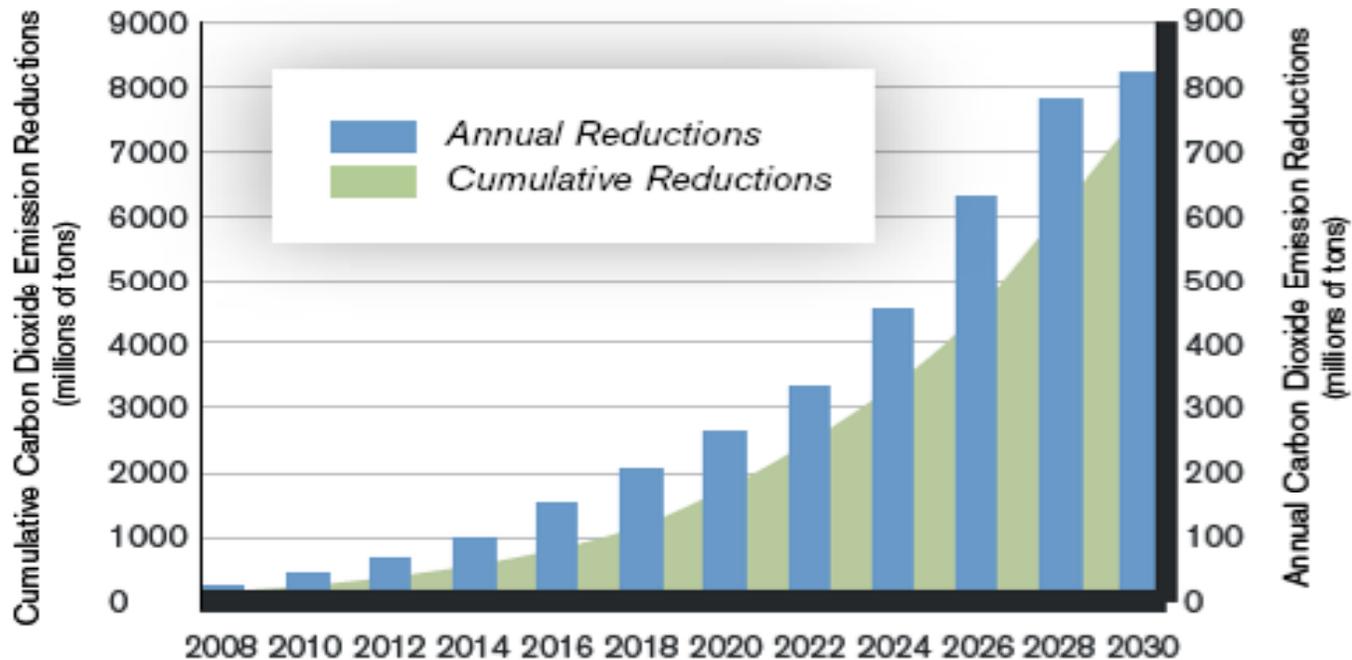
The U.S. installed more than twice the installations necessary in 2008 to get to 20% electricity generation by 2030. The cumulative capacity of 25.3 GW was not projected to be reached until late 2010.



Wind is a Powerful Climate Change Tool

1% fleet availability improvement = taking 1.4 M cars of the road in 2030

CO2 Emissions Reductions from 20% Wind Energy by 2030



Achieving the 20% wind vision would avoid the emissions of 7,600 million metric tons of carbon dioxide by 2030, equivalent to removing 140 million vehicles from the roads. Source: U.S. DOE, 20% Wind Energy by 2030 Report

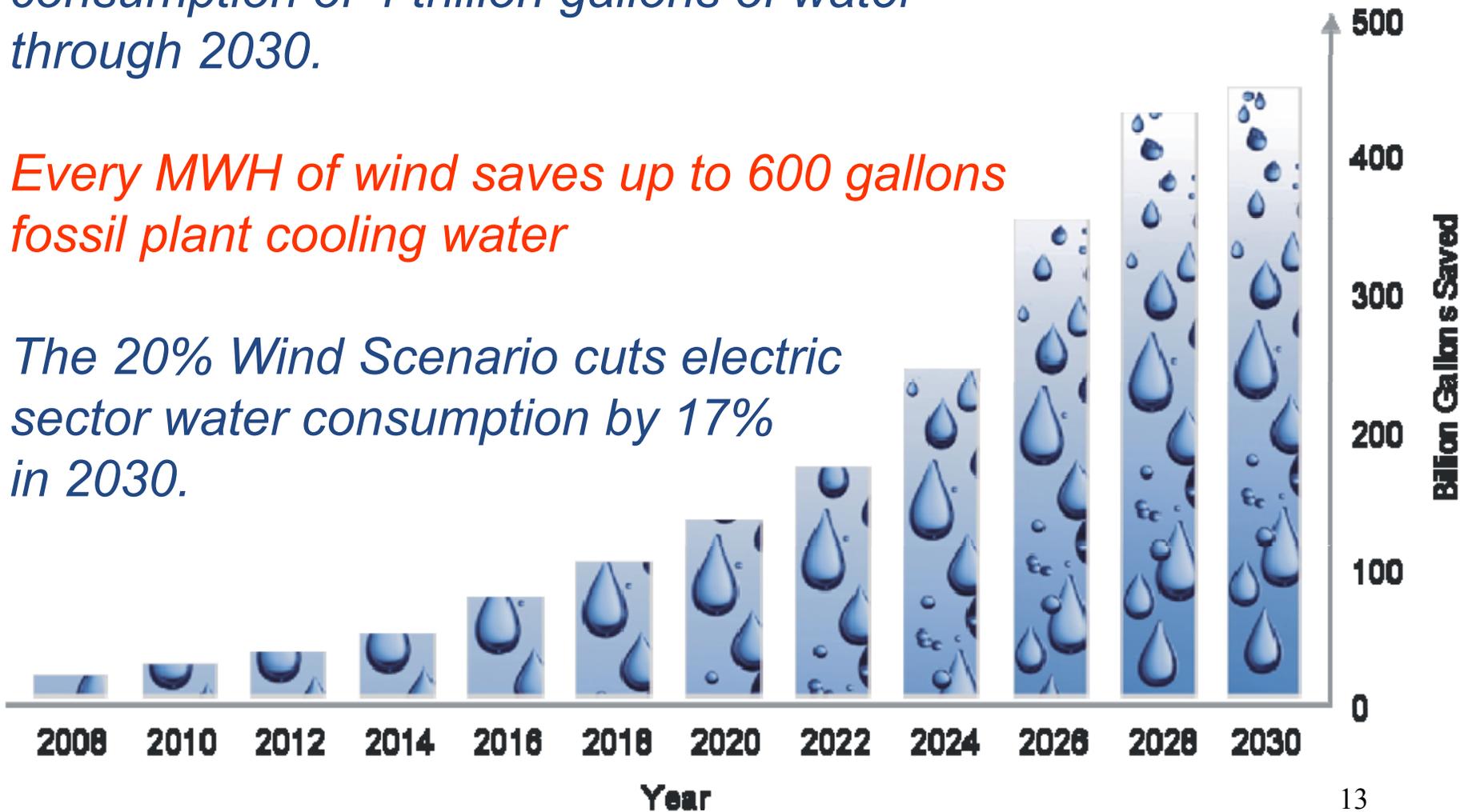


Significant Water Use Savings

Cumulatively, the 20% Wind Scenario would avoid the consumption of 4 trillion gallons of water through 2030.

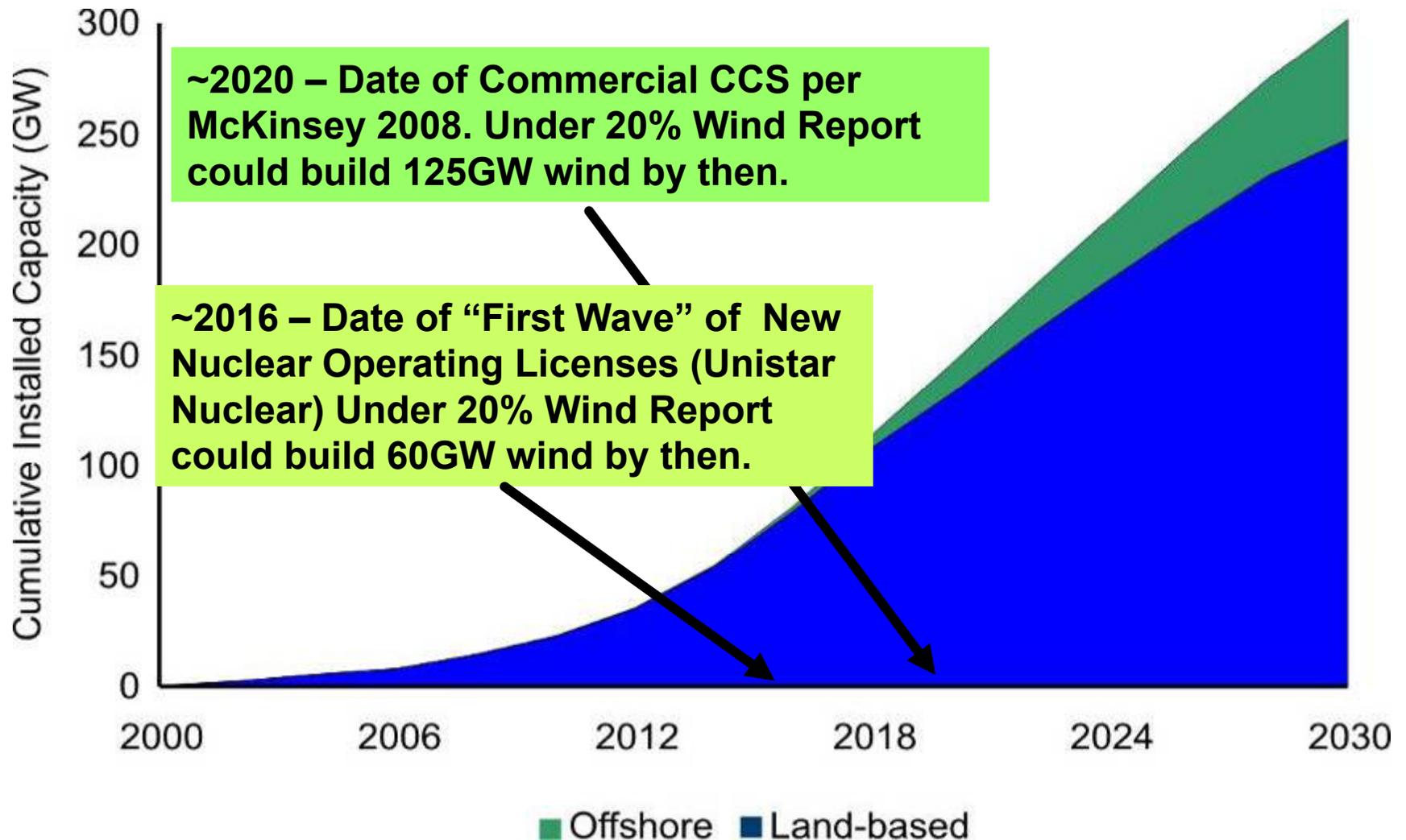
Every MWH of wind saves up to 600 gallons fossil plant cooling water

The 20% Wind Scenario cuts electric sector water consumption by 17% in 2030.





