ECE 333 – Renewable Energy Systems

7. Wind Status

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2013 WIND STATUS

- Wind power additions stalled in 2013, with only 1,087 *MW* of new *US* capacity additions
  - roughly 8 % of capacity added in 2012
  - about 7 % of *US* electricity capacity additions in 2013
  - an increase in cumulative wind capacity below 2 %

2013 WIND STATUS

- The cumulative wind capacity by the end of 2013 was 61 *GW*
- *TX* remained the leading state in terms of cumulative wind capacity even though *CA* implemented the largest *MW* capacity in 2013
- The wind generated electricity in 9 states constituted 12 % *or more* of each respective state's electricity consumption

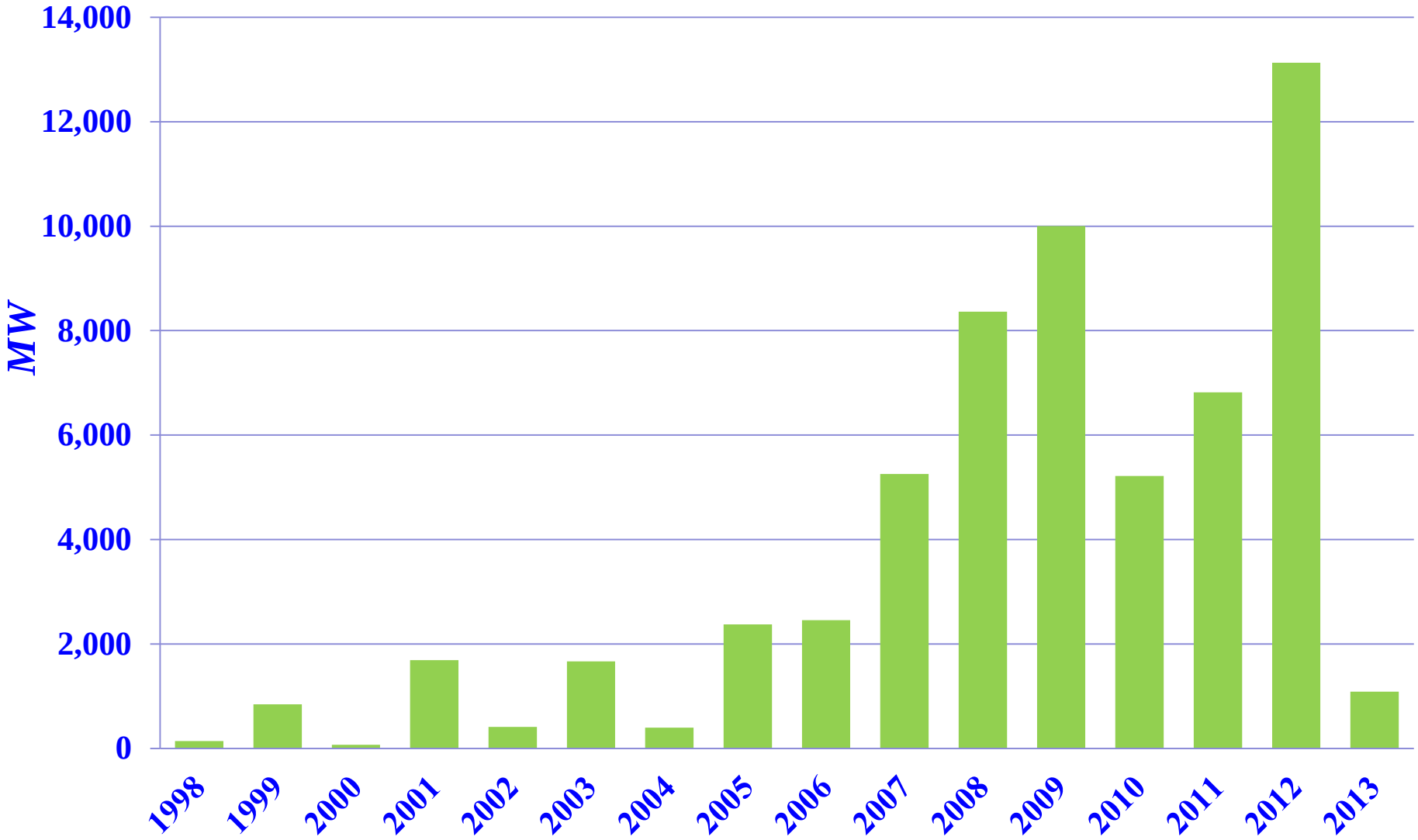
2013 WIND STATUS

- Overall, wind power ranked as the fourth largest source of new generation capacity in 2013 – a major drop from 2012, when it was the largest source
- Before the end of 2013, 12,000 MW was under construction – a clear signal of improvement in 2014 and 2015 wind capacity additions

CAUSAL FACTORS OF 2013 DEVELOPMENTS

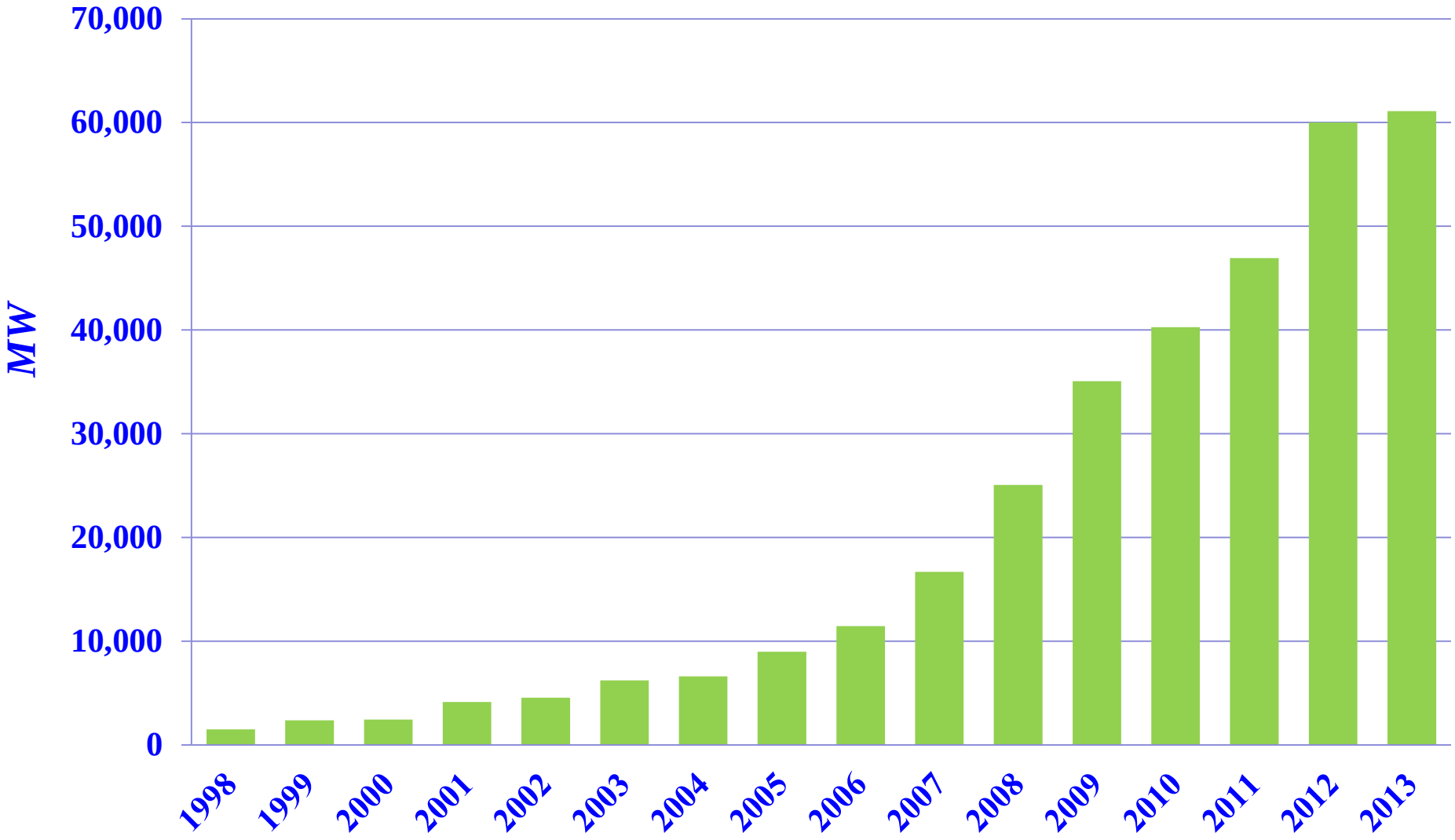
- The late extension of the federal production tax credit (PTC) resulted in the reduction of the work force or the closure of facilities in the turbine manufacturing sector
- Also, the $30\ \%$ investment tax credit (ITC) in lieu of the PTC was extended too late to be used advantageously by virtually any developer

