Wind Energy Technology

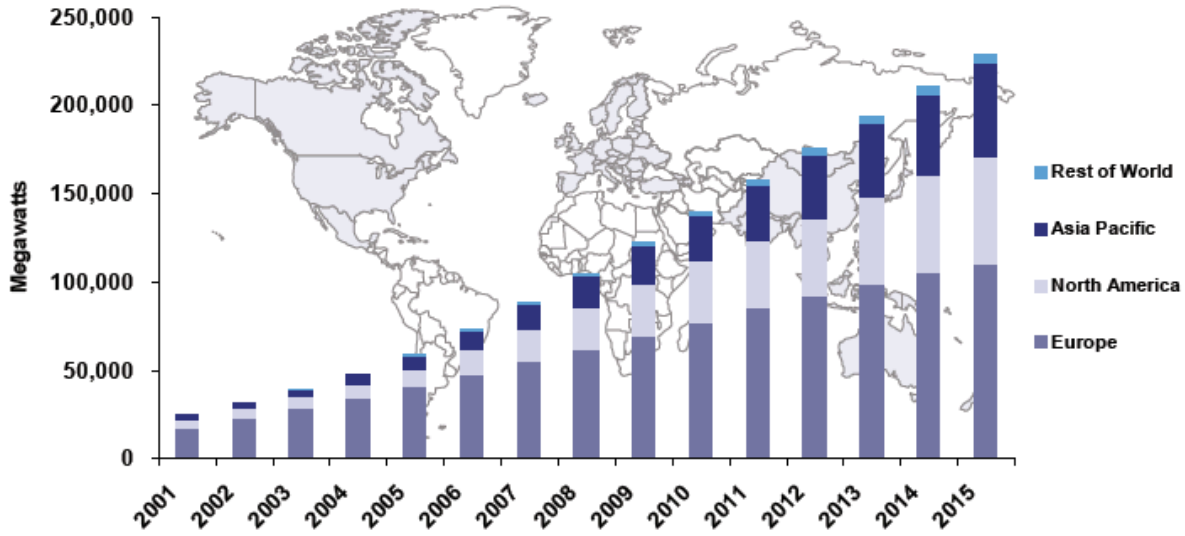
RNRF

12 Dec 2009

JP Lyons - Novus Energy Partners

Wind Now Mainstream

- Booming market, $50B industry growing at 25% CAGR
- GE $8+B 2009 revenues, 10,000 1.5 machines installed
- Good US sites (8+ m/s) - lowest COE of any new generation
- US 20+ GW's, 8.3 GW 2008, 42% new electricity
- GW scale projects in sight



Source: Emerging Energy Research

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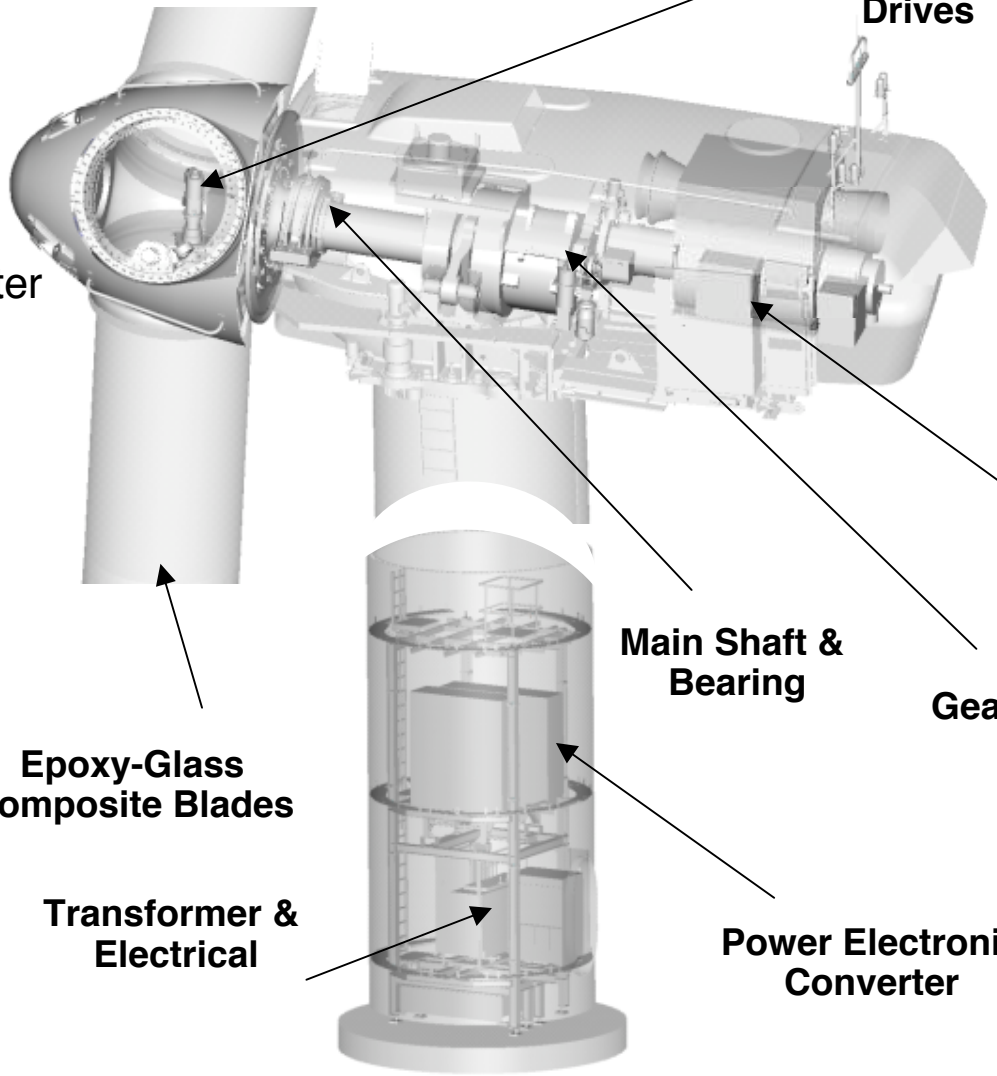
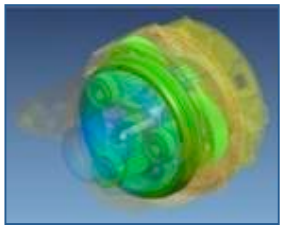
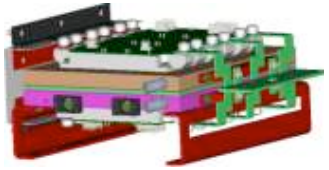
Modern Wind Turbines