Wind is Scalable Now





But Operating Jobs are Forever



Over 500,000 total jobs would be supported by the wind industry

Approx. 180,000 jobs supported directly by the wind industry in operations, construction, and manufacturing



The Many Facets of Reliability

- ▶ Can we rely on wind energy as a major weapon against the climate crisis?
- ▶ Can we rely on wind to be 10-20-30%+ of our electric generation portfolio and by when?
 - What would government and the private sector have to do to rely on your (or any) projection?
 - At what cost?
- ▶ Will high wind penetrations decrease grid reliability and utilities' ability to meet their "obligation to serve"?
- ▶ Can banks and investors rely on pro formas that show 95%+ availability and Certificates for 20 year design lives?
- ▶ What do field operators say about component and turbine system reliability?



Some Concerns

- ▶ Recent publicized failures:
 - Suzlon 1,200+ blade replacements
 - Clipper \$325M charge related to blade issues
 - Gearbox life times falling short of certified design lives
 - Heavy impact on market valuations, cost of capital
- ▶ We are at the “bottom of the hill” of the 20% wind scenario – if we succeed, we will have an operating fleet of over 100,000 turbines in the 2020s.
 - If wind turbines get the reputation of unreliability, will hurt the brand as well as the operating results
 - Opponents of wind jump on any news item to link wind’s inherent variability to “unsafe,” “unreliable,” “costly,” “not ready for prime time.”
- ▶ ITC vs PTC – Was urgently needed to restart the industry, but will we avoid the perverse incentives of the 1980s?
- ▶ New market entrants – managing quality control
 - Do we have the needed standards in place?



Some Other Observations

- ✦ It is difficult if not impossible to test large wind turbines or components under actual operating conditions.
 - Suspicion that factors affecting fatigue life not being captured
- ✦ Critical design errors still being made
- ✦ Critical full scale test facilities not available in US
- ✦ Manufacturers providing less and less warranty protection
- ✦ After market supply chain still developing and adversely impacted by economic crisis.
- ✦ Wind turbine failures seldom result in major safety incidents, publicized environmental impacts
 - Ironically, this lets manufacturers “get away” with selling units which may not last 20 years
 - If a wind turbine falls in a wind farm and there is no reporter there to report it, did it really fail?
- ✦ During “sellers market,” developers had little leverage, now manufacturers claim they have little money and too much competition.



There's "Trouble in Windy City"

People

Oh, we got trouble

Right here in Windy City

With a capital "T"

That rhymes with "P"

Which comes before "Q"

And that stands for Quality

We're in terrible, terrible trouble

Apologies to Meredith Willson and "The Music Man"

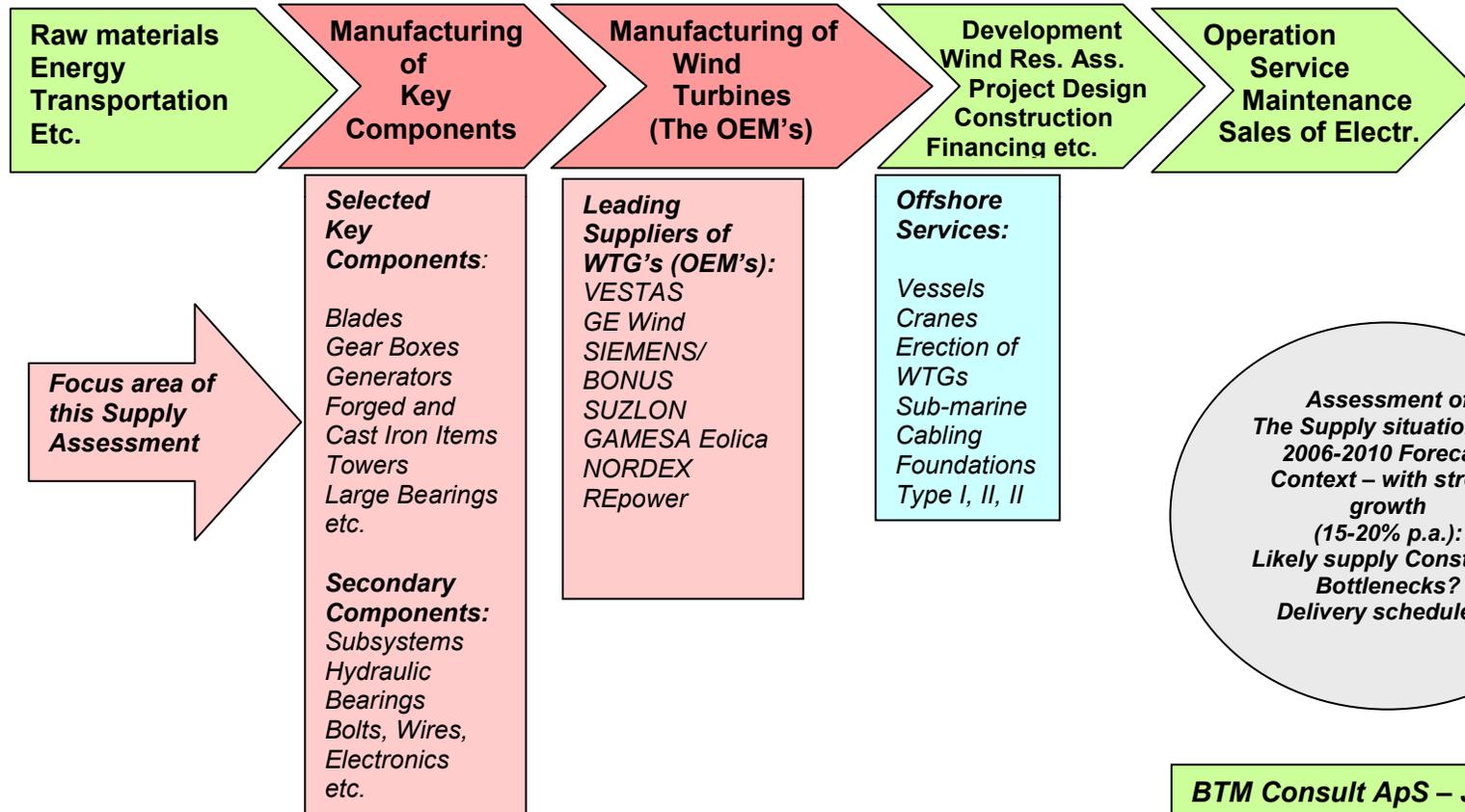


The Trouble Goes All the Way Through the Value Chain

The Supply Chain in the Wind Power Industry:

2006 through 2010 - Onshore & Offshore Wind Farm Projects

Area of the Supply Assessment (Onshore & Offshore)





What Part of Any of These Don't You Understand?

- ▶ The Customer is always right
- ▶ Quality is Job 1
- ▶ Safety First
- ▶ The Quality Goes in Before the Label Goes On

THE EINSTEIN FIELD EQUATION *

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

***Engineers get extra credit**



The First Gearbox Failure in History

A LUMP OF BRONZE FOUND IN A SHIPWRECK IN 1900 TURNS OUT TO BE THE WORLDS FIRST ASTRONOMICAL COMPUTER

Antikythera mechanism

From Wikipedia, the free encyclopedia

The **Antikythera mechanism** (Greek: Ο μηχανισμός των Αντικυθήρων, *O mēchanismós tōn Antikythērōn*) is believed to be an ancient mechanical calculator (also described as a "mechanical computer"^[1]) designed to calculate astronomical positions. It was discovered in the Antikythera wreck off the Greek island of Antikythera, between Kythera and Crete, and has been dated to about 150-100 BC. It is especially notable for being a technological artifact with no known predecessor or successor; other machines using technology of such complexity would not appear until the 18th century.

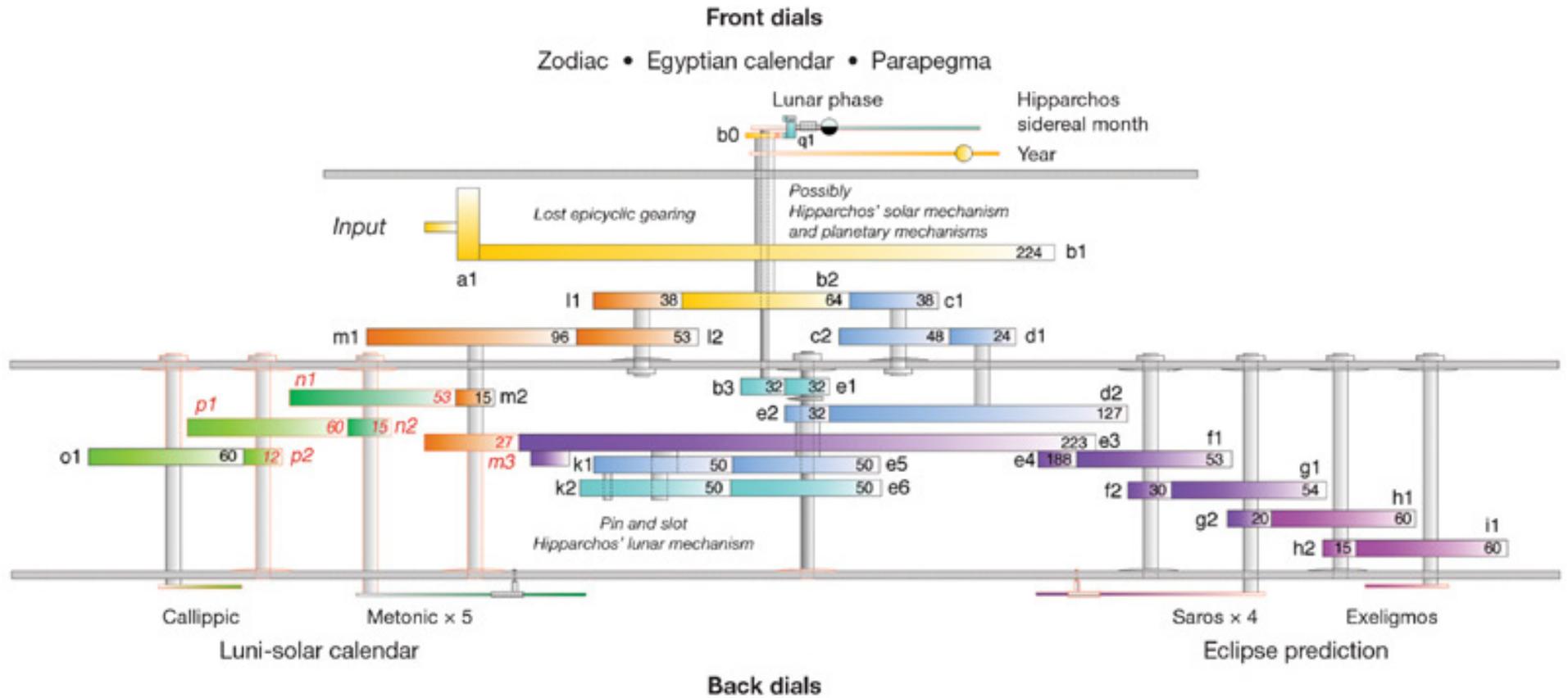


The Antikythera mechanism (main fragment).