US ANNUAL WIND CAPACITY ADDED



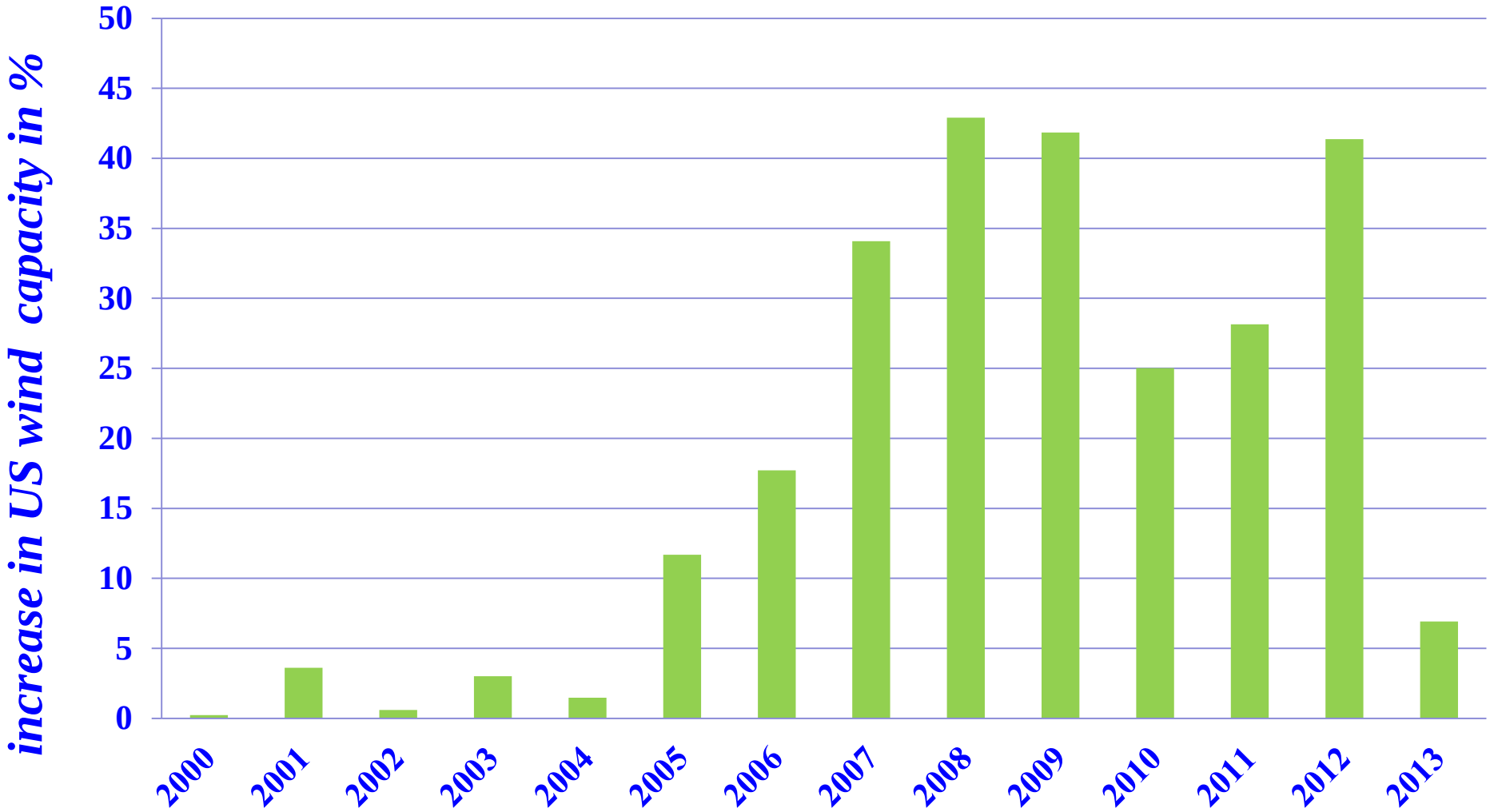
Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

US CUMMULATIVE WIND CAPACITY



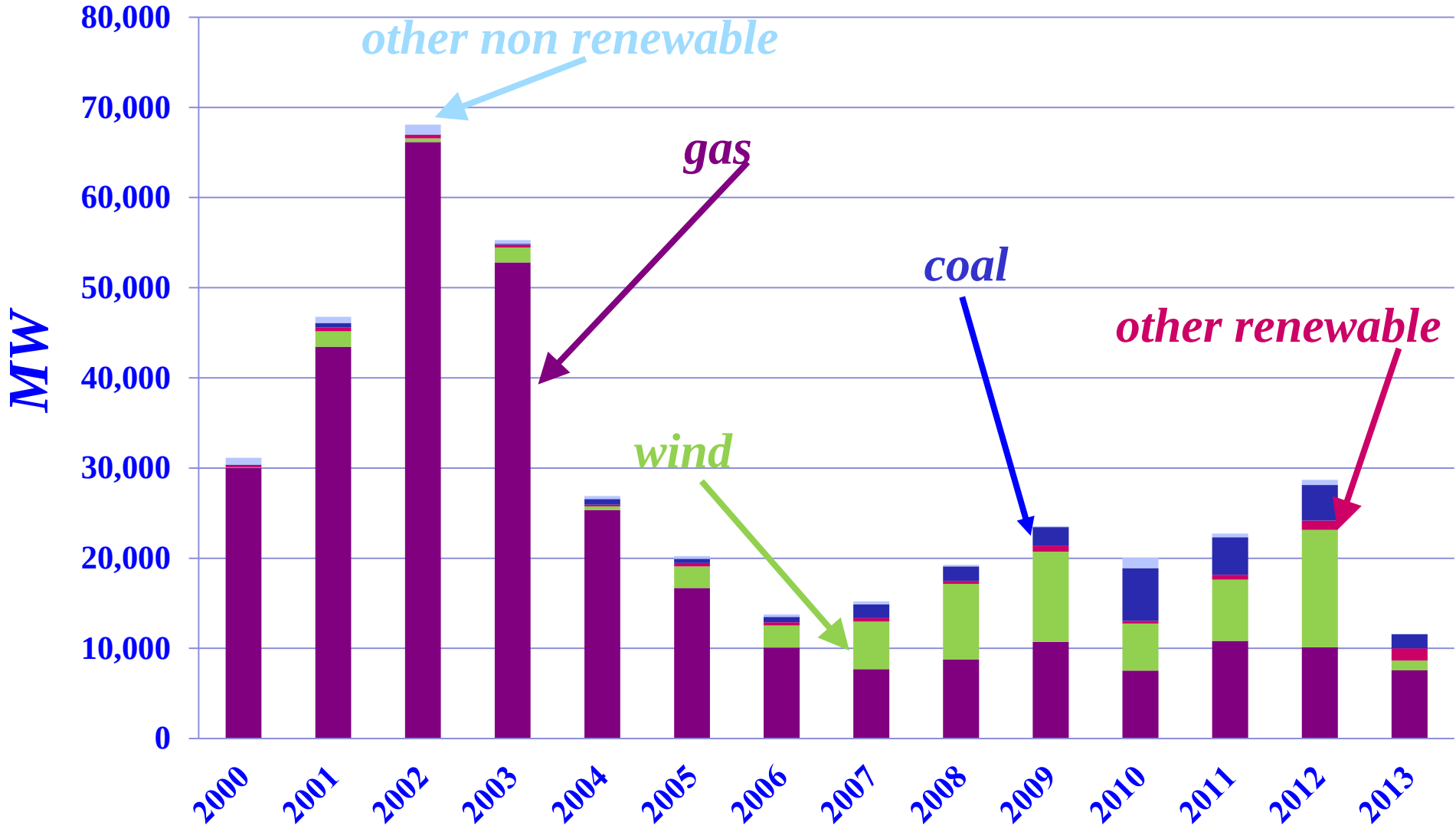
Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

PERCENTAGE OF TOTAL ADDED CAPACITY IN 2000 – 2013



Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

US 2000-2013 CAPACITY ADDITIONS



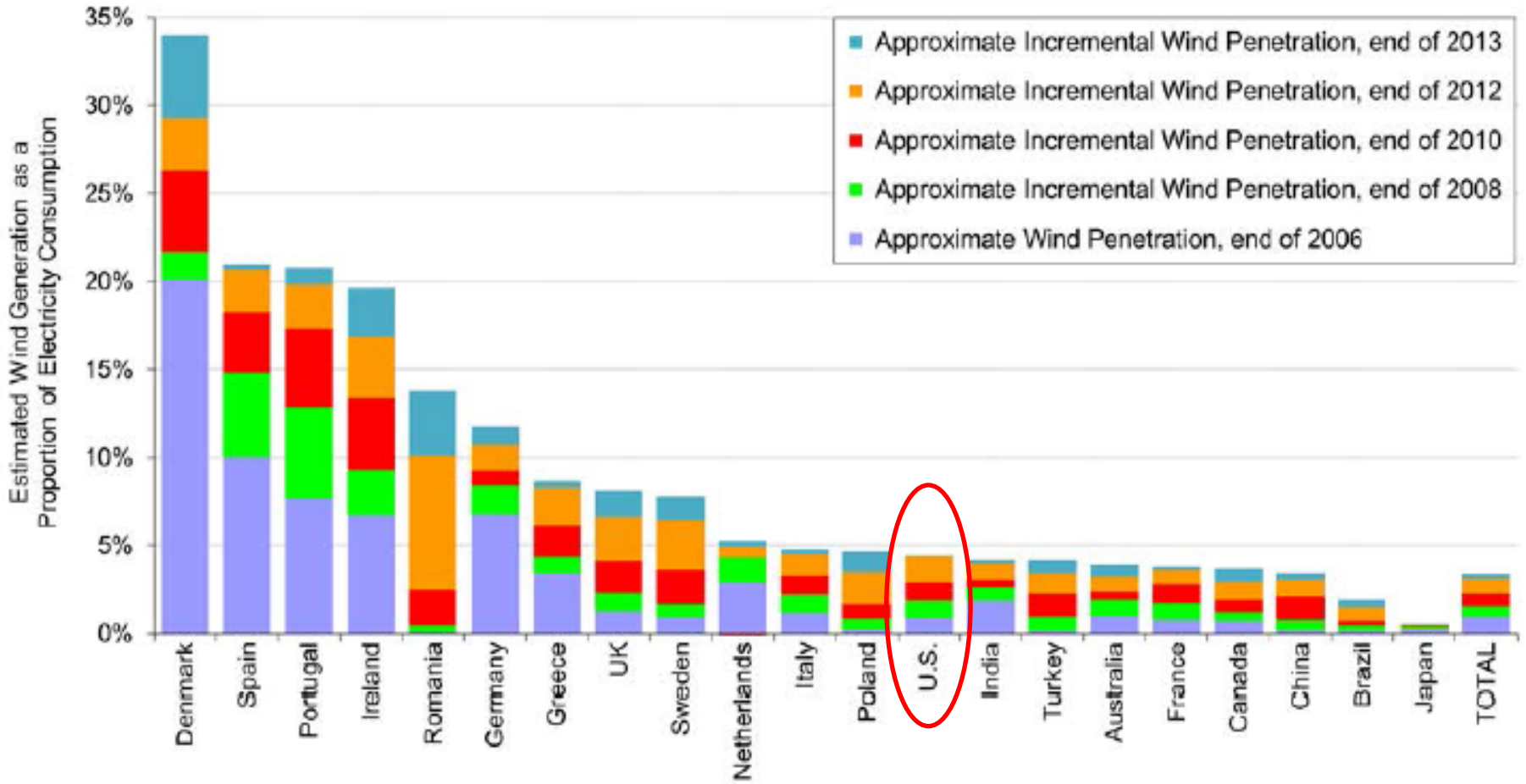
Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

2013 WIND CAPACITY ADDITION AND CUMULATIVE TOTAL

added capacity	*MW*	cumulative capacity	*MW*
China	16,088	*China*	91,424
Germany	3,237	*USA*	61,091
India	1,987	*Spain*	34,250
UK	1,833	*India*	22,959
Canada	1,599	*UK*	20,150
USA	1,087	*Italy*	10,531
Brazil	948	*France*	8,552
Poland	894	*Canada*	8,254
Total	36,137	*Total*	318,105