GE 1.5sl

- 1.5 MW
- 77 M Rotor Diameter
- 50-100 M Tower
- 98% Availability
- Speed 10-20 RPM
- Variable Pitch







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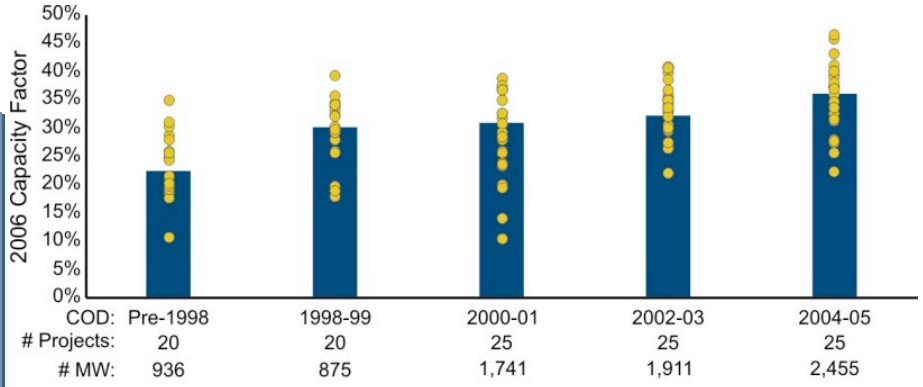
SOA Land Based Technology

Enercon E82-2MW

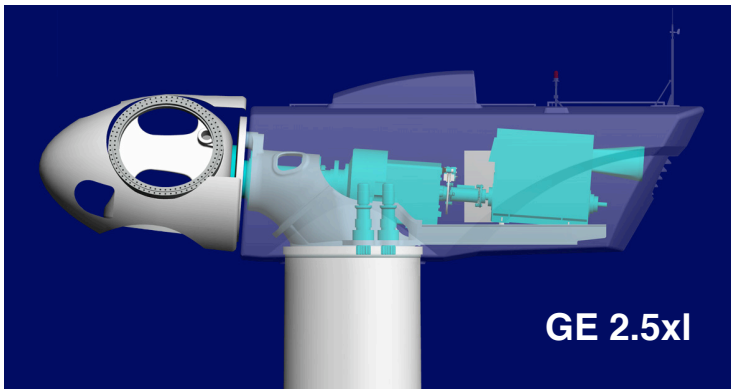
- 1.5 -3.0 MW upwind configuration
- 80-100m tapered cylindrical steel towers
- 3 stage gearbox
- Distributed component drivetrain
- Full span pitch control
- 200+MW Windfarms



Capacity Factor = (Annual Yield MWHrs)/(24*365*Power Rating)

Performance

- 97+% Availability
- 40+% CF at IEC-II 8.5 m/s
- CF% +10 pts since 2000
- ~65 kWhr/kg tower top mass



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Large Scale Wind Penetration

25% wind penetrations can be accommodated

- Studies: DENA, NY, MN, CA, ERCOT, ...

Integration costs modest ~ $3/MWHr

- Wind forecasting can reduce costs

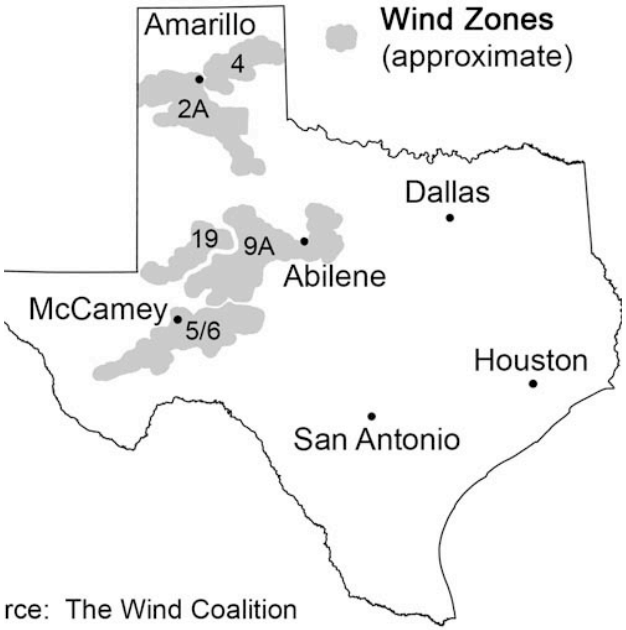
Load following at light net load can be an issue

Increased flexibility needed in generation portfolio

- Better ramping capability
- Low cost stop/start
- Lower minimum load

Large balancing area improves forecasting ~40%

- Diversity greatly reduces short-term variability
- Can improve forecasting up to 40%
- Reduces regulating reserve requirements > 50%



rce: The Wind Coalition

- **ERCOT CREZ proactive plan to deliver wind power from West Texas and Panhandle**
- **Study up to 25GW wind power**

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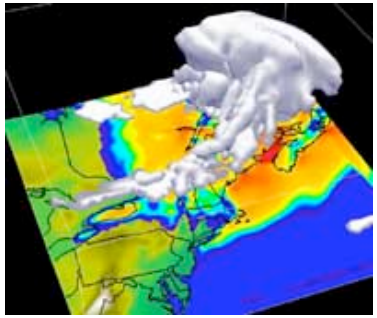
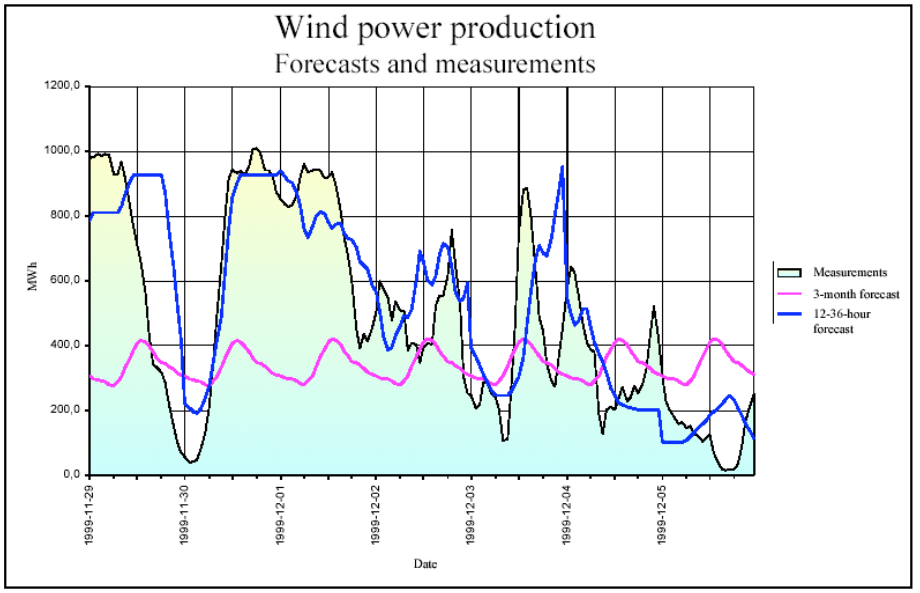
Wind Forecasting