Those who do not learn from history are condemned to repeat it



Gear Layout – 2006 Reconstruction by HP



Working Model Based on Nature Articles



John Gleave, Maker of Orreries





Features and Faults

- ✦ Manufactured circa 180 BC
- ✦ Able to predict lunar and solar eclipses +/- 1,500 years by turning crank
- ✦ Tracking of Olympic and other Games cycles
- ✦ Full digital simulation of orbits of earth around sun, moon around earth, passage of moon through ecliptic, non-circular orbit of moon with precession
- ✦ Tracking of phases of the moon
- ✦ Technology unsurpassed until AD 1400
- ✦ Portable
- ✦ Inadequate lubrication system
- ✦ Not designed for high stochastic torques (Roman grandchildren fiddling)
- ✦ Inadequate gear tooth design (triangular)
- ✦ Sole source supplier (probably school of Archimedes)
- ✦ No local service department
- ✦ Repair times circa 4 months
- ✦ No realistic fatigue testing
- ✦ Limited warranty
- ✦ Inadequate shipping container
- ✦ No Goth/Lloyd certificate

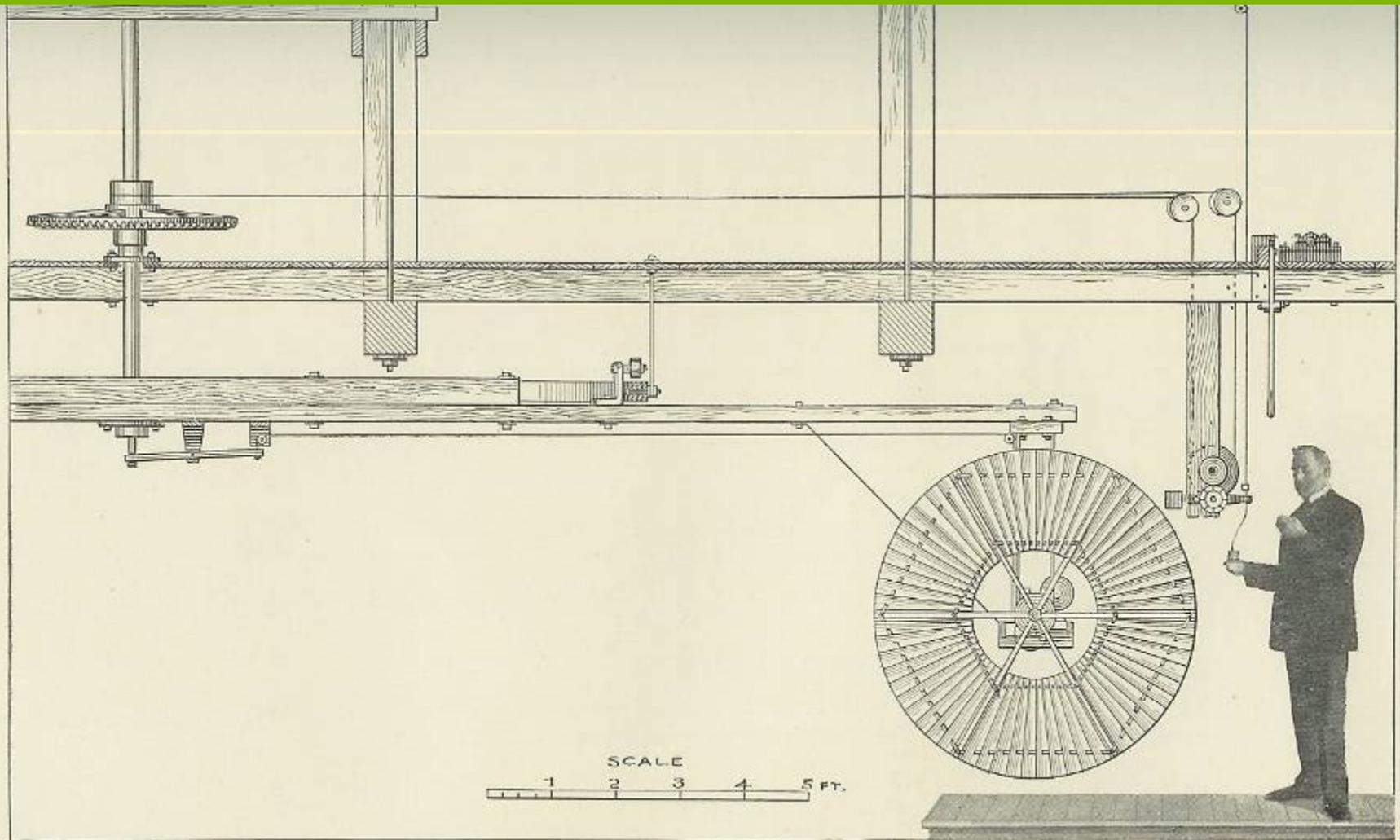


Relevance to “Modern” Times

- ✦ Gearboxes routinely failing far short of “Certified” design life.
- ✦ Root causes still uncertain
- ✦ Financial community likely to require Banking Base Cases to assume all gearboxes will be replaced on or about year 10.
- ✦ In some recent projects, 1/3 failure by year 5 expected
- ✦ Independent Engineers already requiring Major Component Repair operating cost item comparable to scheduled maintenance
- ✦ Developers who do not take this into account run risk of financing “surprises” and operating budget shortfalls
- ✦ What are we all missing?



Use Test Facilities to Gain Technology Lead



ELEVATION OF APPARATUS USED IN WHEEL TESTS.



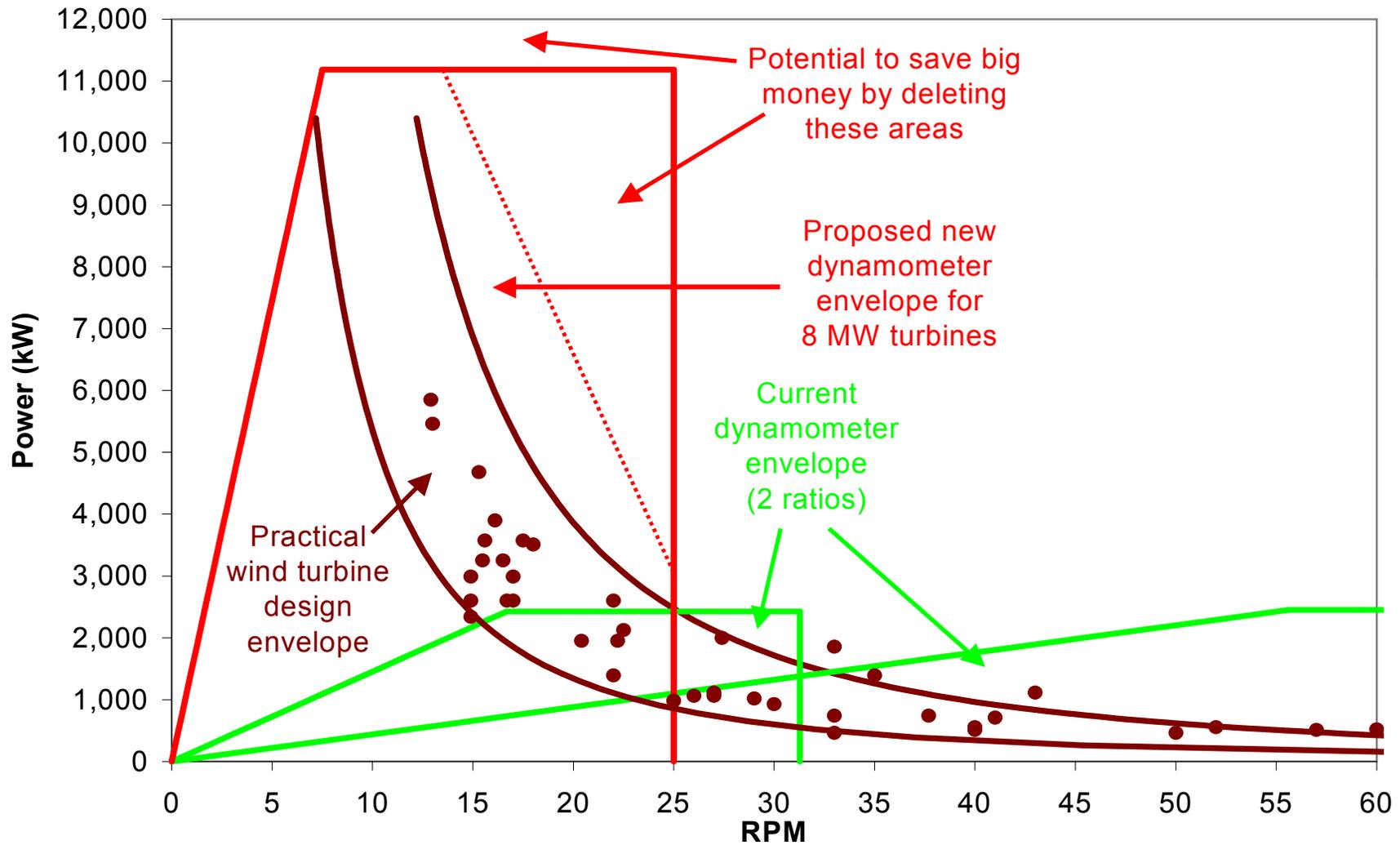
Systematic Experimentation Pays Off

- ✦ Thomas Osborn Perry was born in Franklin, Michigan on February 28, 1847. In 1882 and 1883, while working for the U.S. Wind Engine and Pump Company, Perry conducted a series of over five thousand experiments on windmill rotors and rotor blades. His experiments resulted in a windmill design that was 87% more efficient than other windmills manufactured at that time. Perry's main improvements were the use of concave windmill blades made from steel, rather than flat wooden blades. In order to conduct his experiments, Perry had designed and built an enclosed wind tunnel, a research tool that was not in common use at this time.
- ✦ In 1888, Thomas Perry and LaVerne Noyes started the Aermotor Windmill Company and began manufacturing Aermotor windmills. The Aermotor was used for pumping water for livestock and became indispensable to midwestern farmers and ranchers in the 19th and early 20th centuries. Selling only 45 windmills in its first year, Aermotor sales increased rapidly and by the turn of the century had sold hundreds of thousands of windmills.



