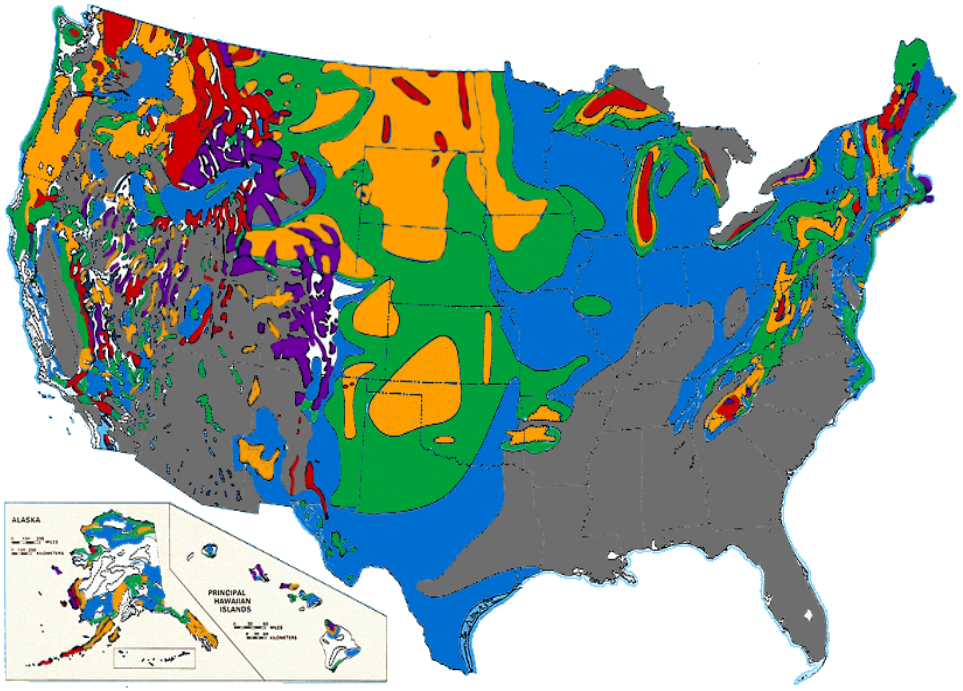
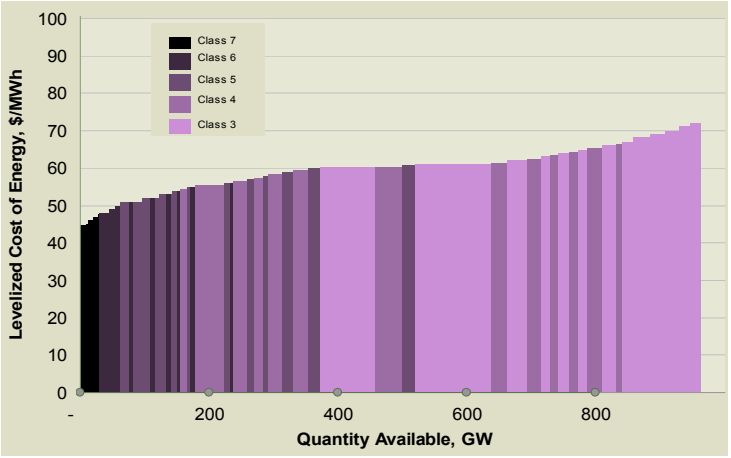
20% US Wind Technology & Manufacturing

JP Lyons
GE Research
June 2007

20% Wind is Feasible

- Resource exists
- Realistic technology path
- Mfg is a (manageable) challenge
- Raw materials tight
- Economics work
- Electric grid can expand to support
- Siting challenges manageable





Black & Veatch Supply Curve*

- Broad flat supply curve, robust wind resource
- 5-7 c/kwhr with 1000 GW availability
- With new transmission build capacity is 10x

Wind Technology

Today's Land Base Utility Class Turbines

- 1.5 – 3.0 MW Upwind Configuration
- 80 – 100 Meter Tower Height
- VS/VP
- Distributed component drivetrain
- Tubular Steel Towers
- ~65 kWhr/kg tower top mass
- 200 MW + Windfarms