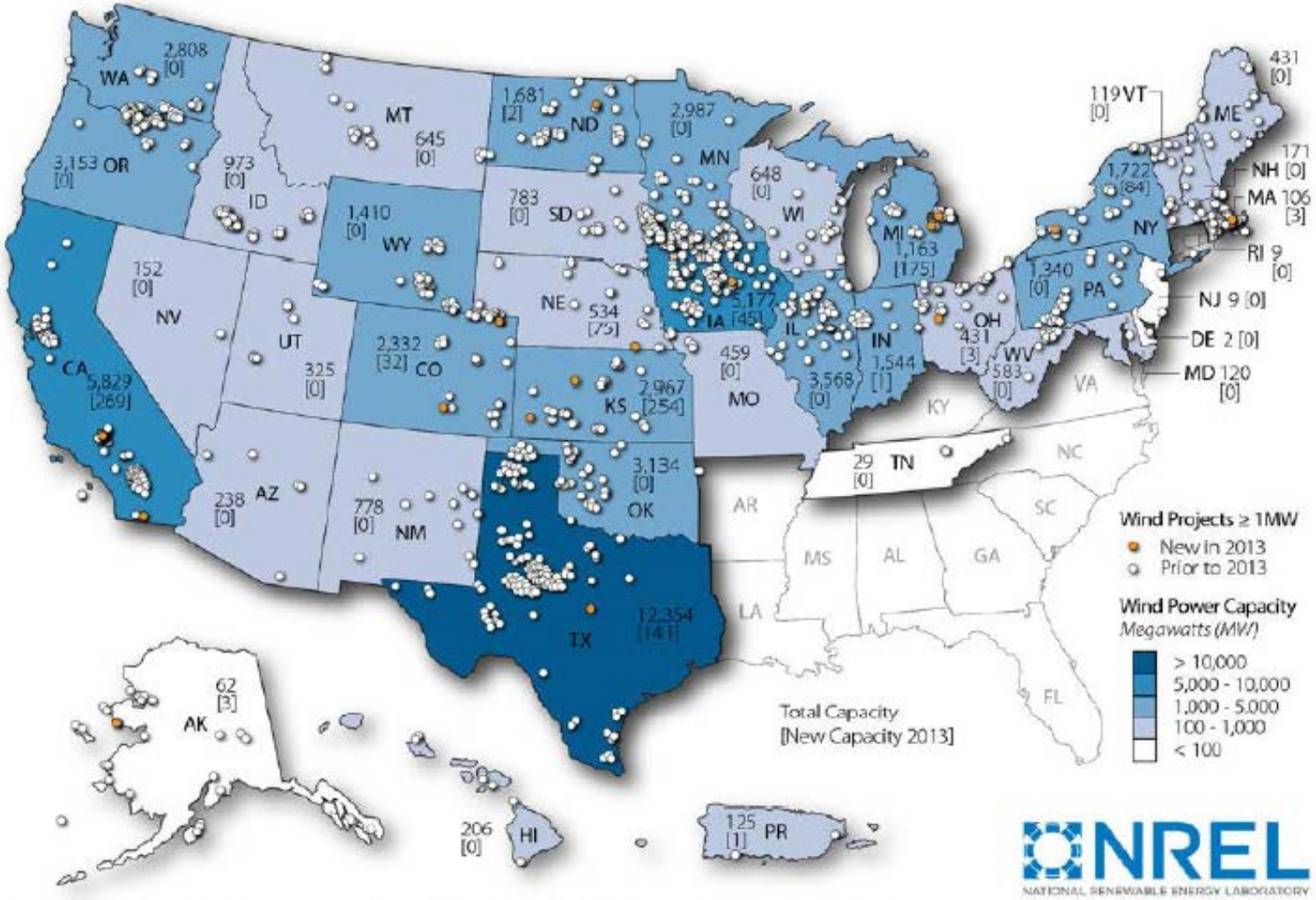
Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

LEADING NATIONS IN WIND ENERGY CONSUMPTION IN 2013



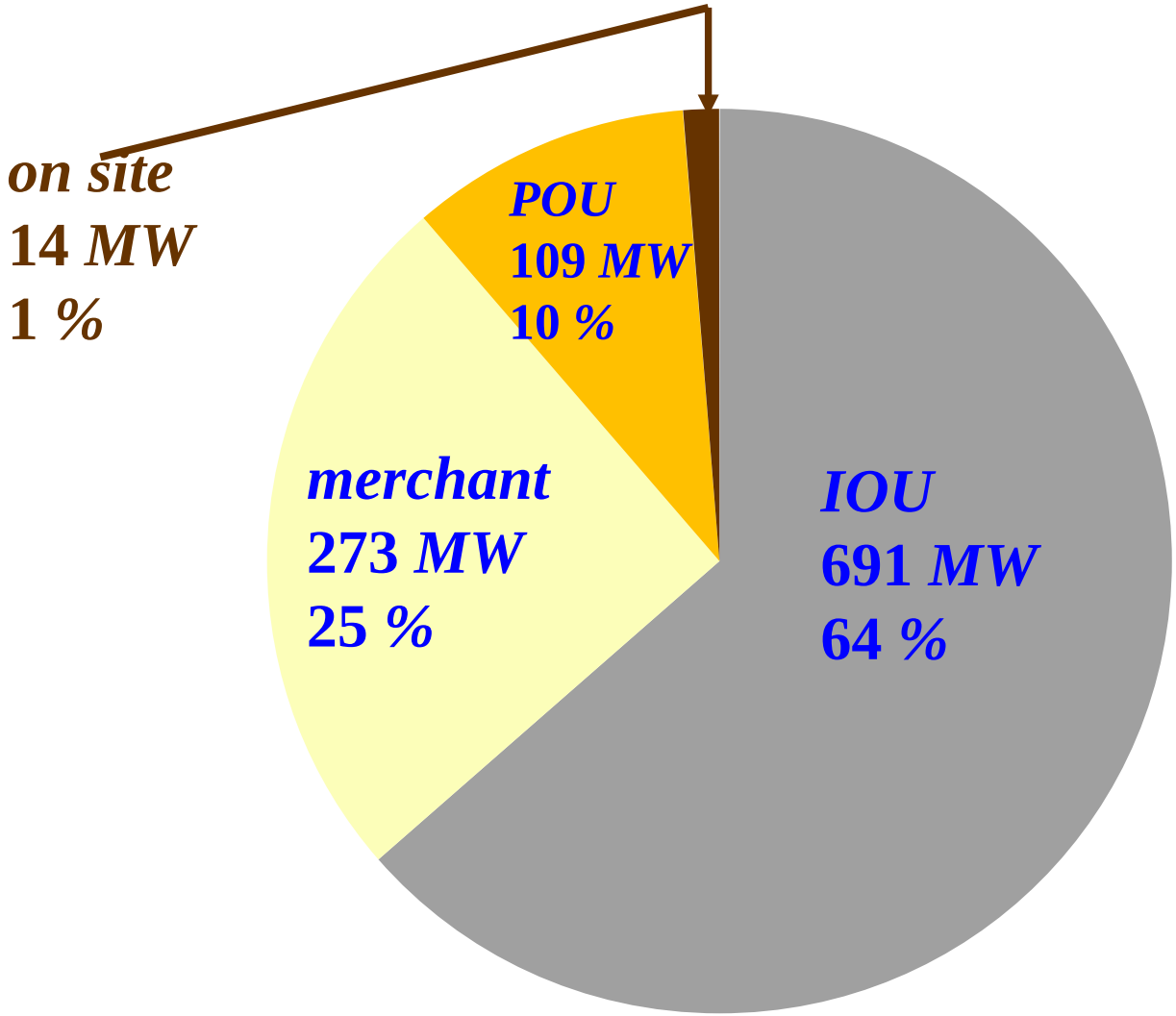
Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

US WIND POWER FARM 2013 STATUS



Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2013.

2013 WIND CAPACITY ADDITIONS BY OFF-TAKE CATEGORY



Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

2013 STATUS OF OFFSHORE WIND

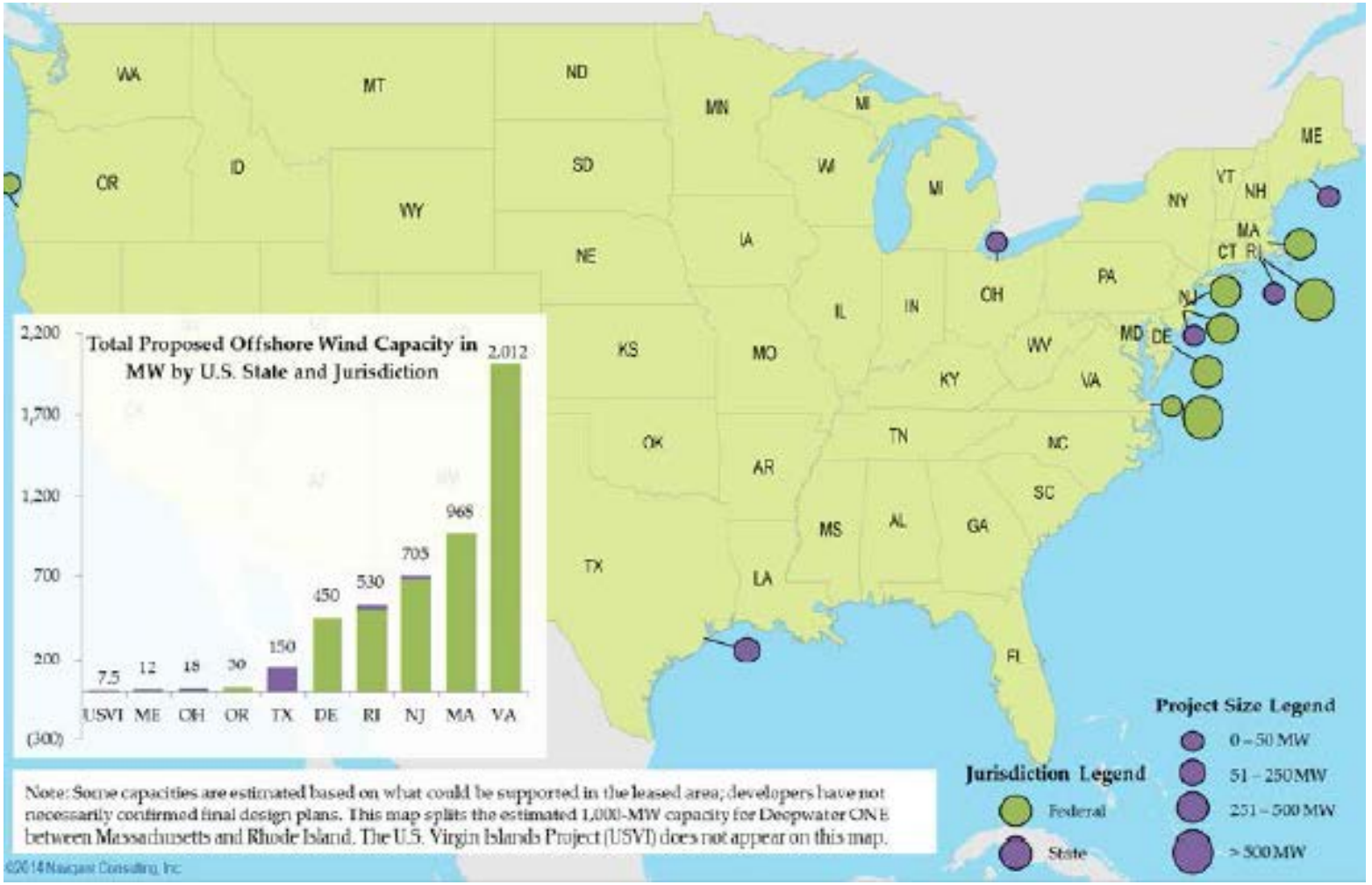
- No commercial offshore projects have been installed in the US but 14 projects, totaling $4.9\ GW$, are somewhat more advanced in development
- Two projects
  - Cape Wind (MA)
  - Deepwater Wind (RI)