AWEA R&D Committee Calling for 15-20 MW Dynamometer (bigger than below)

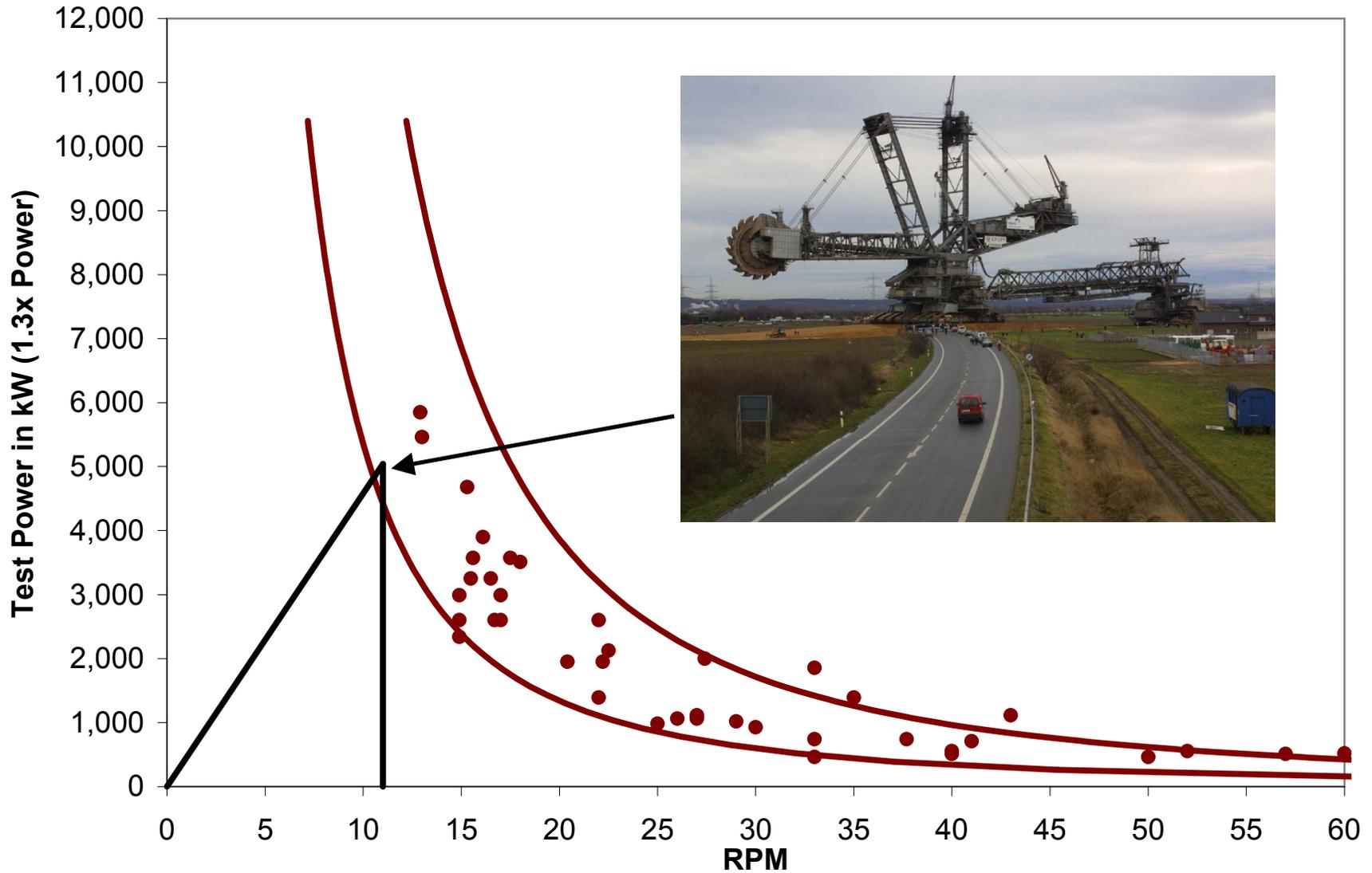
Proposed new large dynamometer



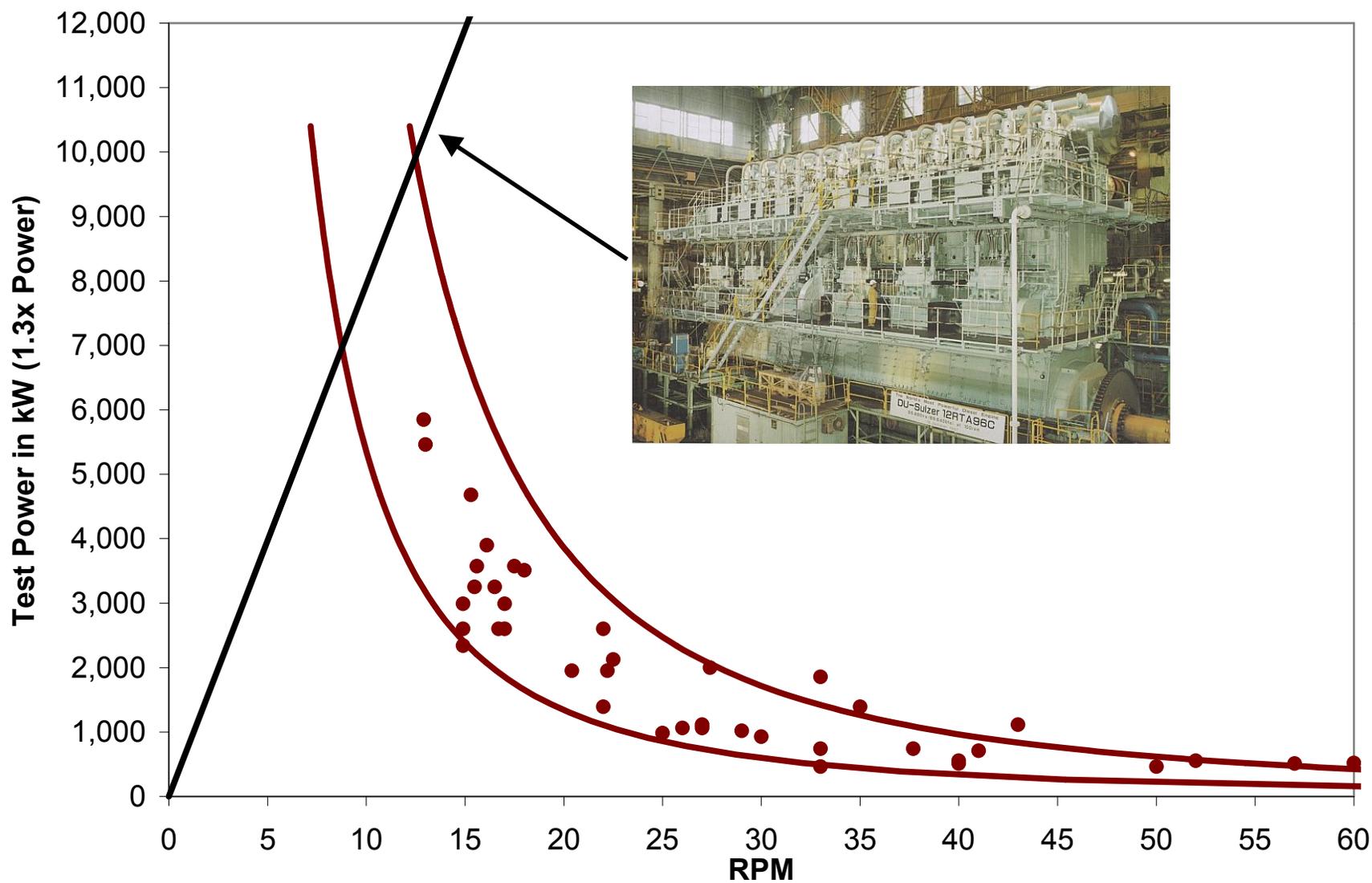


The Stresses on Wind Turbines are Extreme

World's largest excavator



World's largest Diesel engine



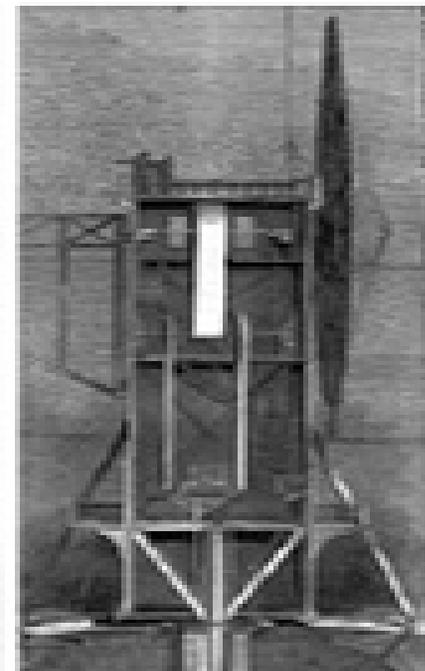
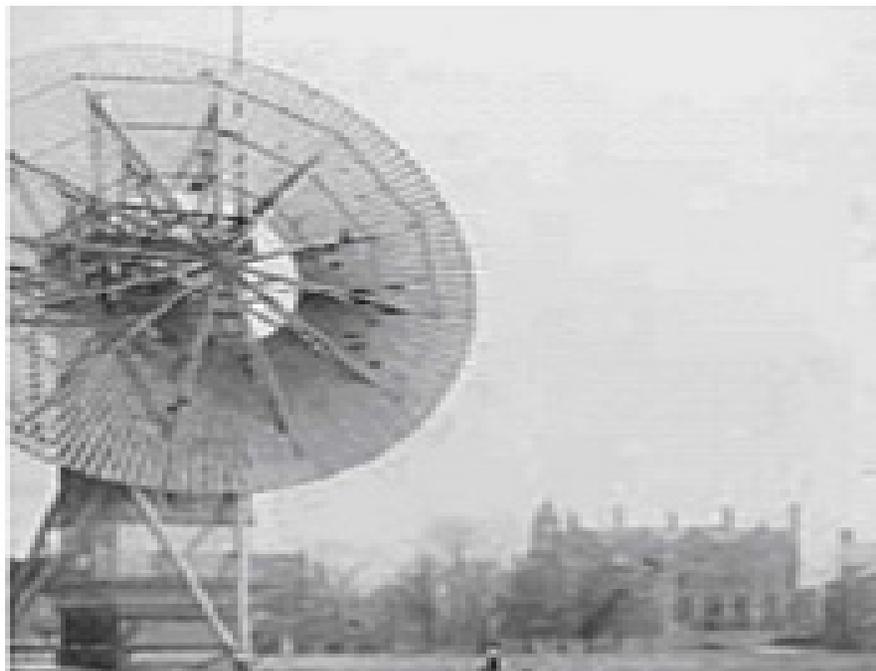


Don't Give Up Too Early

- ▶ GE's First Wind Turbine Generator – The Brush Turbine 1888-1908

BRUSH WINDMILL AT CLEVELAND, OHIO

In 1887 Charles F. Brush (1849-1929) built the first operational wind machine for electricity generation. Brush is one of the pioneers of the American electrical industry. He invented an efficient Direct Current (DC) dynamo used in the public electrical grid, the first commercial electrical arc light, and an efficient method for manufacturing lead acid batteries. He founded the Brush Electric Company in Cleveland, Ohio. It was sold in 1889, and in 1892 was merged with Edison General Electric Company under the name of the current General Electric Company (GE).