Performance

- 98% Availability
- 40+% Capacity Factor at IEC-II 8.5 m/s
- CF% +10 pts in last 5 yrs

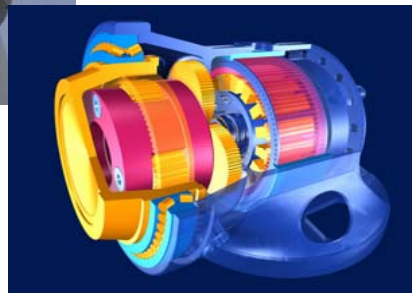
Tech Improvements

Scale

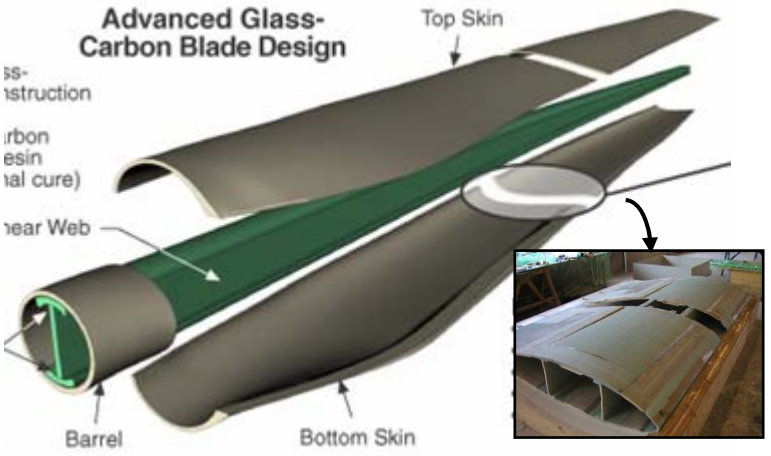
- 5MW machines on the Great Plains
- GW scale land projects
- In-situ blade & tower mfg
- 90 kWhr/kg specific yield

Power Train

- Compact 1-stage integrated gearbox, bearings, generator
- PM generators
- Full MV power conversion



5MW Multibrid – compound planetary gearstage + PM generator



Automated prepreg layup

Blades

- Larger rotors, high eff airfoils + 10% CF
- Load mitigation
  - Independent blade pitch control
  - Bend twist coupled
- Automated CF sparcap & blade root
- On site blade infusion

Offshore Technology

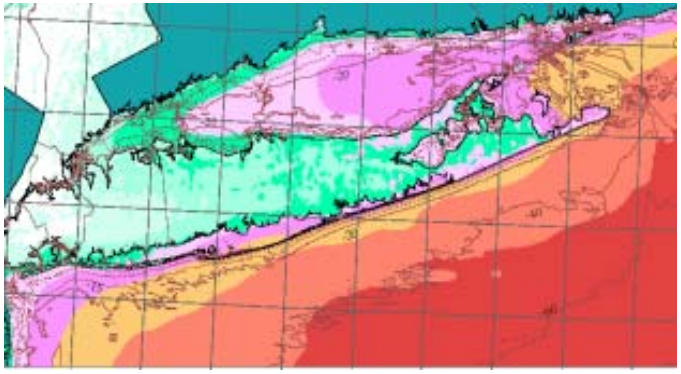
Offshore Technology

- Development and demo stage
- 900 MW Installed, shallow water
- 3 – 4 MW Upwind Configuration
- 80 m towers
- Monopile & gravity foundations < 15m
- Infrastructure not yet available in US

Performance

- Average 45+% Capacity Factor
- Availability & Cost Not Established
- 10-11 c/kwhr UK Thames Estuary site