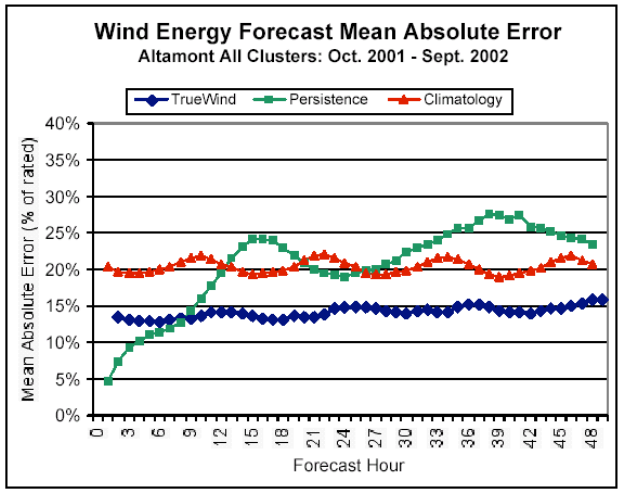
Eltra, Denmark - 2000 Study

- 1.9GW onshore farms, 16% consumption
- 3.4TWh produced, 1.3TWh miscalculated (38%)
- Climatology-based forecast, inaccuracies up to 800MW
- **$12M imbalance payments (0.3c/kWh)**



Advanced forecast using a combination of local statistical models, and 3D meso-scale climatology





Current State-of-the-Art

- **Local statistical model + 3D climatology model** - 10-15% mean abs error for day-ahead and 5-10% error for 6 hr ahead forecasts
- 2005 regulations in **Spain** provide:
  - Penalties for >20% error on 24hr production forecast
  - Incentives for <10% error over rolling 4hr forecast
- 2003 **Cal ISO** regulations – unbiased hourly, daily forecasts – settlement monthly for net deviations at average rate
- **Utilities** need short (<6h), med (24-36h) and long term (>72h) forecasts

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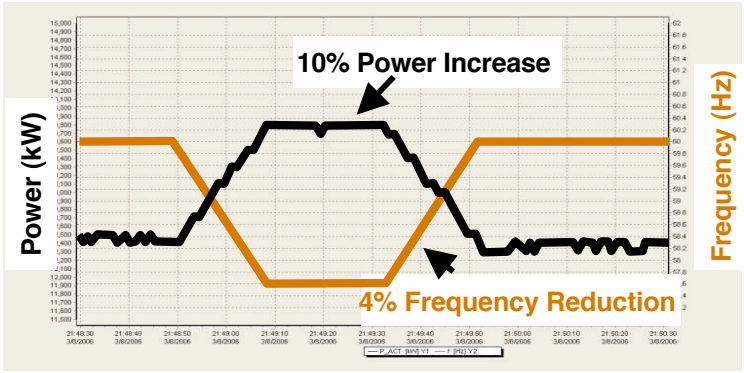
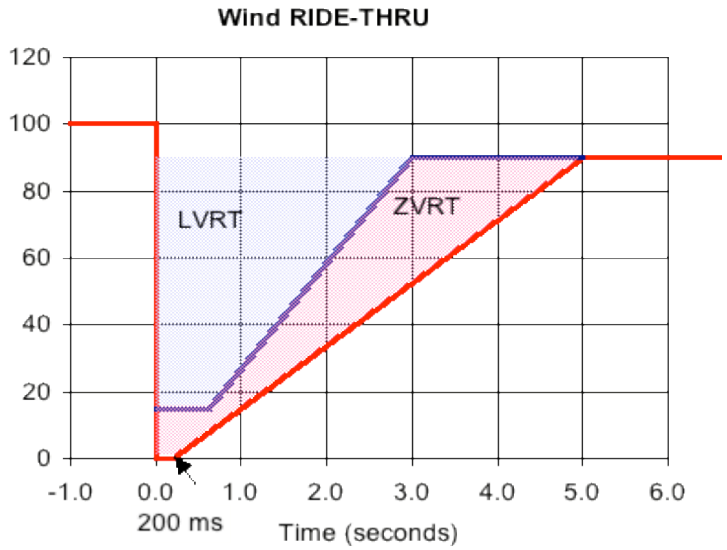
Grid (Friendly) Integration

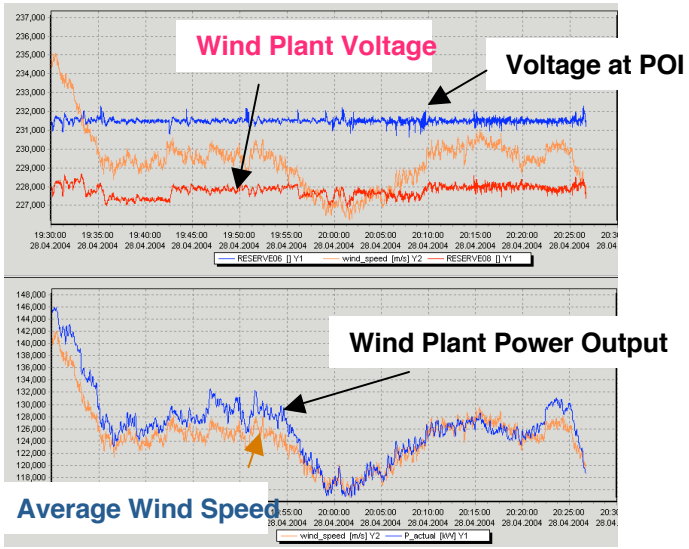
- Rapid evolution of Grid Codes
- Mimic thermal plants – freq droop, var support
- Power electronics have changed wind technology from a detriment to an attribute
- ZVRT fault ride-thru to be required by FERC
- Reactive power control – voltage regulation, VAR support w/o power
- Active power control - ramp rates, power curtailment, power droop W/ frequency, virtual inertia
- Forecasting can significantly improve scheduling, penetration & integrated system performance