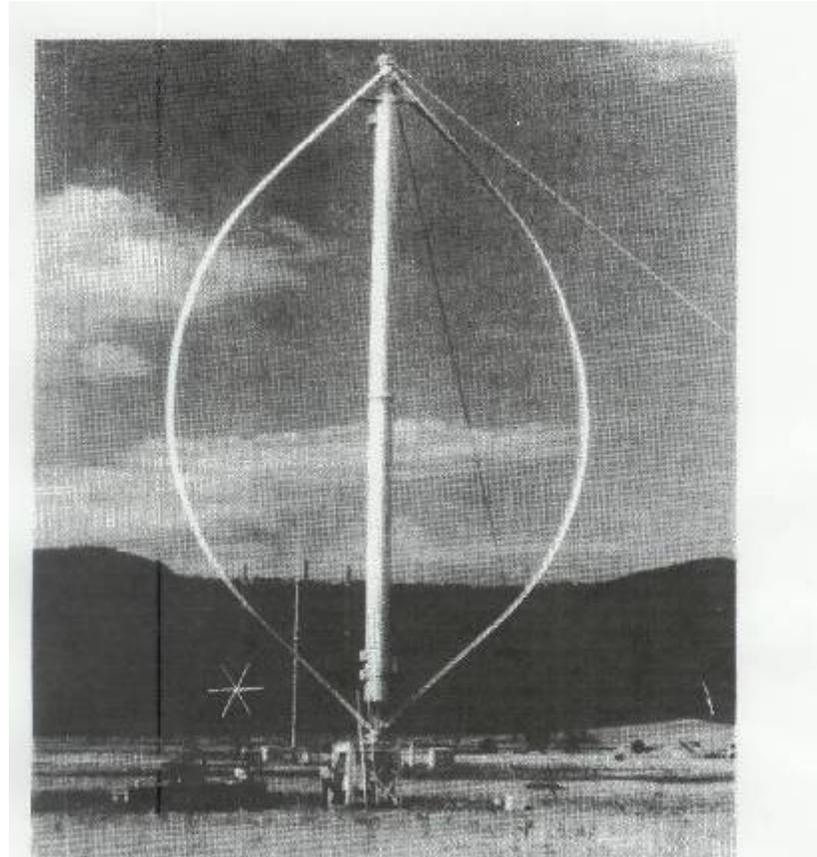


Resist Hubris – This Stuff is not Easy

California Energy Commission 1981 Wind Conference, Palm Springs CA



Bendix 3 MW tripod mounted hydraulic transmission – They went back to washing machines

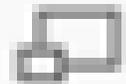


Alcoa 17m Vertical axis, twin of the one which “catastrophically disassembled itself” on the conference eve

Don't Waste Time In Denial



The first LS 400 flagship sedan debuted in 1989, introducing Lexus to the world.





The Lexus Recall – Had One Lately?

- ✦ In December 1989, Lexus initiated a voluntary recall of all 8,000 LS 400s sold to date, based upon two customer complaints over defective wiring and an overheated brake light. In a sweeping operation which replaced the affected parts on all vehicles over a period of 20 days, Lexus sent technicians to pick up, repair, and return cars to customers free of charge, and also flew in personnel and rented garage space for owners in remote locations. This response was lauded in media publications and helped establish the marque's early reputation for customer service. In 1990, during its first full year of sales, Lexus sold 63,594 LS 400 and ES 250 sedans in the U.S., the vast majority being the LS model. By 1991, sales had increased to 71,206 cars in the U.S. market, making Lexus the country's top-selling luxury import. That same year, Lexus received first place in J.D. Power's studies on initial vehicle quality, customer satisfaction, and sales satisfaction.

Wikipedia



Face Up to Worst Case Scenarios

1. Caliber of the Advocates



Plainly, mankind cannot renounce nuclear power, so we must find technical means to guarantee its absolute safety and exclude the possibility of another Chernobyl. The solution I favor would be to build reactors underground, deep enough so that even a worst case accident would not discharge radioactive substances into the atmosphere.”

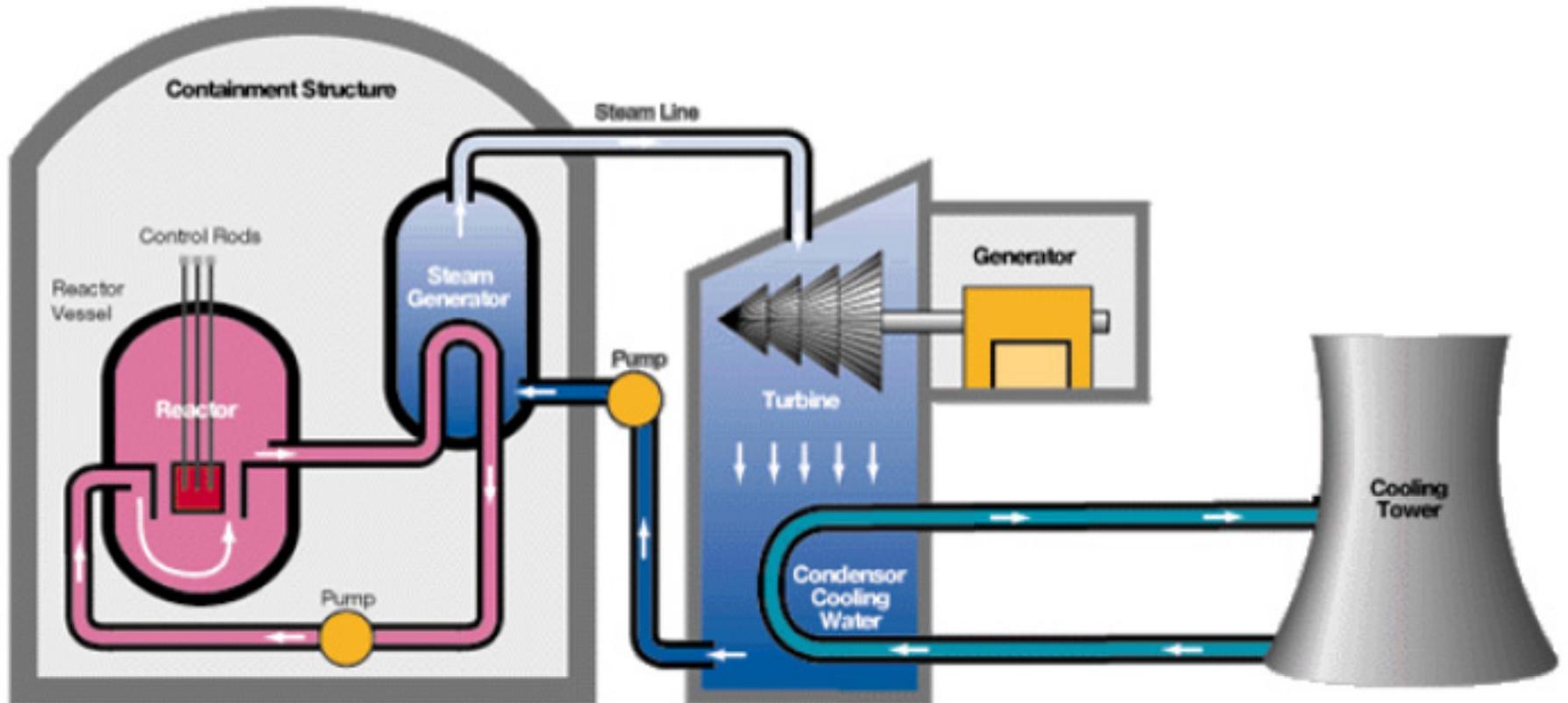
Andrei Sakharov, *Memoirs*, p. 612

“My suggestion in regard to [the containment of nuclear material in case of an accident] is to place nuclear reactors 300 to 1000 feet underground...” I think the public misapprehension of risk can be corrected only by such a clear-cut measure as underground siting.

Edward Teller, *Memoirs*, p. 565



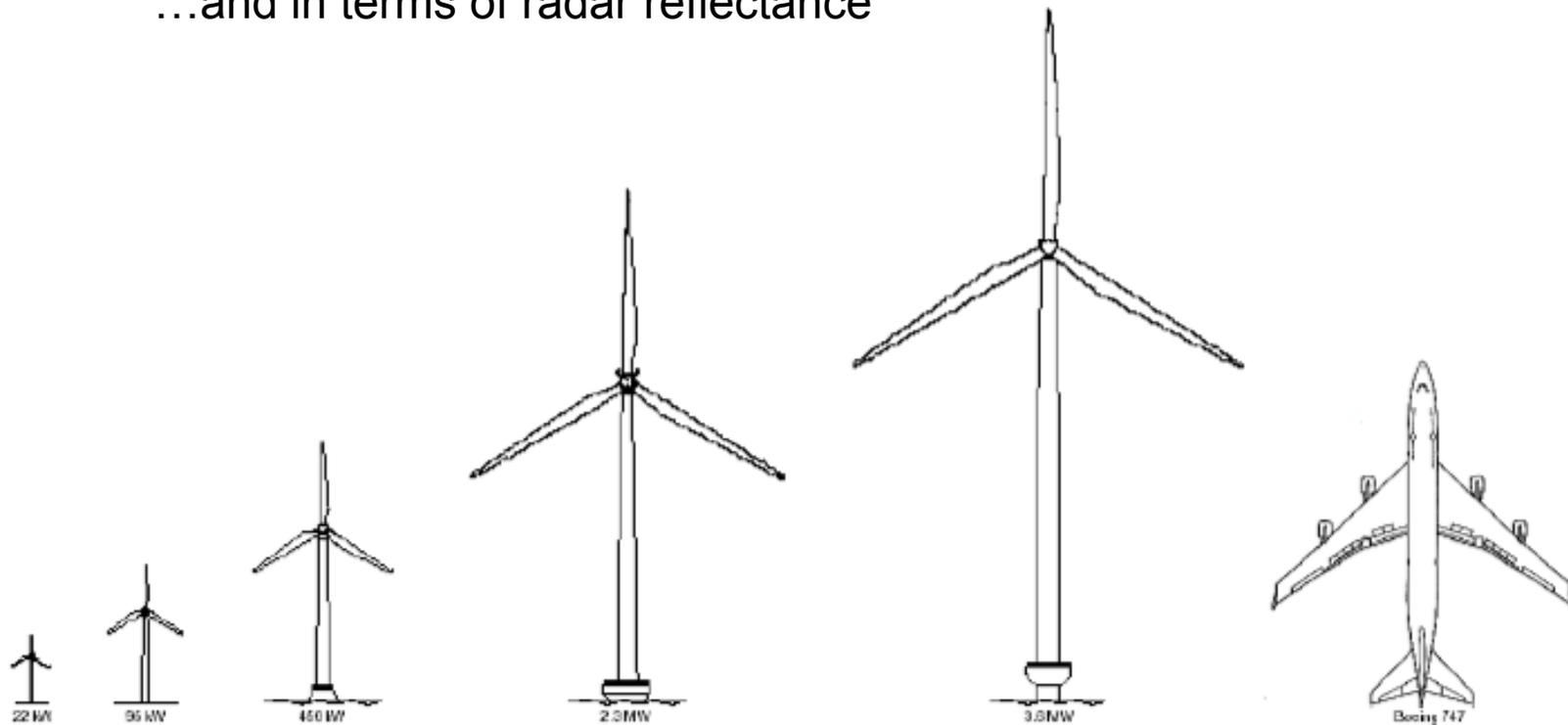
TMI Accident Sequence Used in 1978 CEC Study