Offshore Technology



LI Offshore Wind - 40-50 m Depth

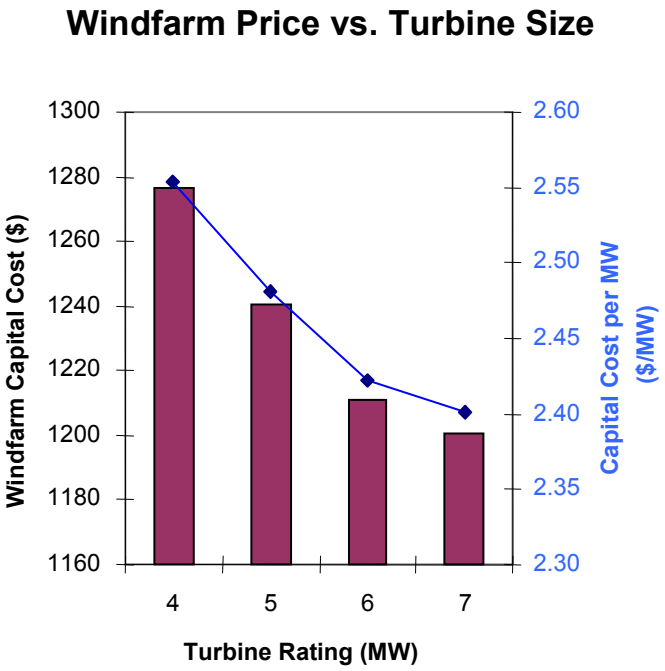
2003 Worlds Largest Offshore Farm –
NYSTED 165 MW w/ 2.3 MW Bomus Turbines

US Offshore Wind

- Shallow (0-20m) limited US sites
- Turbine 30% total Installation costs - staging, foundations, grid connect, O&M costs dominate
- Proactive environmental impact assessments & design mitigation strategies
- Support infrastructure – vessels, dock side sites

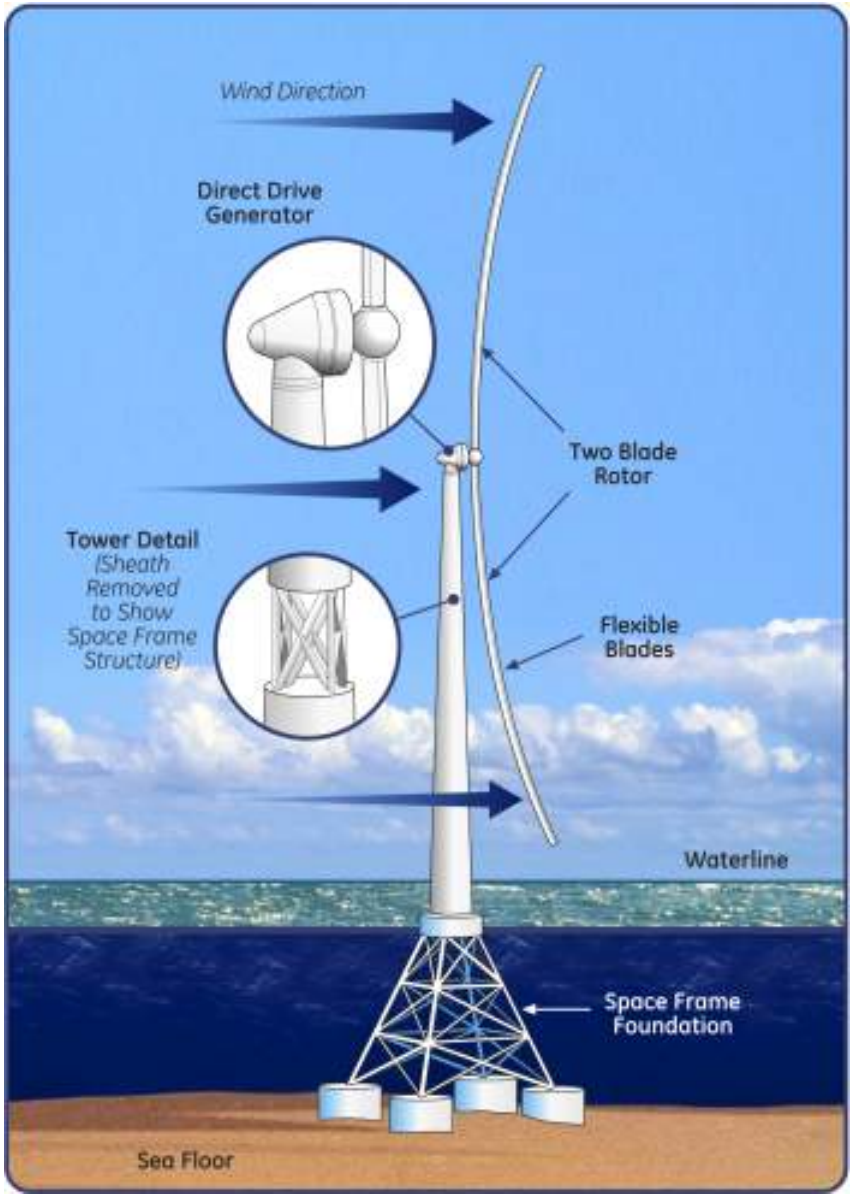
Technology Needs:

- 5-10 MW scale turbines
- Foundation technology 40m
- 8 c/kWhr achievable



10 MW Turbines

- 180 m rotor diameter
- Downwind 2 blade machine
- Flexible compliant blades
- Flow controlled 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



Can we build it?
Do the economics make sense?

Manufacturing Assumptions

- Next decade: manufacturing growth rates of 20-25% necessary to reach annual installations of ~ 20 GW in the U.S.

- Maintaining this rate through 2030 results in 20% Wind generation

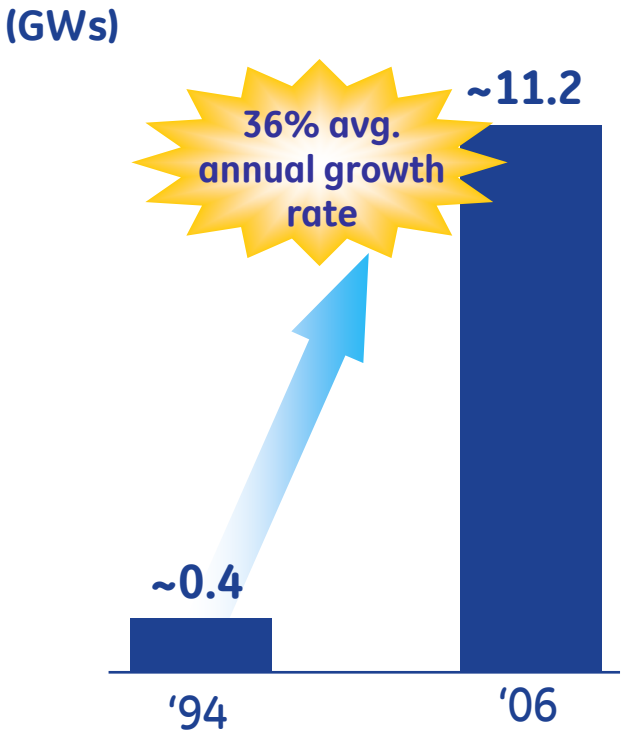
- Annual WTG installations starting at ~2000 to ~7,000+ by 2017

- 10%-20% ↑ in capacity factor and 10% ↓ in capital costs by 2030

- Availability of raw material, investment, and qualified labor is achievable

Wind Growth

Annual Global Manufacturing



Development rates for other power generation technologies:

Nuclear power

1960: 1GW 1960 to
1997: 343 GW
17% avg annual growth

Hydro power

1950: 45 GW
1996: 714 GW
6.2% avg annual growth

Gas turbines

1963 – 1980: 10% avg annual growth

Germany ... more wind power in first decade then nuclear power

Wind: Growth rate consistent with 20% scenario

Raw Materials

Observations

- Some challenges for increased demand of core materials (balsa, foam), carbon fiber and permanent magnets … But manageable

- Increasing cost of resins and adhesives

- Simplification of nacelle machinery and improved labor learning curve … should reduce amounts of raw material and increase supply reliability

- Turbine material usage will likely continue to be dominated by steel, but opportunities exist for introducing lightweight materials

US Market during the "CCGT bubble"
Steel "Material Intensity" on a Tons/MW basis
96 GW/yr CCGT equates to 16+ GW/yr Wind