have power purchase agreements ($PPAs$) in place

2013 STATUS OF OFFSHORE WIND

- A 1:8 scale model of floating turbine deployed in ME in June 2013
- MD passed a legislation in 2013 to establish a set-aside for 200 MW of offshore wind within the state's RPS – the first state to explicitly include offshore wind in its RPS

2013 STATUS OF OFFSHORE WIND



Source: http://www.energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Technologies%20Market%20Report_1.pdf

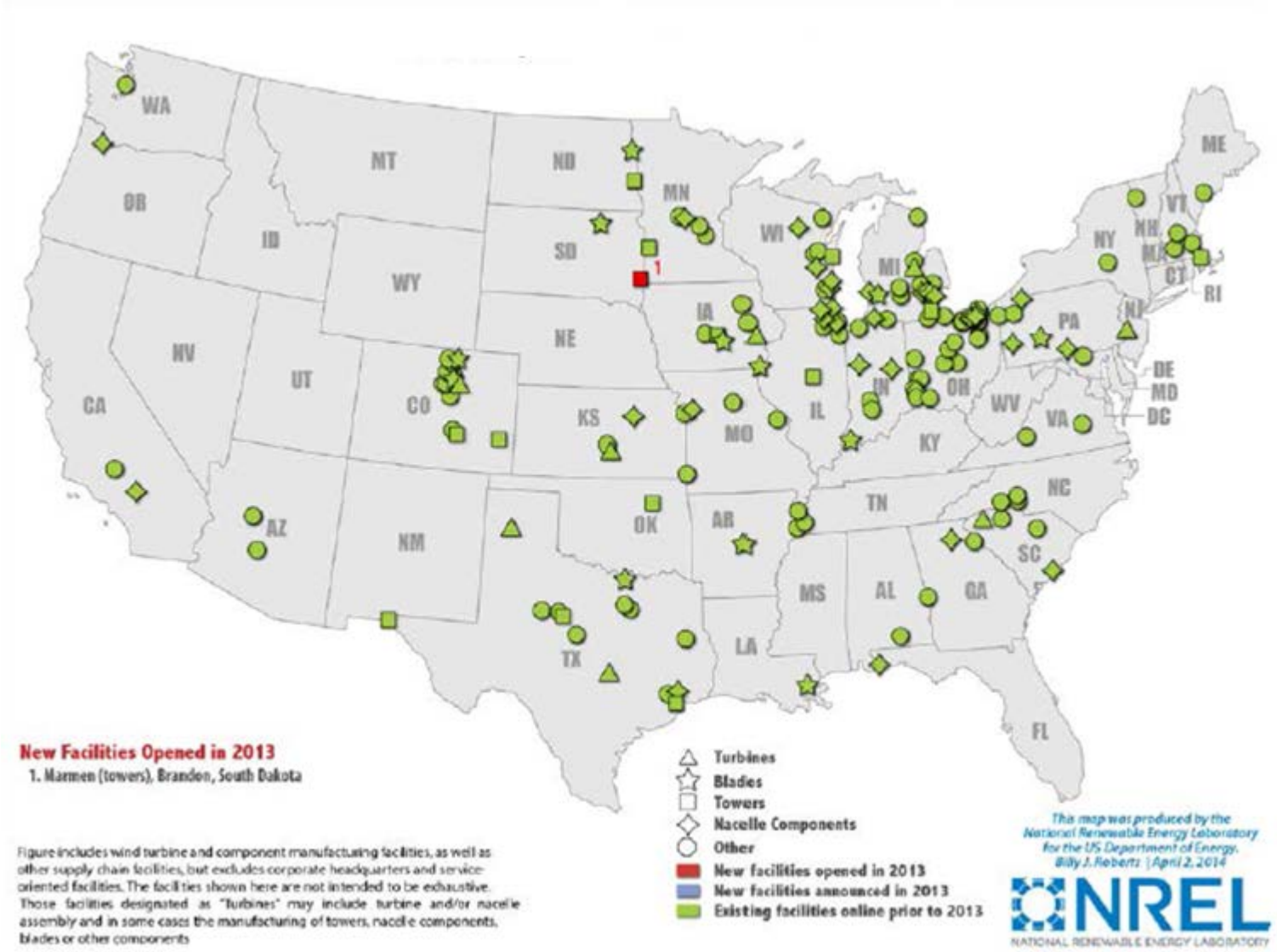
US WIND MANUFACTURER STATUS

- The manufacturing supply chain experienced substantial growing pains in 2013
- Several of the *OEM*s' manufacturing facilities were largely, if not completely, dormant given the lack of turbine orders, and one of these facilities was subsequently closed in 2014 – *Nordex* ceased *US* manufacturing operations in 2013
- Due to the marked decline in new capacity additions in 2013, only one new – *Marmen Inc* – manufacturing facility opened in 2013, as compared to 7 in 2012

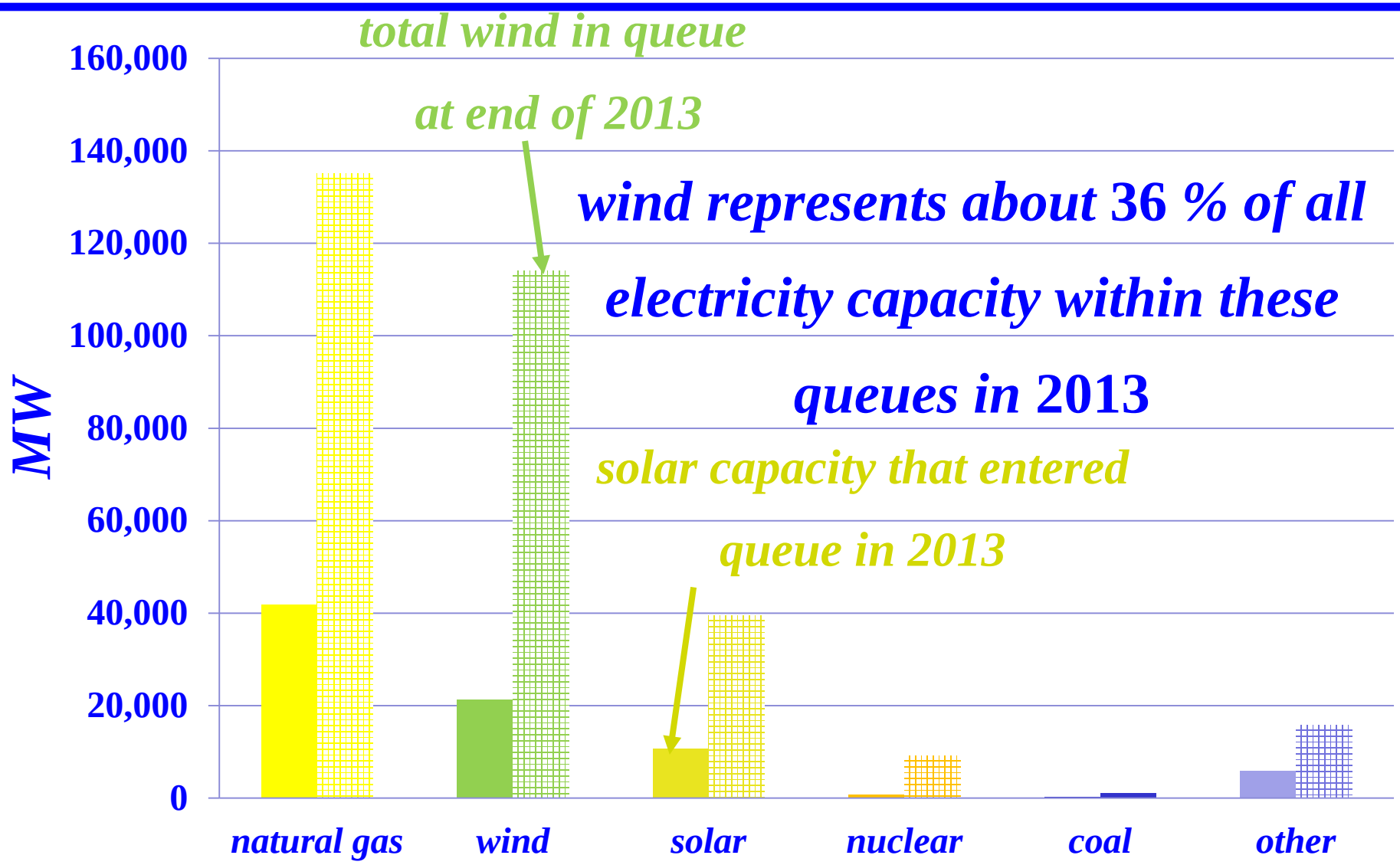
US WIND MANUFACTURER STATUS

- Five of the 10 wind turbine *OEMs* with the largest share of the *US* market through 2013 had manufacturing facilities in the *US* in 2013, *vs.* 1 in 2004
- Exports from the *US*-based small wind turbine manufacturers increased 70 % from 8 *MW* in 2012 to 13.6 *MW* in 2013 so as to compensate for the weak domestic sales