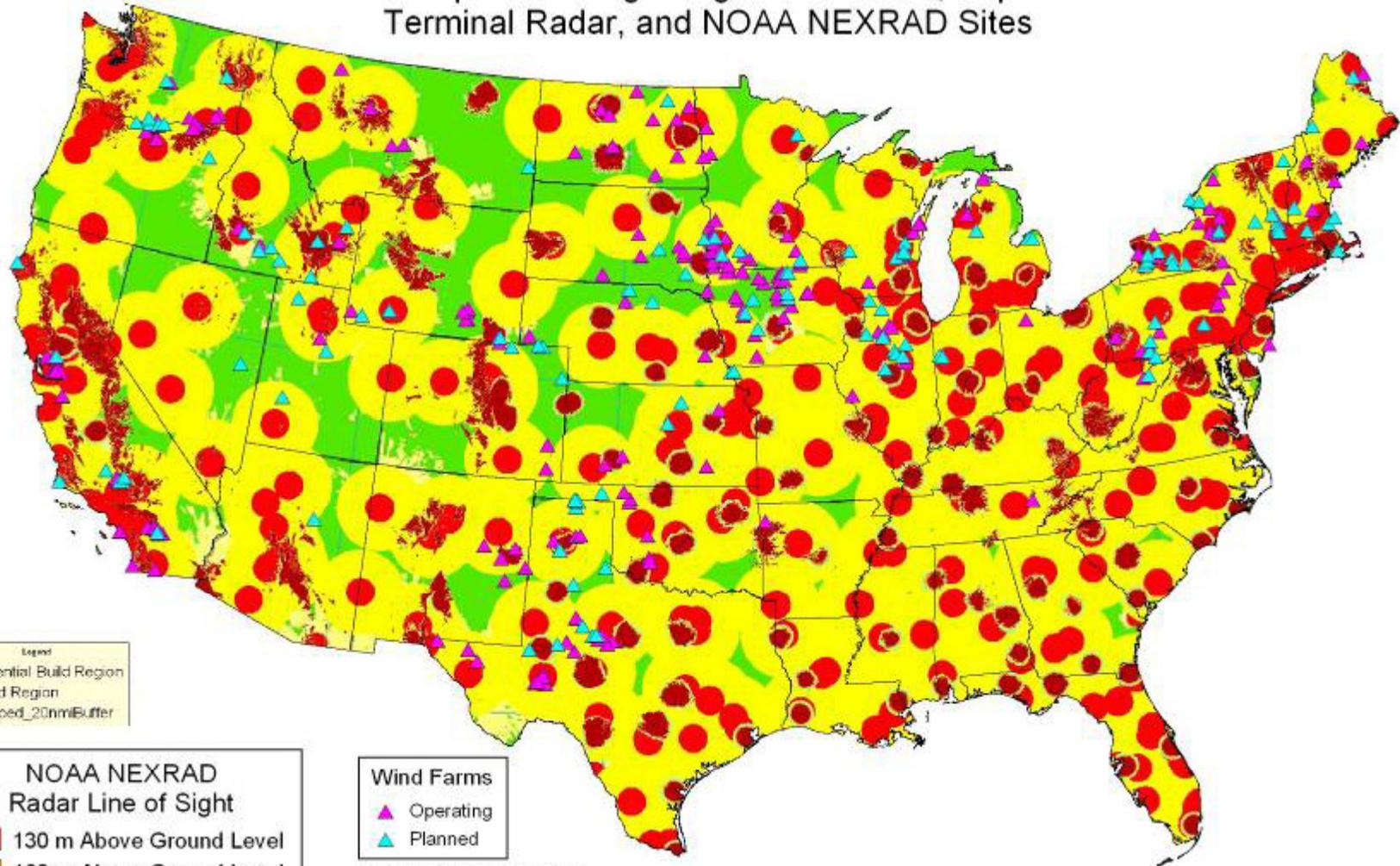
Wind turbines and aircraft are in same range regarding dimensions...

SIEMENS

...and in terms of radar reflectance



Potential Impact of Long Range Radar Sites, Airports with Terminal Radar, and NOAA NEXRAD Sites



Legend
 Potential Build Region
 Build Region
 Clipped_20nmBuffer

NOAA NEXRAD
 Radar Line of Sight
 130 m Above Ground Level
 160 m Above Ground Level
 200 m Above Ground Level

Wind Farms
 Operating
 Planned

Wind plants from POWERmap,
 powermap.platts.com ©2007
 Platts, a division of the
 McGraw-Hill Companies

0 - 30 miles
 30 - 90 miles

100 0 100 200 300 400 Miles

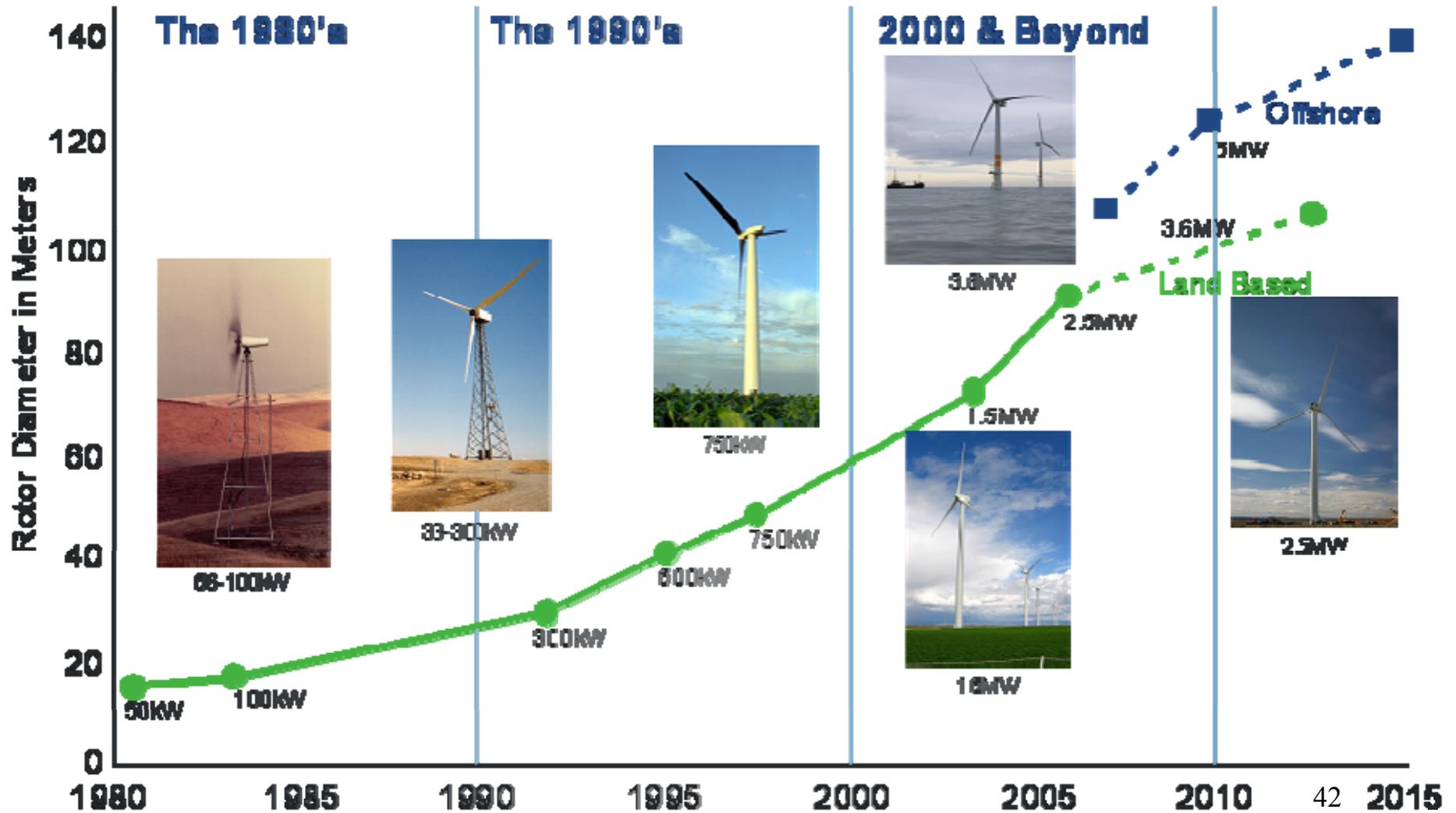


Why Are You Hoarding Data?

- ▶ European Wind Projects routinely report operating details turbine by turbine and still are world leaders
- ▶ Wind Turbine Users Groups getting started but not yet comparable in influence to gas turbine groups
- ▶ Sandia setting up confidential data base – are you participating?
- ▶ Terabytes of wind and SCADA data going down the cyberdrain. Is this any way to learn from experience?



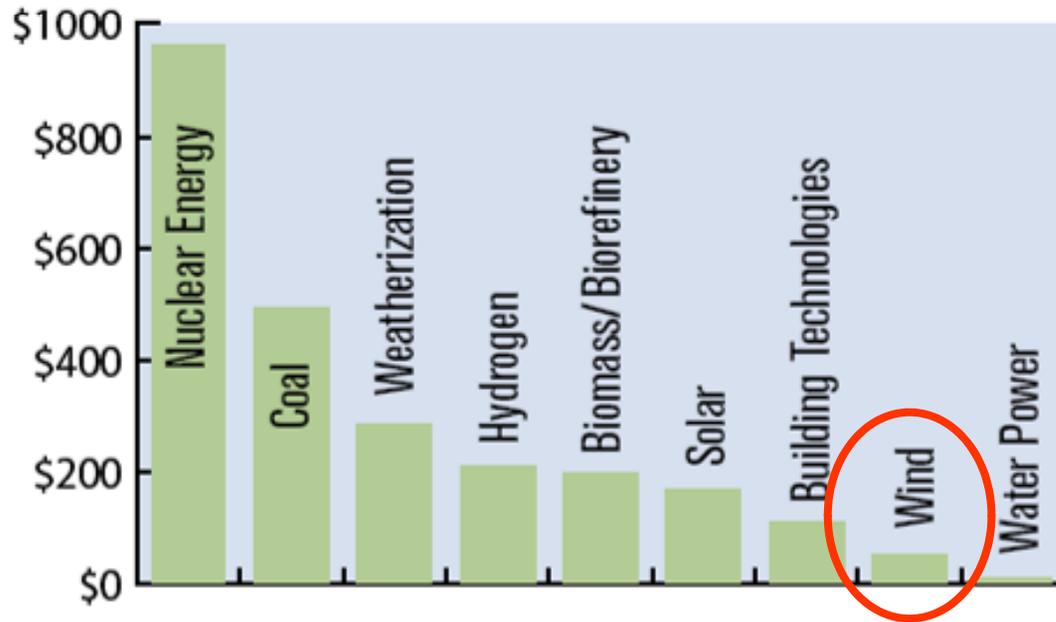
Continued Evolution of Wind Technology is a Good Investment