Active Power Ramp-Rate Control – GE/ESB Ireland



Voltage Transient Ride-Thru Requirements



Colorado Green 220 kV Bus Voltage Regulation

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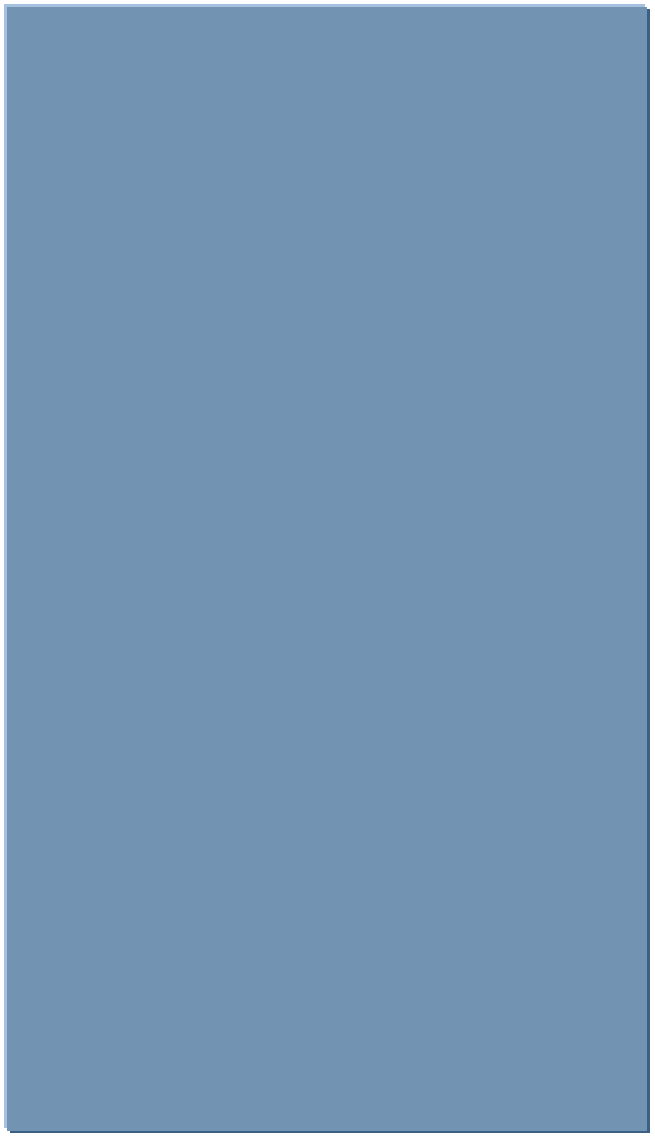
New Innovation

FloDesign Turbine
Venturi + Mixer/Ejector
(Mass)



Coriolis Wind VAWT
(Israel)

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Offshore Wind

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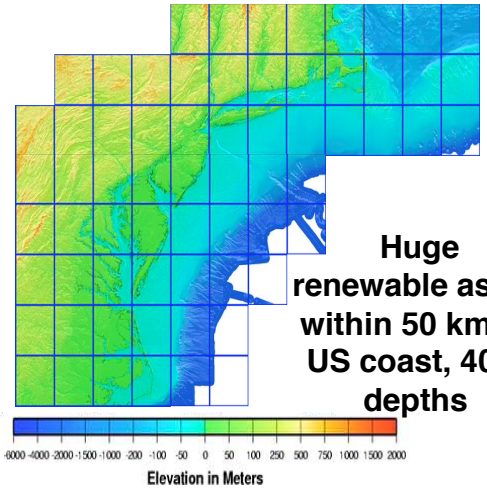
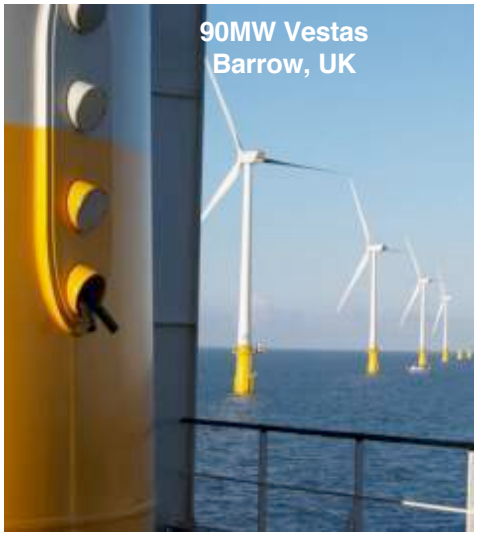
Offshore Wind



Huge renewable asset within 50 km of US coast, 40m depths

Offshore Technology Today

- 19 Projects, 900 MW Installed, shallow water
- 3 -4 MW upwind configuration
- 5-6 MW turbines in prototype
- 80 m towers
- Monopile & gravity foundations < 20m
- Many challenges – turbine only 1/3 project costs



Performance

- Great wind 9+ m/s
- Average 45+% capacity factor
- xx c/kwhr UK Thames Estuary site
- SOA 5 MW viable in UK market