US WIND MANUFACTURER SITES



INTERCONNECTION QUEUES



WIND FARMS

- A wind farm is a collection of a large number of wind turbines
- The motivation for the development of wind farms stems from
  - economy of scale in site preparation and grid interconnection;
  - ability to maximize the utilization of a good wind site; and,
  - centralized access for operations and maintenance
- There are challenges in the determination of the number and placement of the turbines

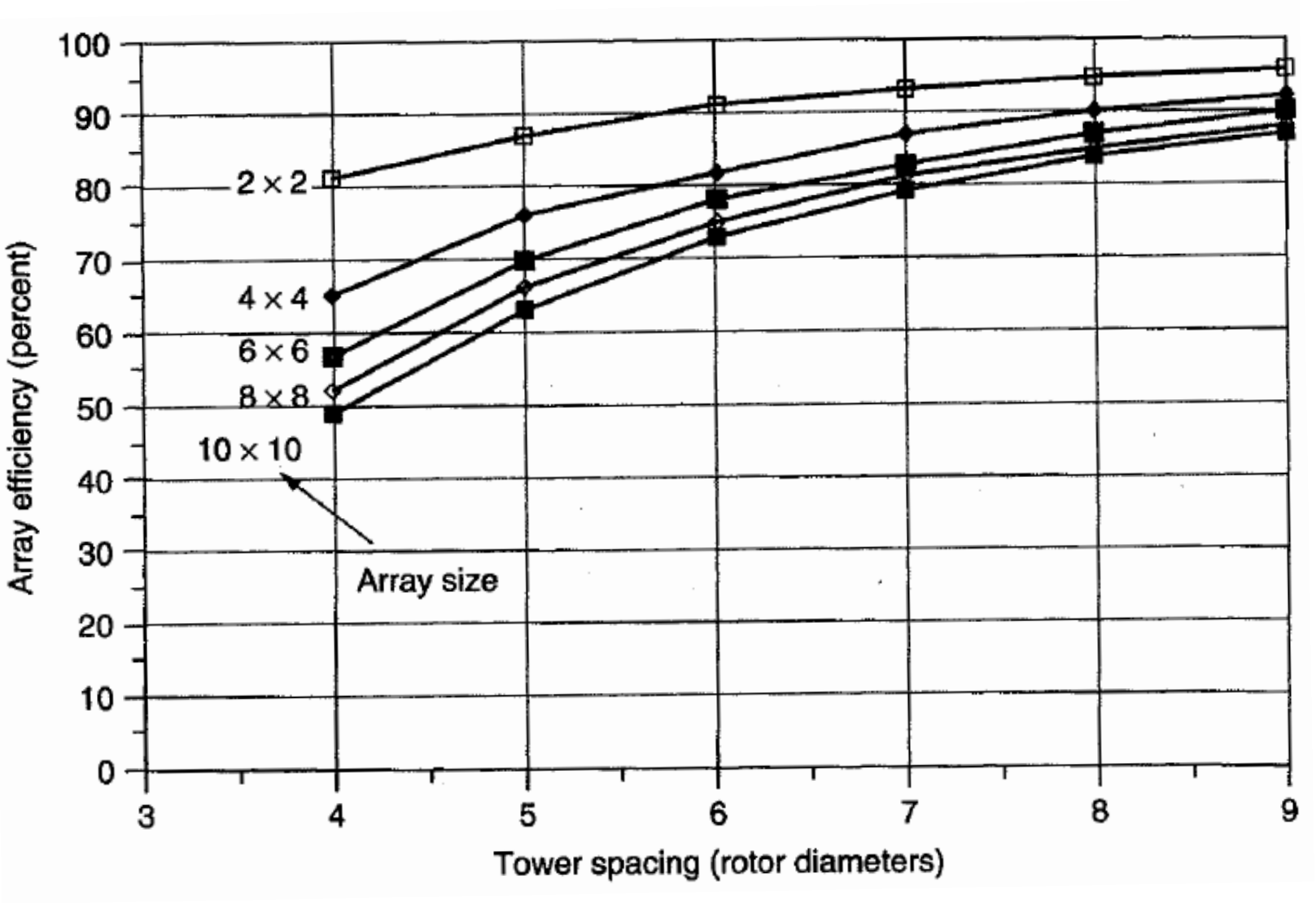
WIND TURBINE PLACEMENT

- The wind turbines require sufficient spacing so as to avoid interference with the wind received by the other turbines
- The extraction of energy as the wind passes the rotor blades reduces the wind speed and so distance behind a turbine is required for wind to recover to its undisturbed value

WIND TURBINE PLACEMENT

- The appropriate placement of turbines requires consideration of various issues, such as
  - good prevailing wind directions
  - terrain irregularities
  - siting of access roads
  - grid interconnection facilities

WIND TURBINE PLACEMENT



WIND POWER PLANT LAYOUT

- A common layout is based on the placement of turbines in a systematic row-and-column array:
  - in each row a separation of 5 rotor diameters is used between two turbines in a row perpendicular to the prevailing wind direction
  - spacing between rows is about 10 rotor diameters
- Such a layout is referred to as a $5\,d \times 10\,d$ array
- In addition, a buffer zone is added around the entire array

EXAMPLE: WIND FARM LAND REQUIREMENTS

- We consider the siting of 30 2-MW turbines each with 90-m rotor diameter using $5\,d \times 10\,d$ spacing and $10\,d$ of buffer zone around the entire array
- The total area required is

$$= \textit{array area} + \textit{buffer zone area}$$

$$= (9 \times 5\,d)\,(2 \times 10\,d) + 2\,(9 \times 5\,d + 20\,d)\,10\,d + 2\,(10\,d)\,(20\,d)$$

$$= 900\,d^{\,2} + 1300\,d^{\,2} + 400\,d^{\,2}$$

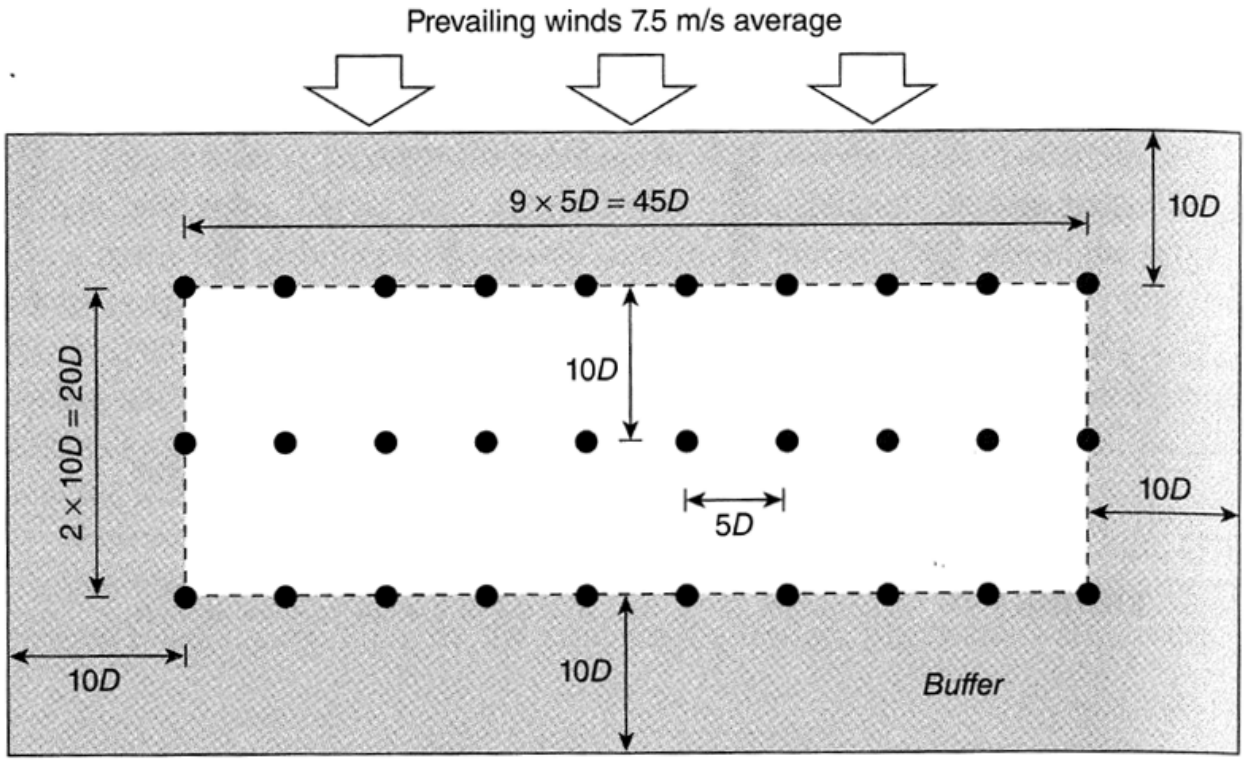
$$= 2600\,d^{\,2}$$

$$= 21.06 \times 10^{\,6}$$

EXAMPLE: WIND FARM LAND REQUIREMENTS

- The power density is

$$\frac{\textit{capacity installed}}{\textit{area required}} = \frac{60 \times 10^6}{21.06 \times 10^6 \ m^2} = 2.85 \frac{W}{m^2}$$



ENVIRONMENTAL ASPECTS

- The 2007 *US* National Academies report on the environmental aspects emphasized the beneficial impacts of wind
  - no air pollution and no CO_2 emissions
  - no water requirements
  - net decrease in pollution due to displacement of energy from fossil-fired sources

ENVIRONMENTAL ASPECTS

- Wind resource is essentially free and operators try to harness as much wind as possible; however, sometimes they have no choice but to curtail wind
- Wind may impact people near wind farms due to noise and shadow flicker