Yet Wind R&D Has Been Underfunded

U.S. Department of Energy R&D Energy Program Funding

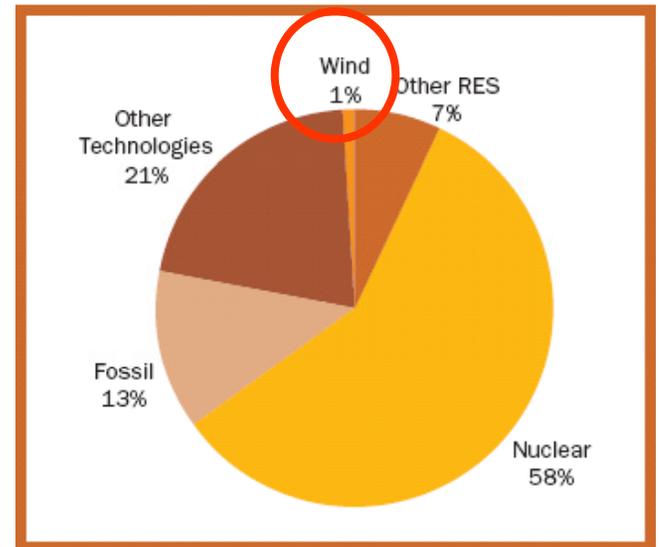


The DOE wind program currently receives about \$50 million annually, a level that is inadequate compared with funding levels for other fuels and energy sources. Source: DOE Congressional Budget Request for 2009

AWEA R&D Committee recommending increase to \$200M+/year

Wind received only 1% of energy R&D funding in IEA countries from 1974-2002

Total Energy R&D Shares in IEA Countries from 1974 to 2002 (US\$)⁵⁷





One Possibly Disruptive Technology

Company Overview

Focus on development and commercialization of adaptive wind turbine blades

- **FlexSys Inc.**
 - 7 employees
 - \$5+ million in Defense Contracts
 - 6 patents issued, 3 pending on base technology
- **Development Contracts with Department of Defense**
 - Fixed wing
 - Helicopter blades
- **Prior work is directly transferable to wind turbine blades**



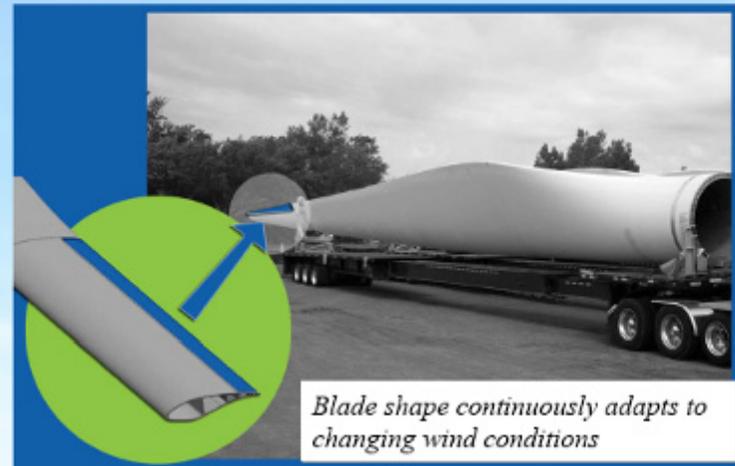
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Potential 10+% increase in output from one technology

FlexSys Inc.

Imagine designing a new turbine from foundation up knowing that you could control wind loads on the same time scale as the resource.

Adaptive Wind Turbine Blade



FlexSys Adaptive Trailing Edge

- 15% Increased Energy Capture
- 75% Fatigue Damage Reduction



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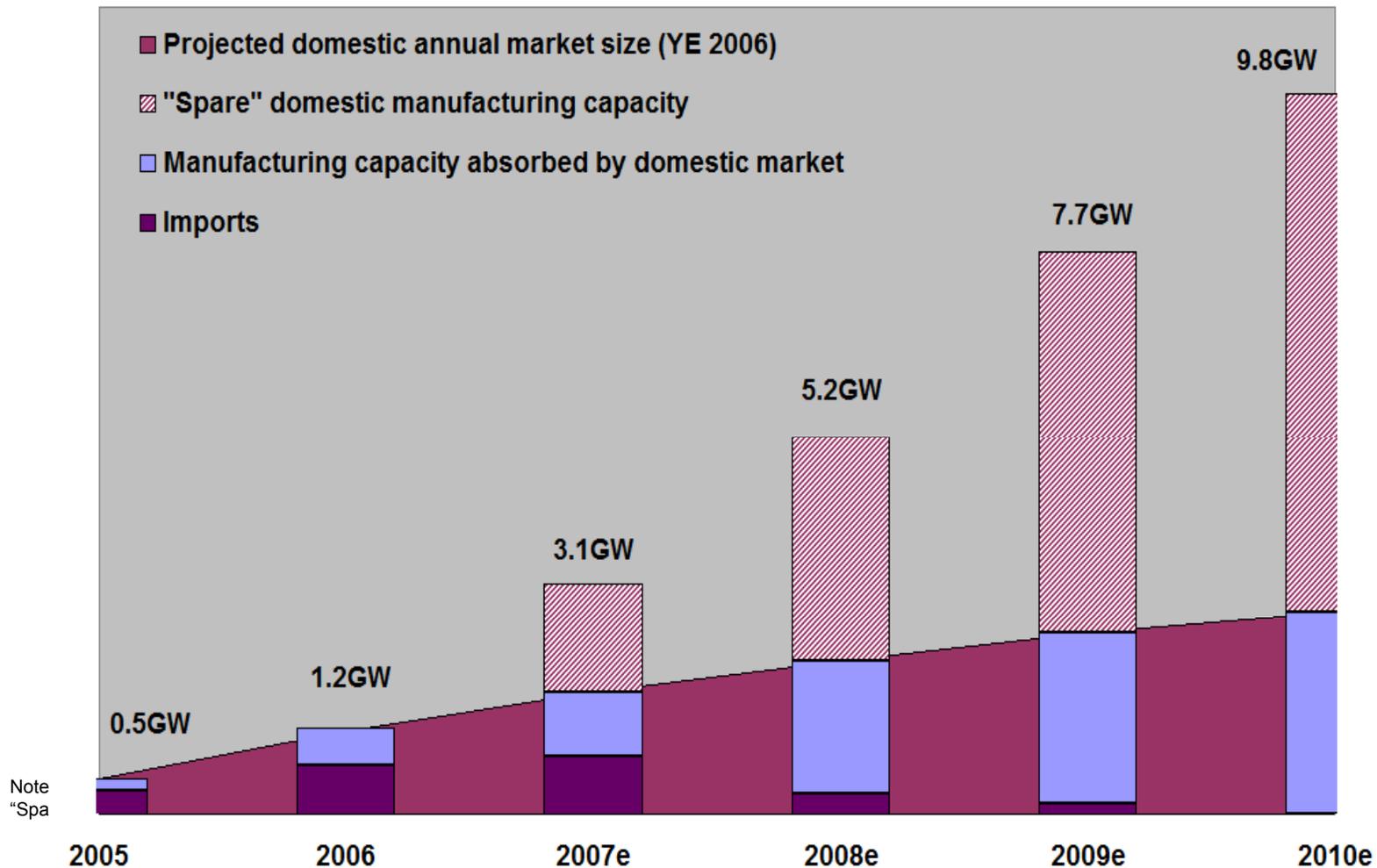


Don't Rest on Your Laurels

- ▲ “Don't Look Back, They Might Be Gaining On You”
 - Satchel Paige
- ▲ Solar PV costs coming down fast – should cross wind in the coming decade
 - We may have the wind at our back, but they have Moore's Law – and no moving parts
- ▲ Don't forget Europe, India and of course China
 - European Technology Platform aims to keep leadership across the pond
 - 4 May 2009 – US Based Tang Energy Group and CATIC, a subsidiary of the China Aviation Industry Corporation (CAIC) committed \$300M to finance wind projects in US using Chinese turbines.
- ▲ Who is going to set the standards??



Surplus Turbine Capacity Forecast for China



Source: New Energy Finance, Bloomberg, 09 October 2007



Where are the Parts Guys When You Need Them?

- ▶ Turbine parts aftermarket still nascent
- ▶ UPS “stealth” facility in Lexington KY –
 - Does all repairs for certain Toshiba divisions
 - All fulfillment for The Gap
 - Inventories parts for Bentley Motors
- ▶ How much would you pay for overnight delivery and swap?
- ▶ Will insurance companies start to push?



Don't Be (Overly) Cynical When Government Says "We are here to help"

- ▲ Bureaucrats not as bad at picking winners as Rush L would like you to believe.
 - Two \$25,000 CEC grants in 1970s to Sam Berman at LBNL yielded CFL and energy efficient ballast
- ▲ Pop Quiz:
 - How long was it taking the "Old DOE" (with help from OMB) to process loan guaranties?
 - **4 [YEARS] [DECADES] [CENTURIES]**
 - How long is it taking the "New DOE" to bring loan guaranties to the term sheet stage?
 - **4 [DAYS], [WEEKS], [MONTHS]**



Some Feel Good

- ▲ US Manufacturing sector is the largest in the world
 - **Twice as big as the next country, China**
 - Growth in US manufacturing since 1990 has been \$800B, more than the entire manufacturing sector of Germany
- ▲ US Auto industry downsizing leaves vast pool of skilled labor and proven suppliers
 - Largest GM suppliers had revenues over \$10B.
 - Used to shaving costs and weight off millions of parts/year
- ▲ US Aerospace Industry a major world exporter
 - Also has idle capacity and transferable technology (it worked for the gas turbine guys)

- **During WWII, US was arsenal to the world**
 - FDR promised 60,000 airplanes, delivered 229,600
 - EVERYBODY pitched in.
- **Then it took 37% of GDP, 87% of Federal budget**
 - Now, as the lone(ly) Superpower, we have the resources to do 300 GW using only 2.5% of domestic steel production (20% Report)
- **Some have called for an “Apollo Program” or “Manhattan Project” for energy, but there are other models...**





Then

Last Year





The Public Underestimates the Capabilities of the US Auto Industry

<<previous year Top 20 motor vehicle producing countries 2007 v · d · e

Motor vehicle production (1000 units)

| Country | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 | 9000 | 10000 | 11000 | 12000 |
|---------------|------|------|------|------|------|------|------|------|------|-------|-------|----------------------------|
| Japan | | | | | | | | | | | | 11596 |
| United States | | | | | | | | | | | | 10781 |
| PR China | | | | | | | | | | | | 8882 |
| Germany | | | | | | | | | | | | 6213 (includes GM Belgium) |
| South Korea | | | | | | | | | | | | 4086 |
| France | | | | | | | | | | | | 3019 |
| Brazil | | | | | | | | | | | | 2971 |
| Spain | | | | | | | | | | | | 2890 |
| Canada | | | | | | | | | | | | 2578 |
| India | | | | | | | | | | | | 2307 |
| Mexico | | | | | | | | | | | | 2095 |
| UK | | | | | | | | | | | | 1750 |
| Russia | | | | | | | | | | | | 1660 |
| Italy | | | | | | | | | | | | 1284 |
| Thailand | | | | | | | | | | | | 1238 |
| Turkey | | | | | | | | | | | | 1099 |
| Iran | | | | | | | | | | | | 997 |
| Czech Rep. | | | | | | | | | | | | 939 |
| Belgium | | | | | | | | | | | | 844 |
| Poland | | | | | | | | | | | | 785 |

Reference: World Motor Vehicle Production by Country: 2006 - 2007 OICA. Retrieved on 2008-03-18.