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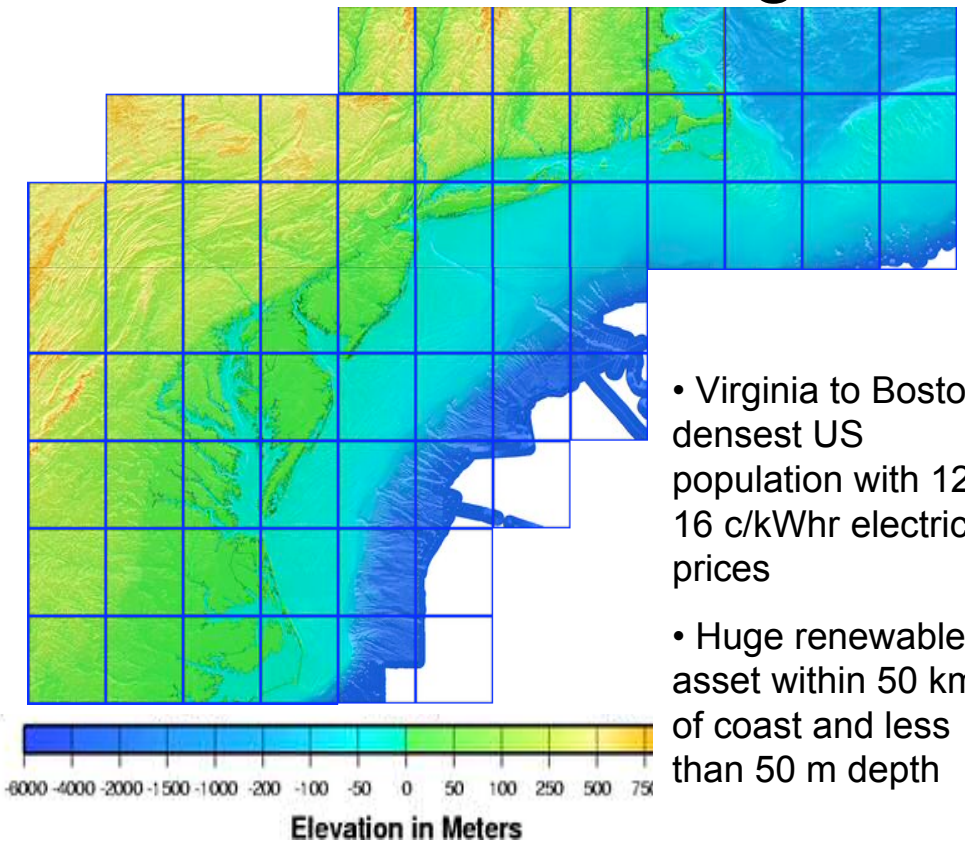
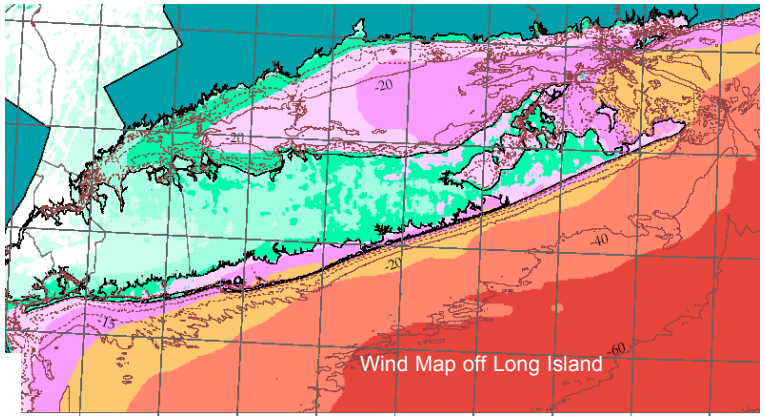
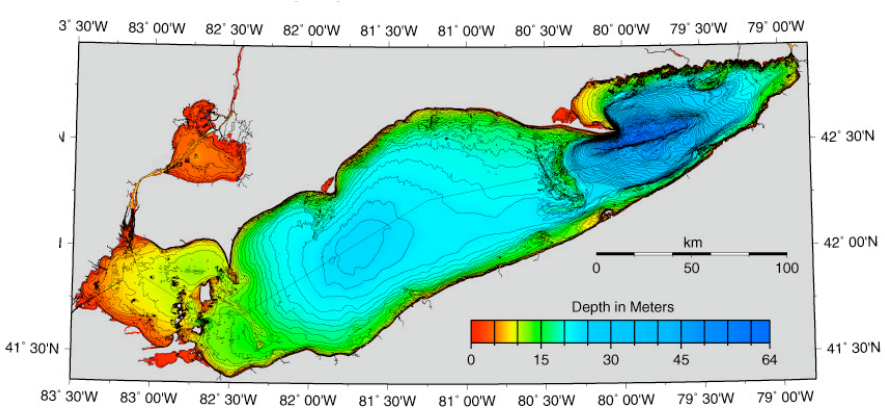
Gamechanger: US Offshore Wind



- Virginia to Boston, densest US population with 12-16 c/kWhr electric prices
- Huge renewable asset within 50 km of coast and less than 50 m depth



ConEd/LIPA planning offshore farm



US Offshore

· RPS in NY, Mass, Conn RPS will drive need for large scale renewables

· Deeper water foundation technology & higher power more economic turbines needed

- Great Lakes close to large load centers in US & Canada – Toronto, Cleveland, Detroit, Chicago, Milwaukee, …
- Lake Erie shallowest at 15-30 m

· Foundation technology 50-70 m would enable large deployment – need to withstand ice conditions

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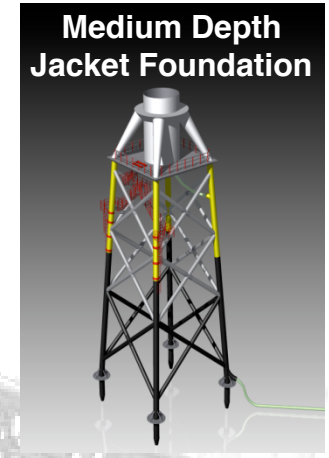
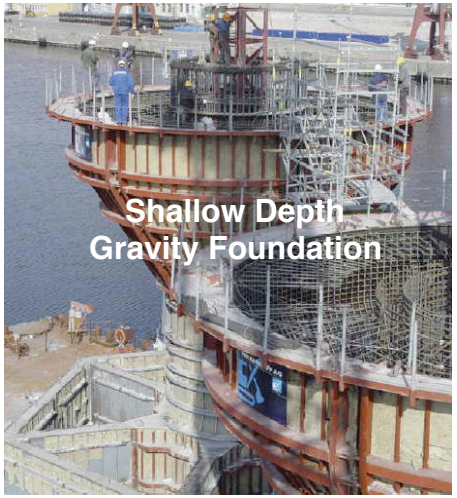
Offshore Technology

US Offshore Wind

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





Technology Needs

- 5-10 MW scale turbines
- Foundation technology 40-50m
- Hydrodynamic coupled design codes
- 10 c/kWhr achievable in shallow water
- Hurricane ride-thru

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Gravity Foundations - Nysted Rødsand

72 foundations: 1300 tons + 500 tons ballast at depths of 7-12 m

- 37,000 m^3 of reinforced concrete
- 33,100 m^3 of ballast material (olivine, rock and sand)
- 22,500 m^3 of Scour Protection
- 53,000 m^3 of Dredging
- 6,800 m^3 of crushed stone (<64mm) for stone pad.

Source: http://www.aarsleff.com/internet/acms.nsf/Webpages/168241DB8B190997C1256D2B0029822E

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Offshore Machines – Is Bigger Better?

Manufacturer	Model	Power (MW)	Rotor (m)	Gear Stages	Nacelle Weight + Rotor (kg)	Generator	kg / kW	m² / k Cf (%)
Enercon	E112	4.5	112	0	440	WF Sync	97.8	44.0
Enercon	E120	6	120	0	440	WF Sync	73.3	41.6
Vestas	V90	3	90	3	108	DFIG	36.0	43.5
Vestas	NM110	4.2	110	3	214	DFIG	51.0	44.6
Vestas	V120	4.5	120	3	214	DFIG	47.6	46.5
GE	3.6sl	3.6	111	3	265	DFIG	73.6	47.9
Siemens/Bonus	3.6	3.6	107	3	200	Induction	55.6	46.4
Repower	5M	5	126	3	400	DFIG	80.0	46.3
Mutibrid	M5000	5	116	1	250	PM Sync	50.0	43.4