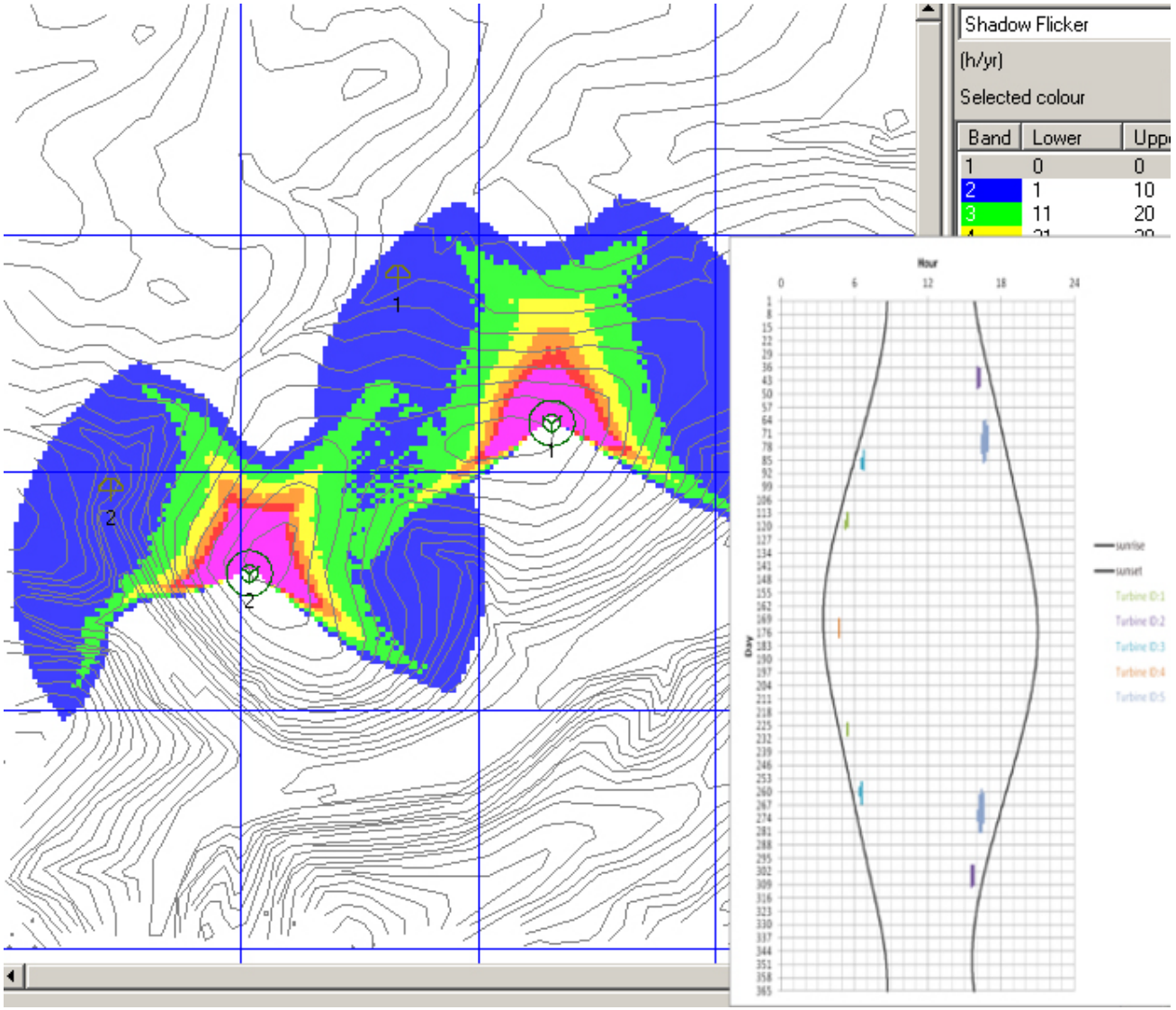
NOISE AND SHADOW FLICKER

- Wind turbines often enhance the well being of many people, but some living nearby may be affected by noise and shadow flicker
- Noise comes from the gearbox of the generator and the aerodynamic interaction of the blades with the wind
- Noise impact is, typically, moderate at $50 - 60\ dB$ within a 40-m distance and lower at further distances with noise at 35-$45\ dB$ at a 300-m distance

NOISE AND SHADOW FLICKER

- The wind turbine spectrum contains frequencies with both a "hum" above $100\ Hz$ and some inaudible or barely audible low frequencies $20\ Hz$ or below
- Shadow flicker is more of an issue in high latitude countries since lower sun casts longer shadows

NOISE AND SHADOW FLICKER



WIND TURBINES AND RADAR

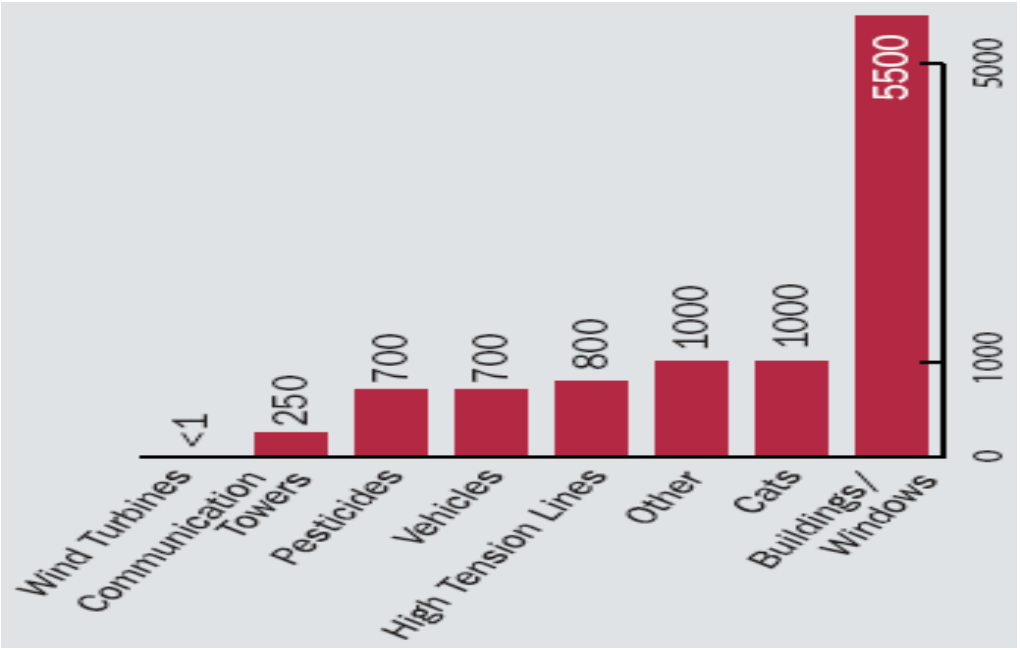
- Wind turbines impact radar through either radar shadows or Doppler returns that look like false aircraft or weather patterns
- As a result of the interference with radar, the *FAA*, *DHS*, and *DoD* have contested many proposed wind turbine sites
- No fundamental constraint with respect to radar interference but mitigation might require either upgrades to radar or new rules that stimulate the installation of telemetry from wind farms to the radar sites

WIND TURBINES AND RADAR

- As a result of such interference, mitigation measures may be imposed; such measures may require the wind farm to compensate for the upgrades in radar needed to overcome interference: e.g., the Fort Cape Wind project developer agreed to pay for $ 1.5 million in radar equipment upgrades at the nearby military base and put an escrow of $ 15 million to meet future requirements

WIND IMPACT ON BIRDS AND BATS

- Wind turbines certainly kill birds and bats, but so do other structures such as windows, which kill between 100 and 900 million birds per year
- The diagram below shows the estimated causes of bird fatalities per 10,000 birds



Source: Erickson, et.al, 2002. Summary of Anthropogenic Causes of Bird Mortality

ENVIRONMENTAL ASPECTS OF WIND ON HUMANS

- Aesthetics is often the primary human concern about wind energy projects since beauty is often in the eyes of the beholder
- Another issue may arise from night lighting

Source: Figure 4-1 of NAS Report, Mountaineer Project 0.5 miles

NREL REPORT ON US OFFSHORE WIND POTENTIAL

- Offshore wind turbines currently need to be in relatively shallow water and the maximum distance from the shore depends on the nature of the seabed
- Capacity factors tend to increase as turbines move further offshore into deeper waters

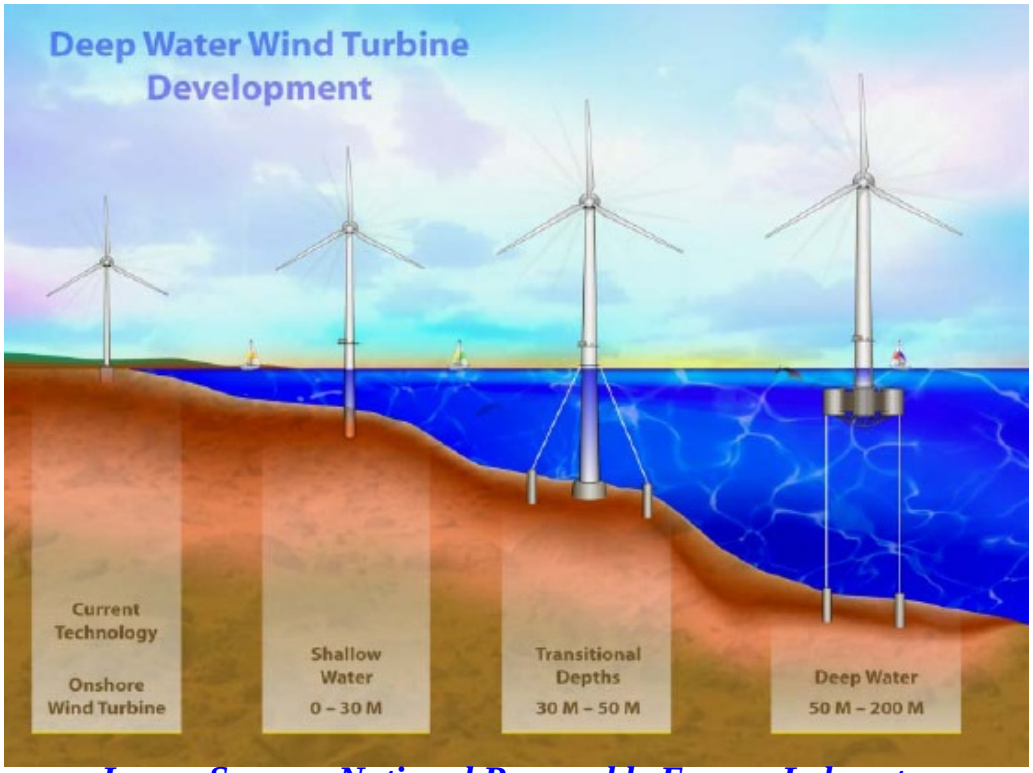


Image Source: National Renewable Energy Laboratory

NREL REPORT ON US OFFSHORE WIND POTENTIAL

- *NREL* issued a report discussing *US* offshore wind potential, with its key conclusion being that *US* could get about 54 *GW* of new offshore wind by 2030
- Offshore wind has a significant advantage that the generation is located relatively close to the high density load regions in urban areas

NREL REPORT ON US OFFSHORE WIND POTENTIAL

- Offshore wind tends to be more constant than on-shore wind
- Key problems with off-shore wind projects are the high costs of infrastructural development and maintenance
- Leading offshore wind producers are Great Britain, Denmark, and Holland