Manufacturing

Observations

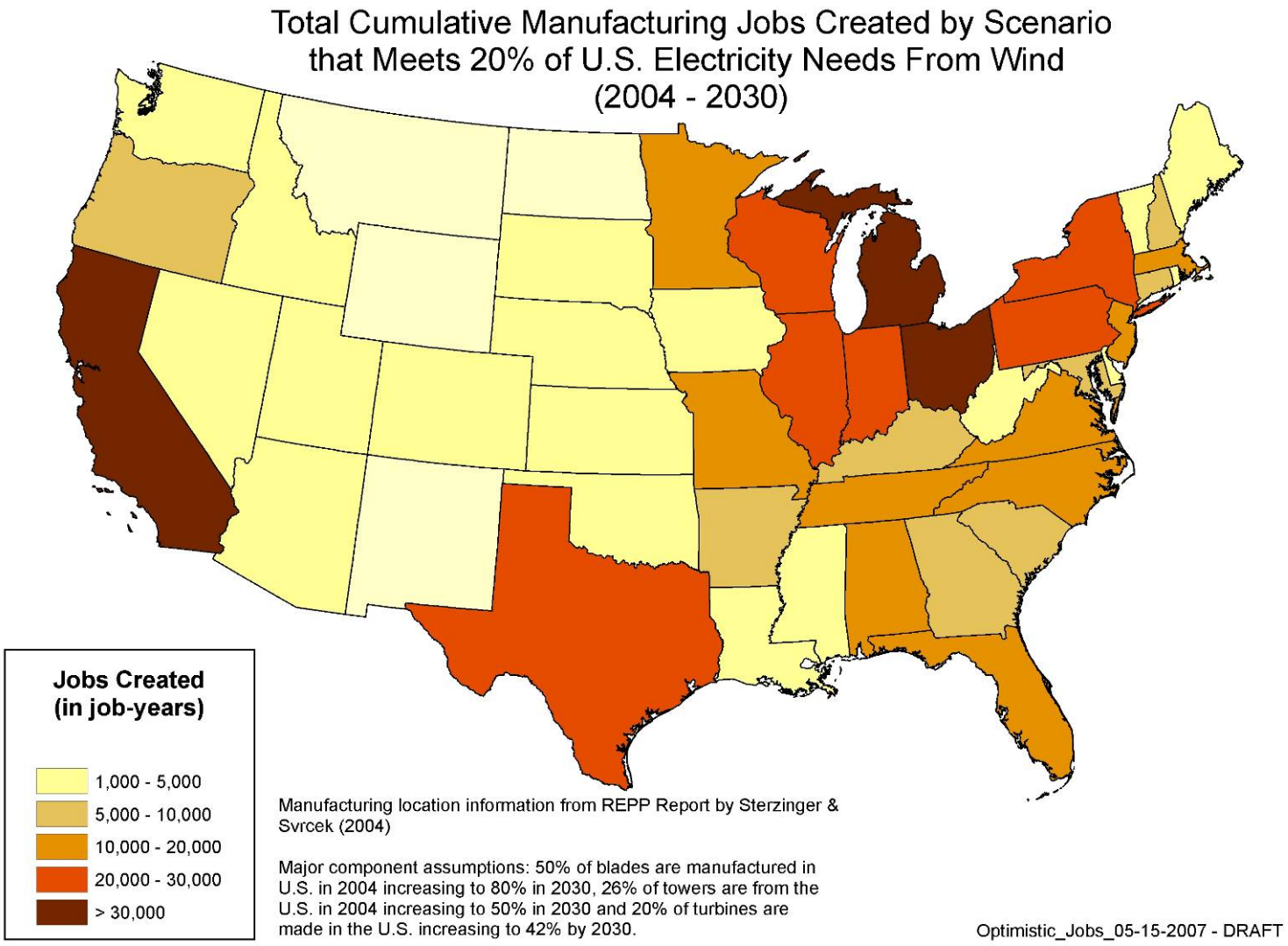
- Mfg capability has to increase with demand ...
  annual 20-25% increase

- Drive towards more local mfg content

Increased manufacturing demand for:

- Permanent magnets manufacturing capacity
- Carbon fiber and fiberglass manufacturing
- Large gearboxes
- Large steel casting
- High-power T&D

Labor and Investment



Conclusions

Reaching 20% by 2030 …

- Policies that reduce financial risk
- Increased local manufacturing content
- Small number of utility scale wind turbine manufacturers in the US today …
- Investment required for manufacturing capacity is reasonable
- Tech investments have big payoff; 1 c/kWh COE worth $12B/y in 2030
- No critical barriers in materials or industrial capacity to achieve goal
- Comparable growth has been managed in other industries