* planned upgrades

Vestas V90
3MW, 90m

Siemens Bonus 3.6
3.6MW, 107m

GE 3.6 MW 104/111m

Vestas NM110/V120m
4.2/4.5 MW

Enercon E-112/120m,
4.5/6MW

Prokon Nord
5MW, 116m

Repower 5M
5MW, 126m

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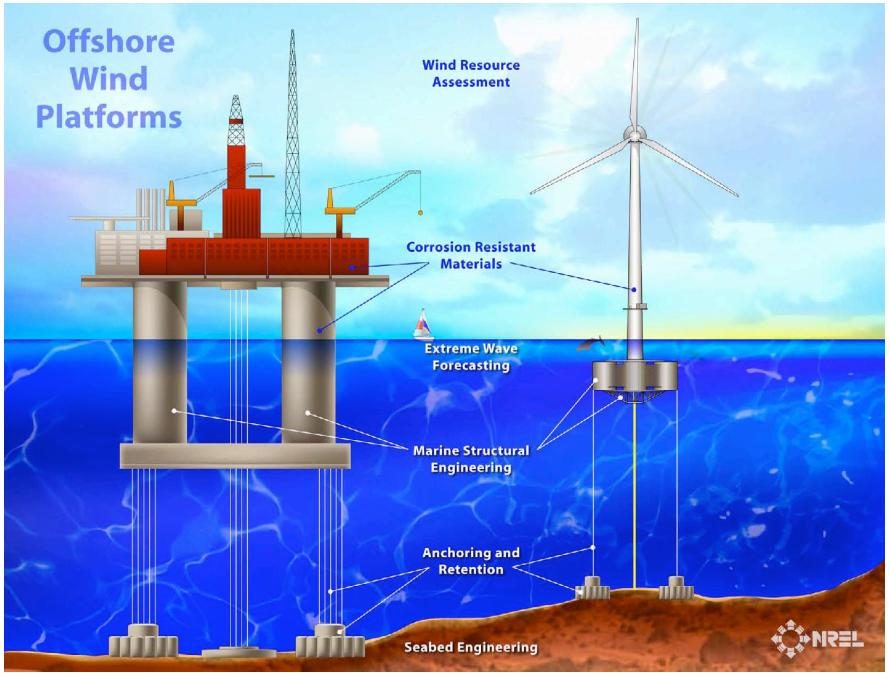
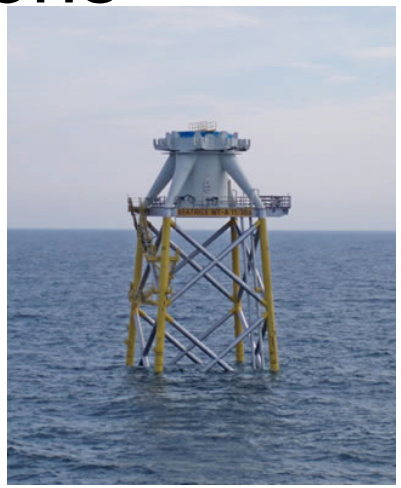
Deep(er) Water Foundations

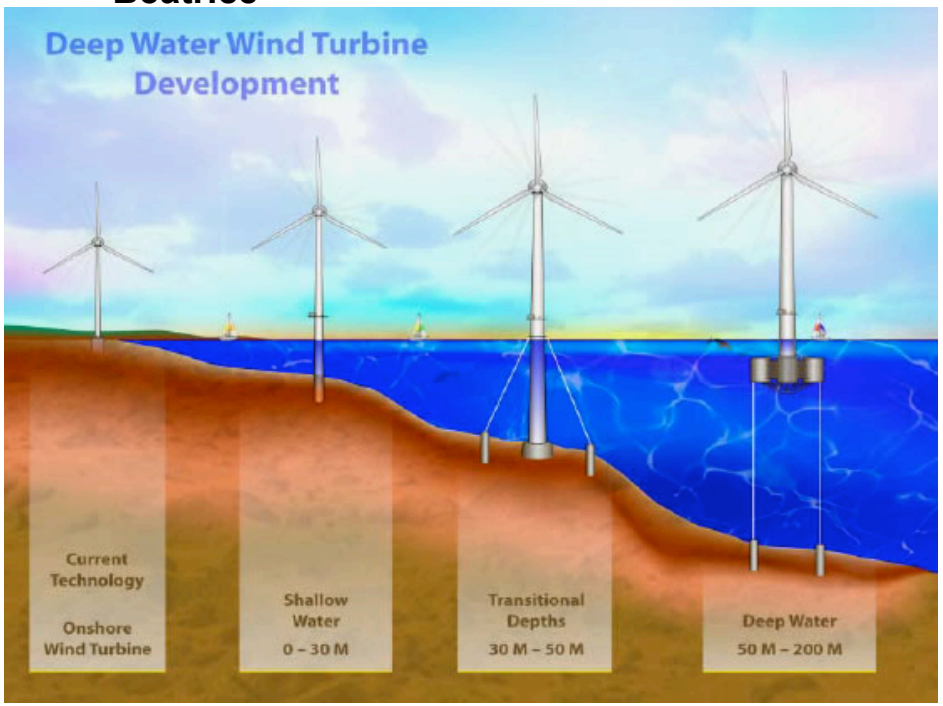




Quad Jacket - Beatrice

Blue H

Principle Power



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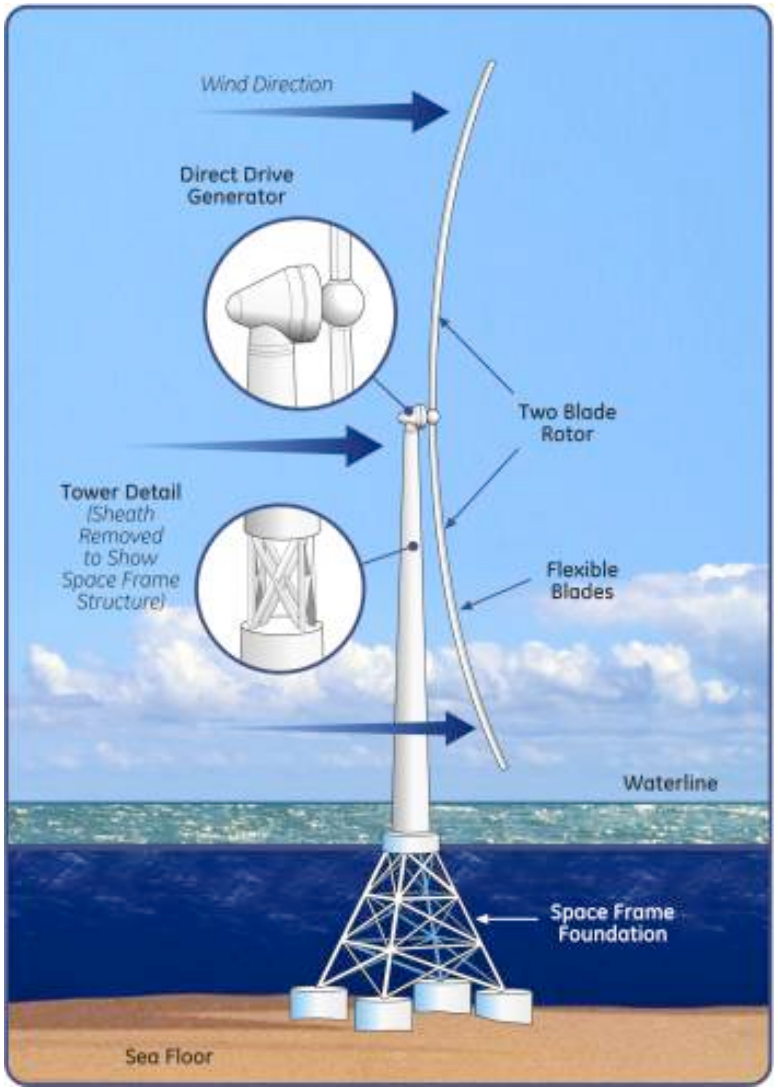
Large Offshore Turbines