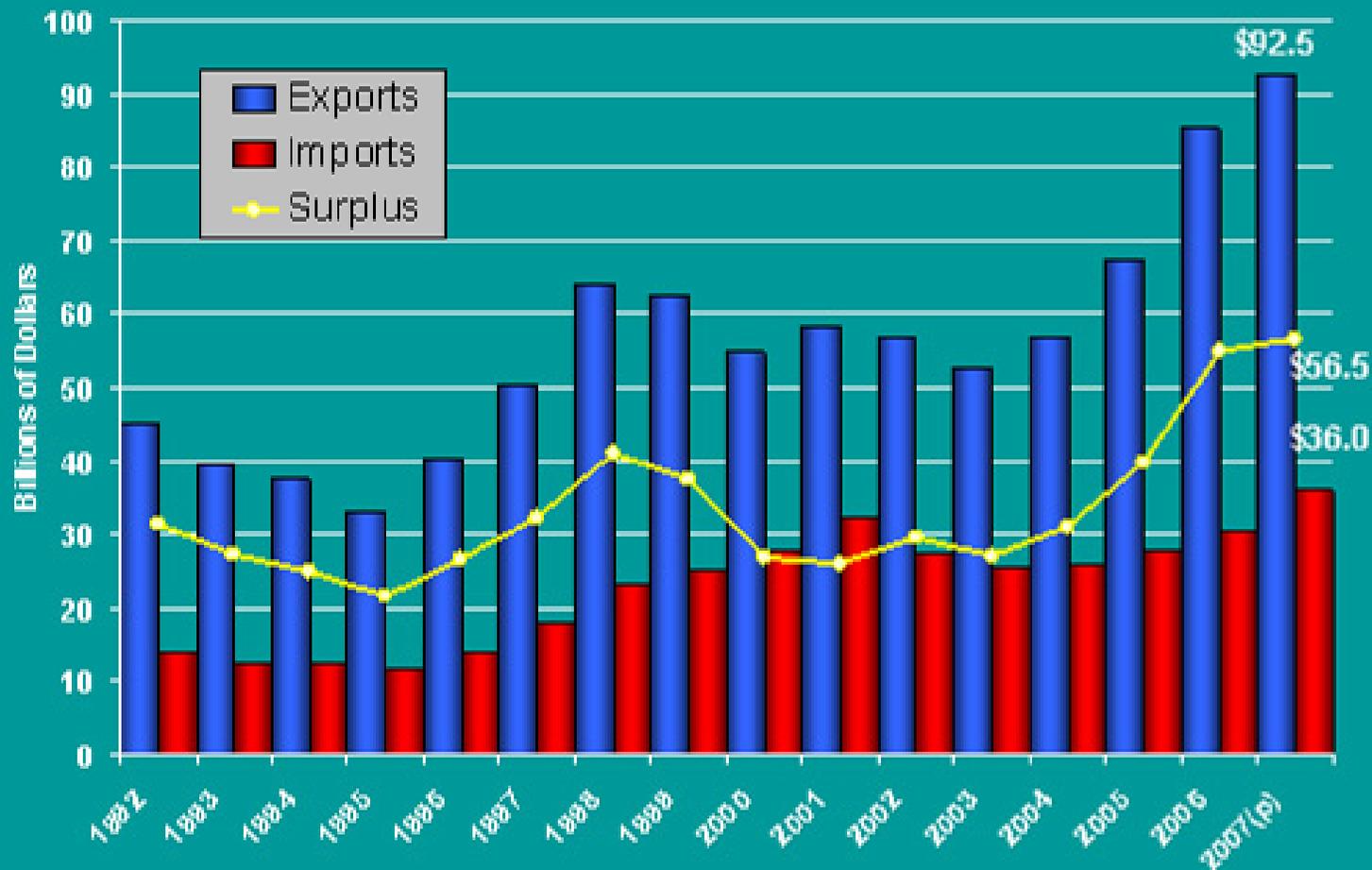
Table 3-5. Toyota North America vehicle production and sales

| | |
|--|--|
| Direct U.S. Employment (2005) | 32,003 employees |
| 2005 Payroll | \$2,244,946,444 |
| Cumulative U.S. Production | 12,374,062 vehicles |
| Cumulative Sales | \$272,390,226,806 |
| U.S. Vehicle Sales (2005) | 2,269,296 vehicles |
| U.S. Vehicle Production (2005) | 1,393,100 vehicles |
| Average Engine Power 2004-2005 | 227 horsepower or 0.17 MW |
| 2005 U.S. Production in Power Output Terms | 275 million horsepower 236 million kW or 236 GW |
| 2005 U.S. Sales in Power Output Terms | 448 million horsepower 384 million kW or 384 GW |

Source: Adapted from website data

<http://www.toyota.com/about/operations/manufacturing/>).

Aerospace Foreign Trade

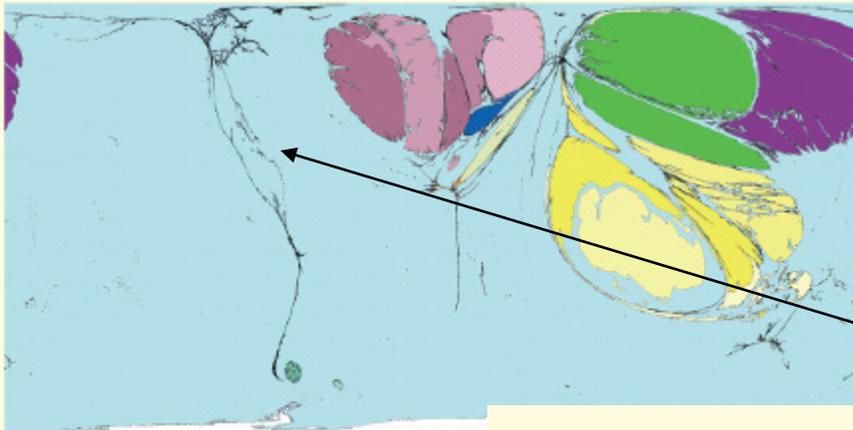




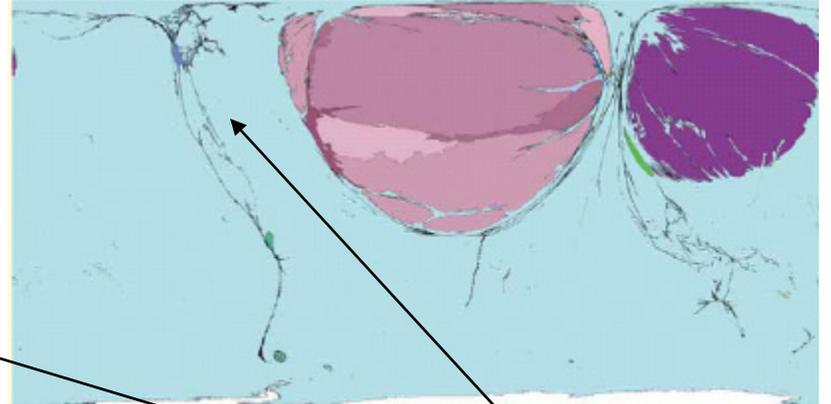
Key is Comparative Advantage & Domestic Value Added, not everything has to be made at home

Source: www.worldmapper.com

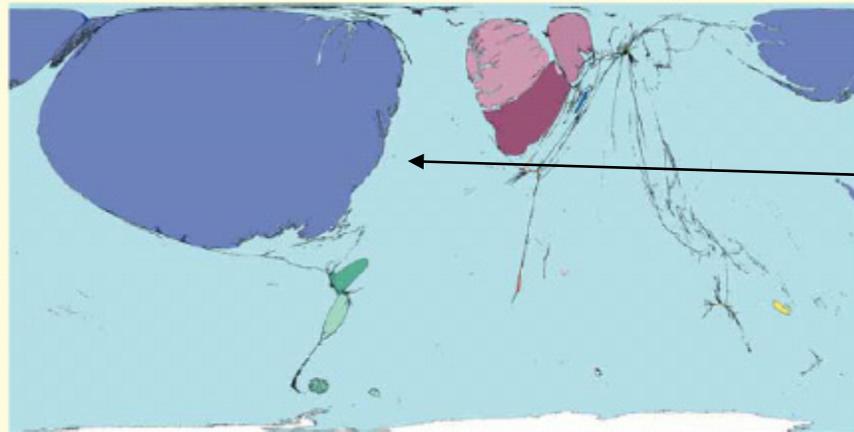
Computer Exports



Machine Exports



Royalties and License Fee Exports



Country “balloons” are inflated or deflated according to their global rank

US as 98 pound weakling and/or 800 pound gorilla



It Is Not Just the Turbine Suppliers that need to get with the program

- ▶ Developers need to approach siting, permitting and landowner issues with “six sigma” standards
- ▶ On siting, safety and other standards, industry is nearing the point of “last best chance to self regulate”
- ▶ American Wind Wildlife Institute is a positive example
- ▶ Wind is an acquired taste – so far only a handful of the 2900+ utilities in the US have acquired a serious appetite.
 - Many IPPs still fighting the PURPA wars – which was a slightly negative sum game for utilities.
 - Coca Cola was a yucky medicine at first (OK, there may have been some secret sauce). IPPs need to offer an attractive value proposition in lieu of 100% rate base.
- ▶ Cost of capital is as important as capital cost, yet wind depends on an incredibly narrow base of investors, in contrast to EU



Every Utility Operator's Nightmare





Quality, Quality, Quality

- ▶ Quality – leading to Reliability and Safety - needs to be the central theme for the wind industry.
- ▶ We should be the “Lexus” of the new generation resources.
- ▶ Wind is in stiff competition with efficiency & other forms of generation, especially in periods of low gas prices – it cannot afford to let reliability problems impact its real or perceived competitiveness or margins throughout the value chain.
- ▶ Notwithstanding the concerns expressed herein and the room for improvement, the current generation of wind turbines is remarkably efficient and reliable – **There is an urgent need to deploy them at scale to create jobs, fight climate change and gain greater energy independence.**
- ▶ (We cannot afford to wait for Wind 3.0, but we do want to be the ones who get there first.)