LARGEST OFFSHORE WIND FARM

- *UK* ministry approved the proposal for *East Anglia One* offshore wind farm, comprising 240 turbines with a capacity of 1,200 *MW*
- The project will be more than double the size of the London Array, the largest offshore wind farm currently in existence

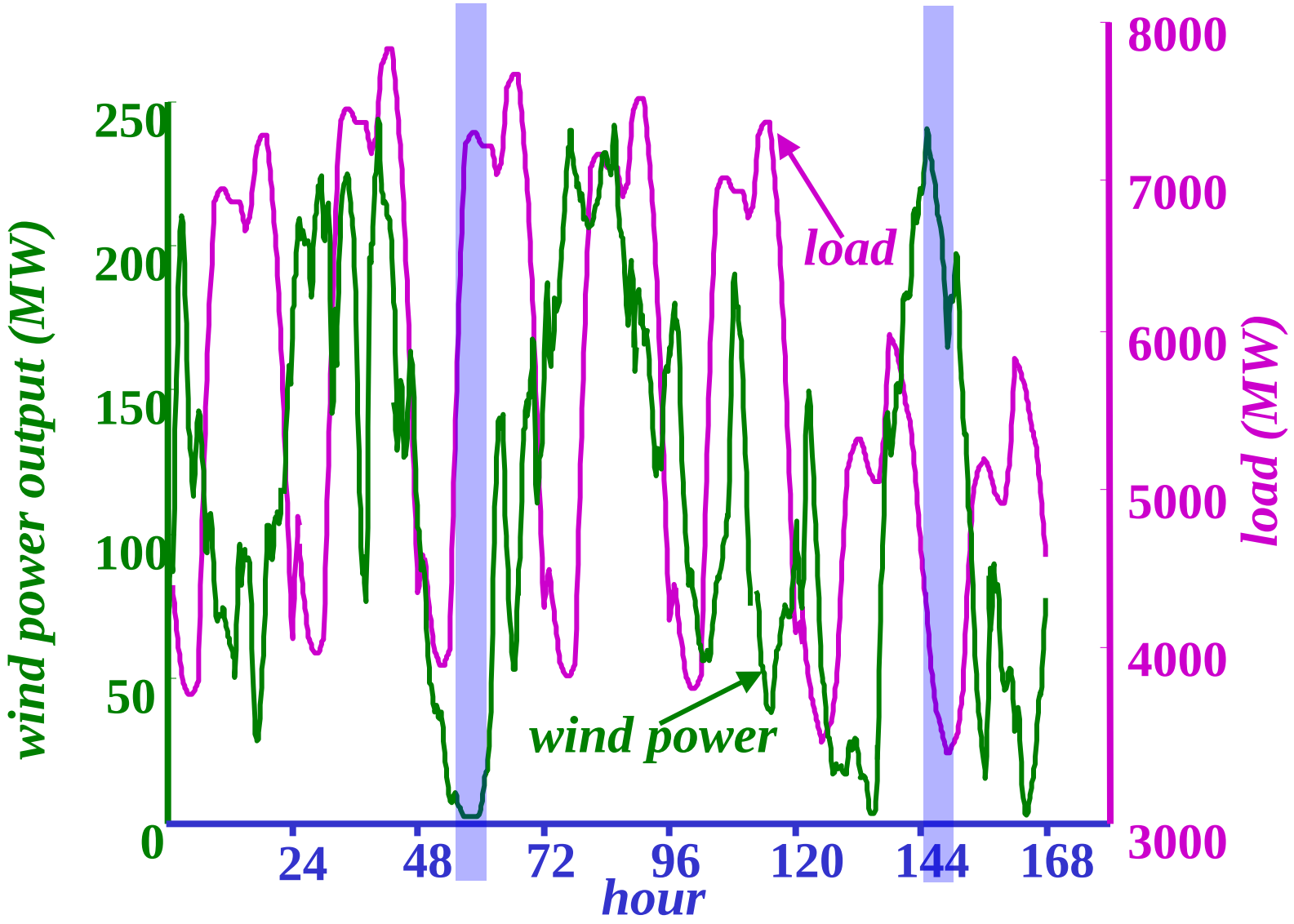
LARGEST OFFSHORE WIND FARM

- *East Anglia One* is located about $45\ km$ from the Suffolk coast and will have up to 4 undersea DC cables for interconnection with the National Grid's transmission network
- The project will will cover roughly $300\ km^2$ and will be able to create energy for $820{,}000$ British households

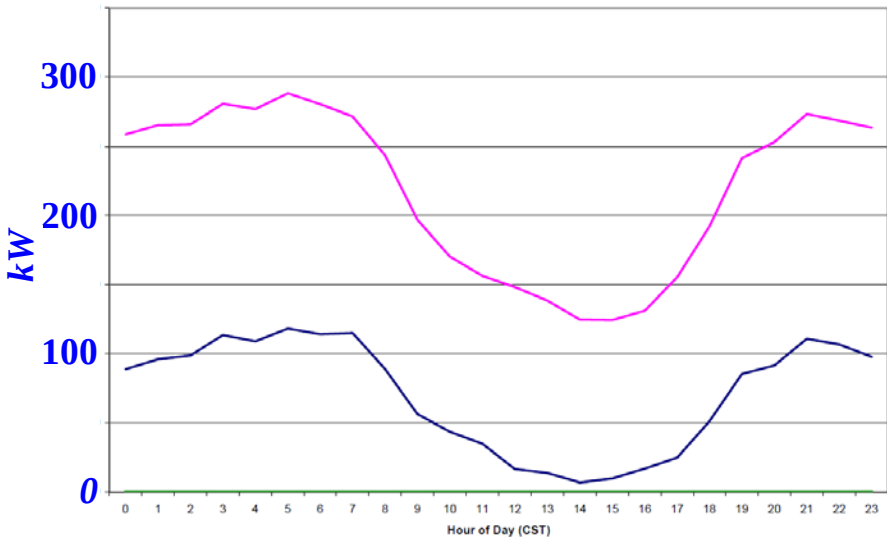
VARIATION OF WIND WITH TIME

- A key consideration in the effective utilization of wind is the correlation between wind and the load: how good is the timing of high wind speeds vis-à-vis the loads that must be supplied
- Wind patterns vary quite a bit with geography – costal and mountain regions have more steady winds – and climatic conditions such as temperature
- In the Midwest the wind tends to blow the strongest when the electric load is the lowest and so there is a perfect mismatch