EU Upwind R&D Program 8-10MW
Clipper Britannia 7.5-10 MW

10 MW Concept

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



Industry Contemplating 7-10 MW Offshore Machines

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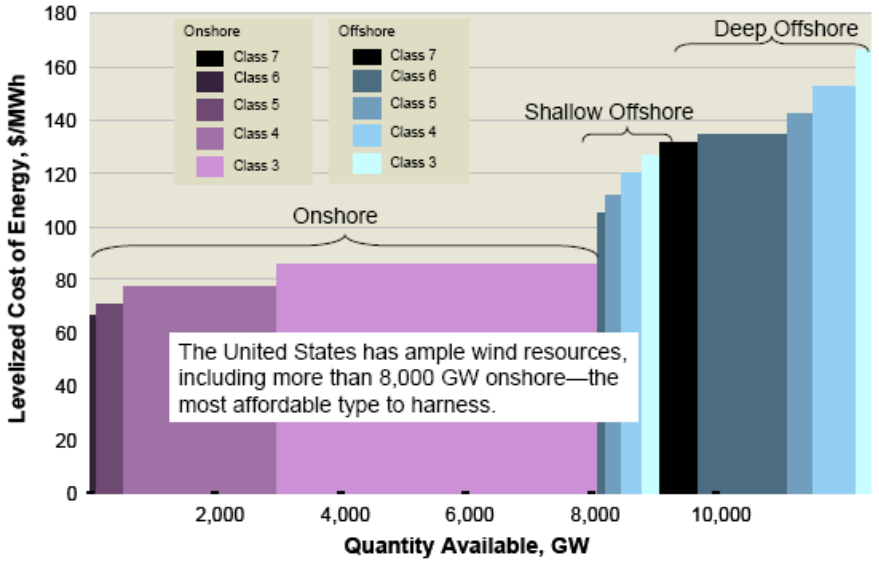
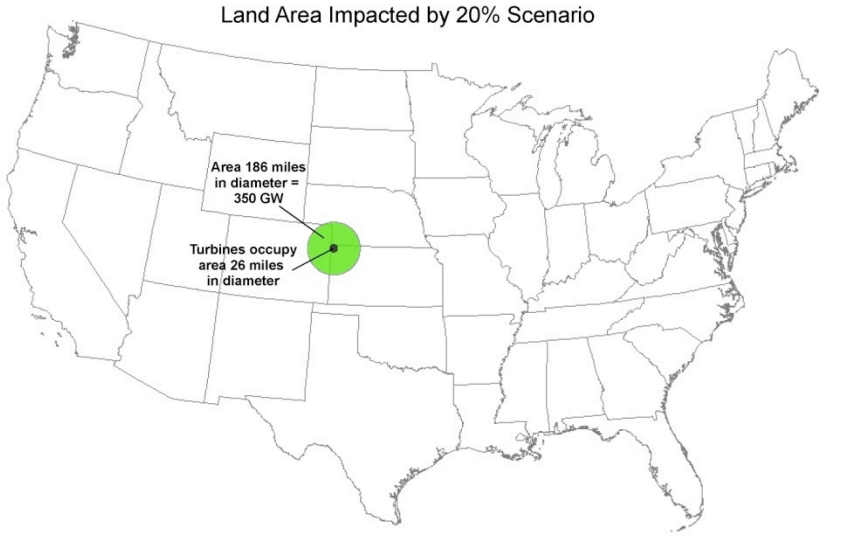
20% US Wind Vision

- 2030 DOE, AWEA, 20% Energy Roadmap
- 300+ GW, 15% CAGR, 25 years
- $60B investment in Transmission
- Benefits (2030):
  - 50% reduction NG electric gen
  - 18% reduction in coal gen
  - 7500 MMTCE cumulative carbon reduct
  - 17% water use reduction for west gener
  - 150,000 direct jobs created