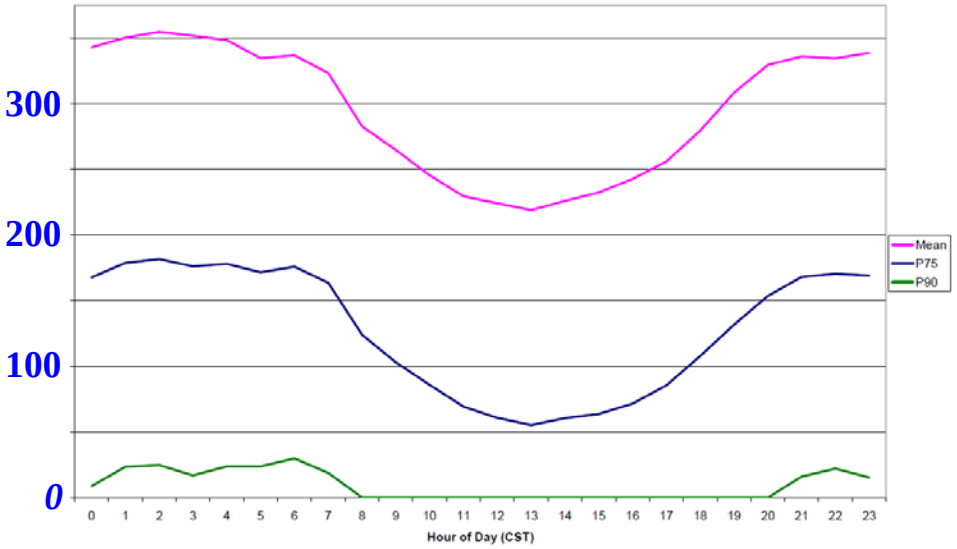
MISALIGNMENT OF WIND POWER OUTPUT AND LOAD



UPPER MIDWEST HOUR WIND VARIATIONS



August



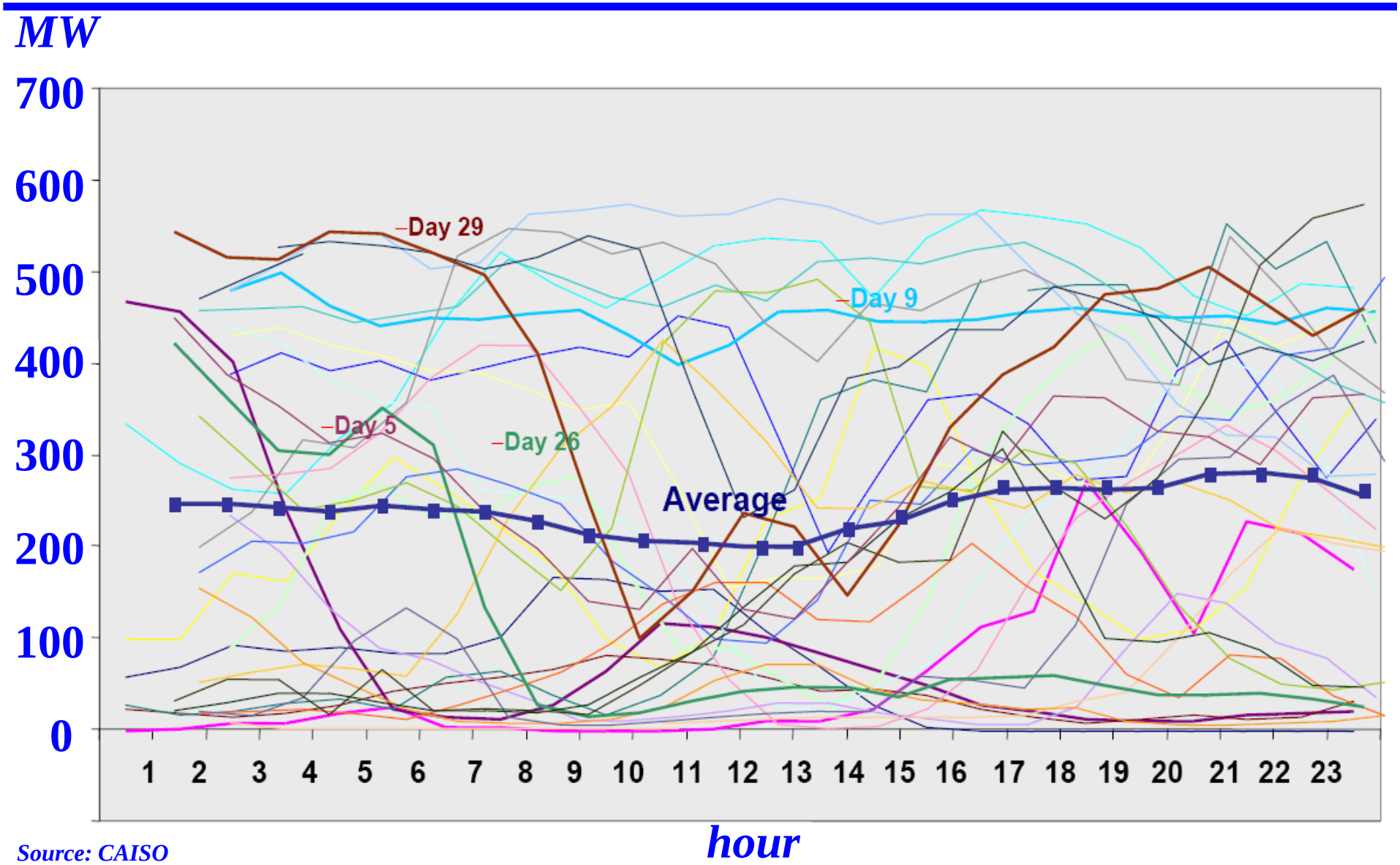
April

Source: www.uwig.org/XcelMNDOCwindcharacterization.pdf

INTEGRATION OF WIND ENERGY INTO THE POWER GRID

- Wind power impacts grid operations in many ways ranging from transient and dynamic effects to steady-state power flow behavior, with voltage and frequency impacts being key concerns
- The large variability of wind necessitates operators to take measures to manage their impacts

CAISO APRIL 2005 DAILY WIND PATTERNS

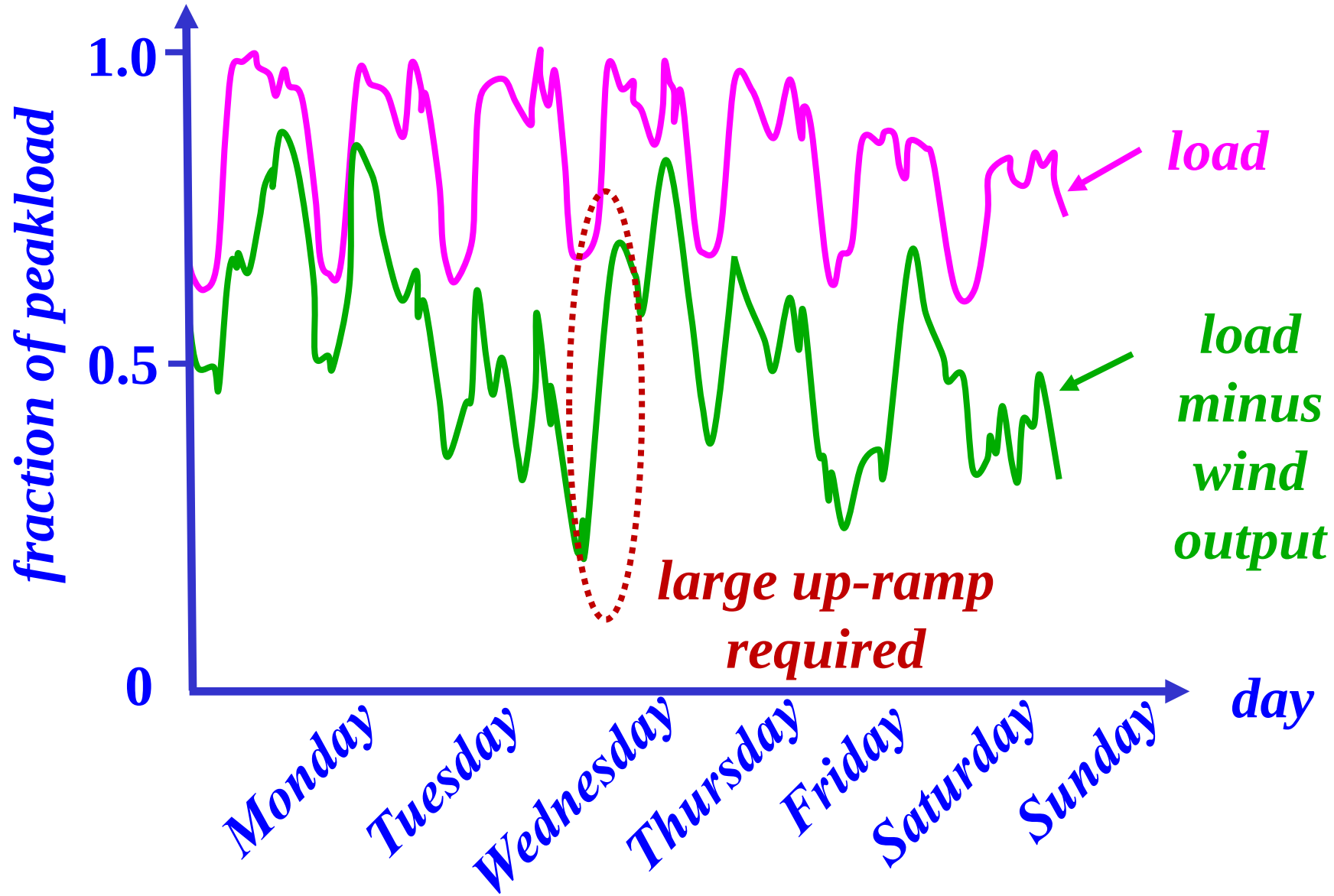


Source: CAISO

CAPACITY RESERVES AND FREQUENCY REGULATION

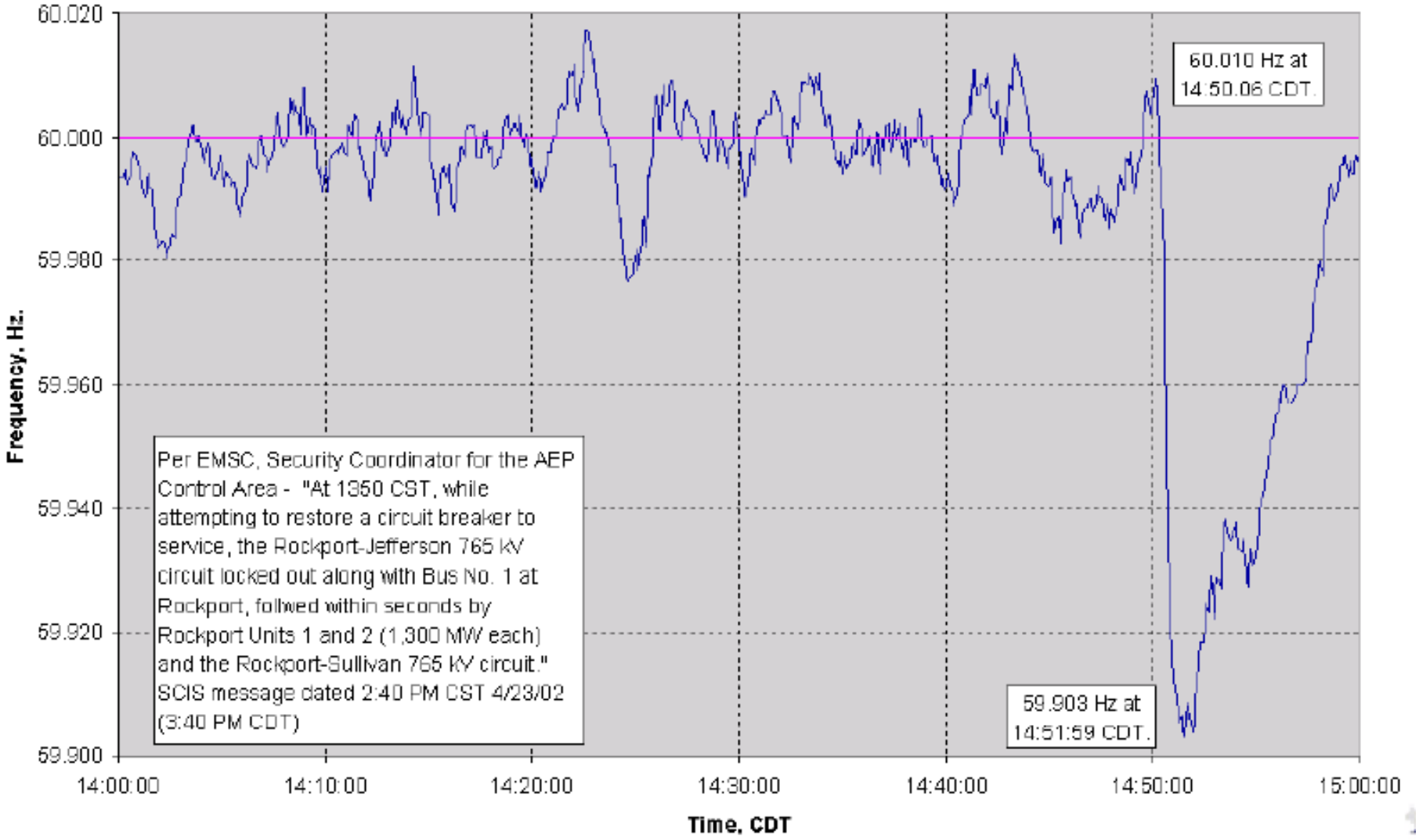
- A key need in power system operations is to ensure that power system generation exactly matches the total load plus losses at all times
- Generation shortfalls can suddenly occur because of the loss of a generator and operators must maintain sufficient reserves – generation that is on-line but not fully loaded – to account for the loss of the largest single generator in a region and other possible contingencies
- Moreover, the operators must ensure that the frequency in the system is maintained at its nominal value

EFFECTS OF DEEP WIND PENETRATION INTEGRATED INTO THE GRID



Adapted from: M. Lange & U. Focken, "Physical Approach to Short-Term Wind Power Prediction", Springer, 2006

EASTERN INTERCONNECT FREQUENCY RESPONSE FOR LOSS OF 2600 *MW*



CAPACITY RESERVES AND FREQUENCY REGULATION

- As a wind turbine output varies with the cube of the wind speed, even a modest drop in the wind speed can result in a major loss of generation
- Due to the limited controllability of wind resources, the operator has no choice but depend more extensively on conventional resources to supply adequate reserves and frequency regulation