Black & Veatch US Wind Supply Curve





US Wind Resource

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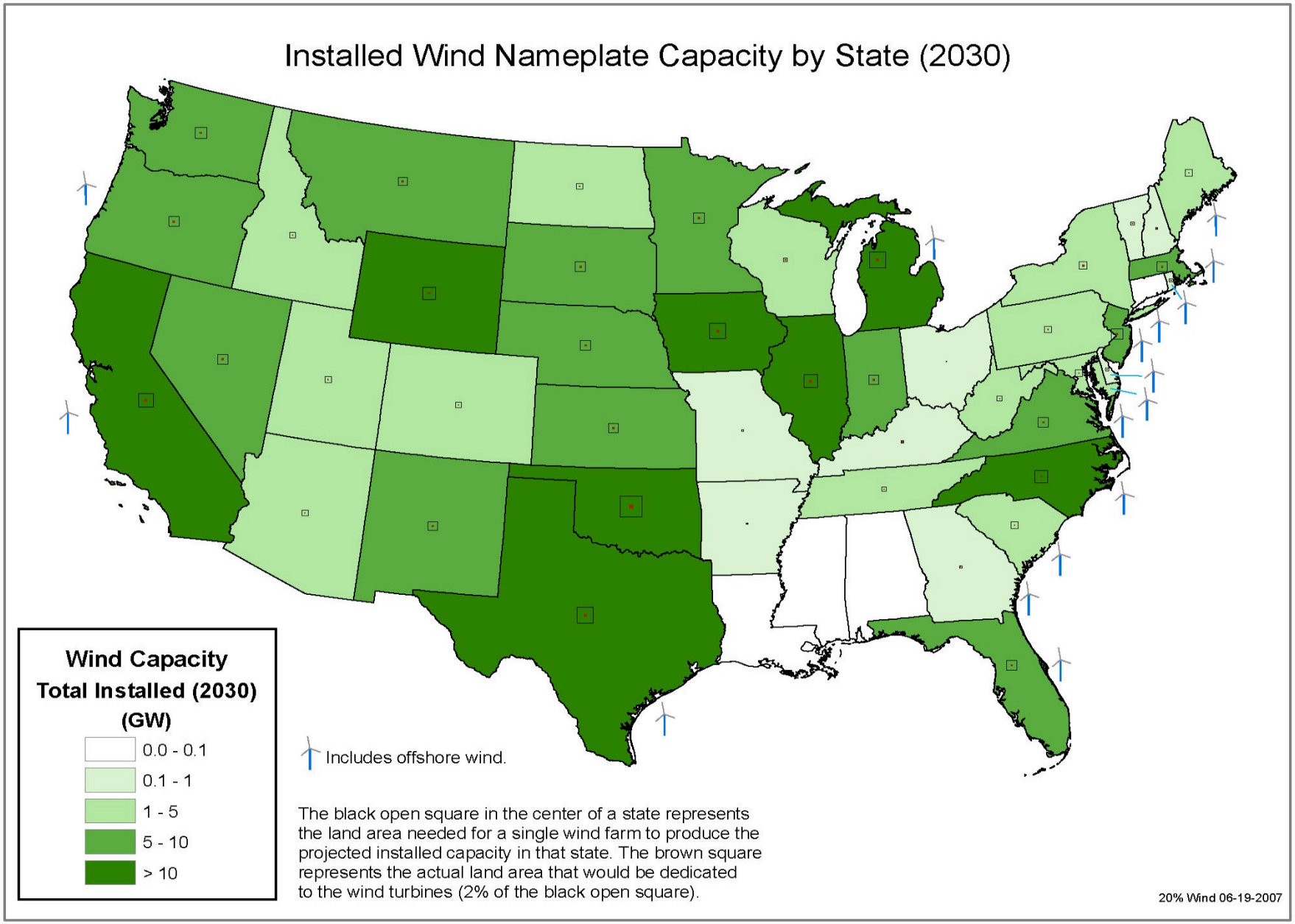
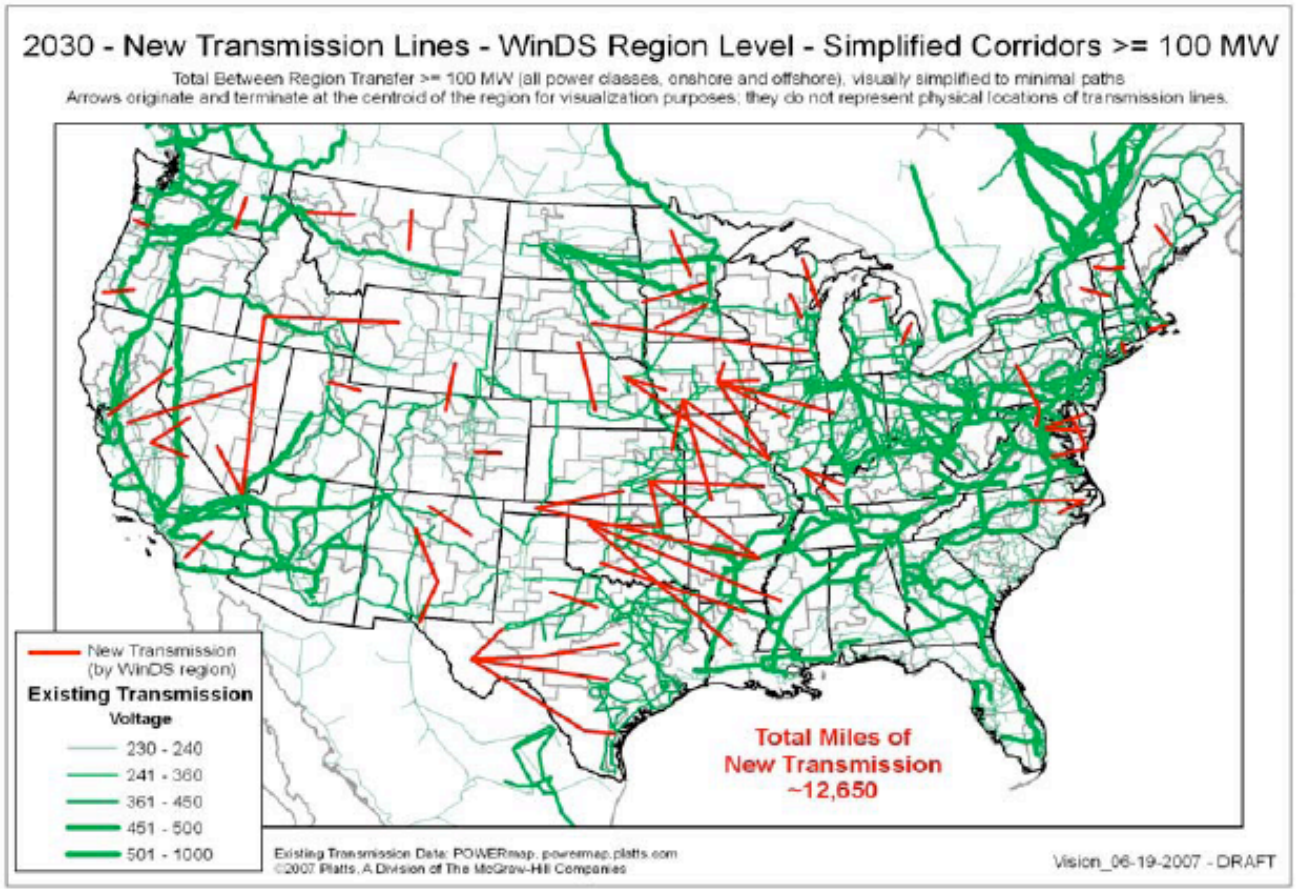

Installed Wind Nameplate Capacity by State (2030)
Wind Capacity
Total Installed (2030)
(GW)
0.0 - 0.1
0.1 - 1
1 - 5
5 - 10
> 10
Includes offshore wind.
The black open square in the center of a state represents the land area needed for a single wind farm to produce the projected installed capacity in that state. The brown square represents the actual land area that would be dedicated to the wind turbines (2% of the black open square).
20% Wind 06-19-2007

Fig 1-6

NREL – New Transmission



Penalties for variable resources

- Eliminate imbalance penalties
- Promote spot energy markets

Balkanized electricity markets

- Eliminate pancaked rates
- Develop RTO's to increase pooling
- Regional trading

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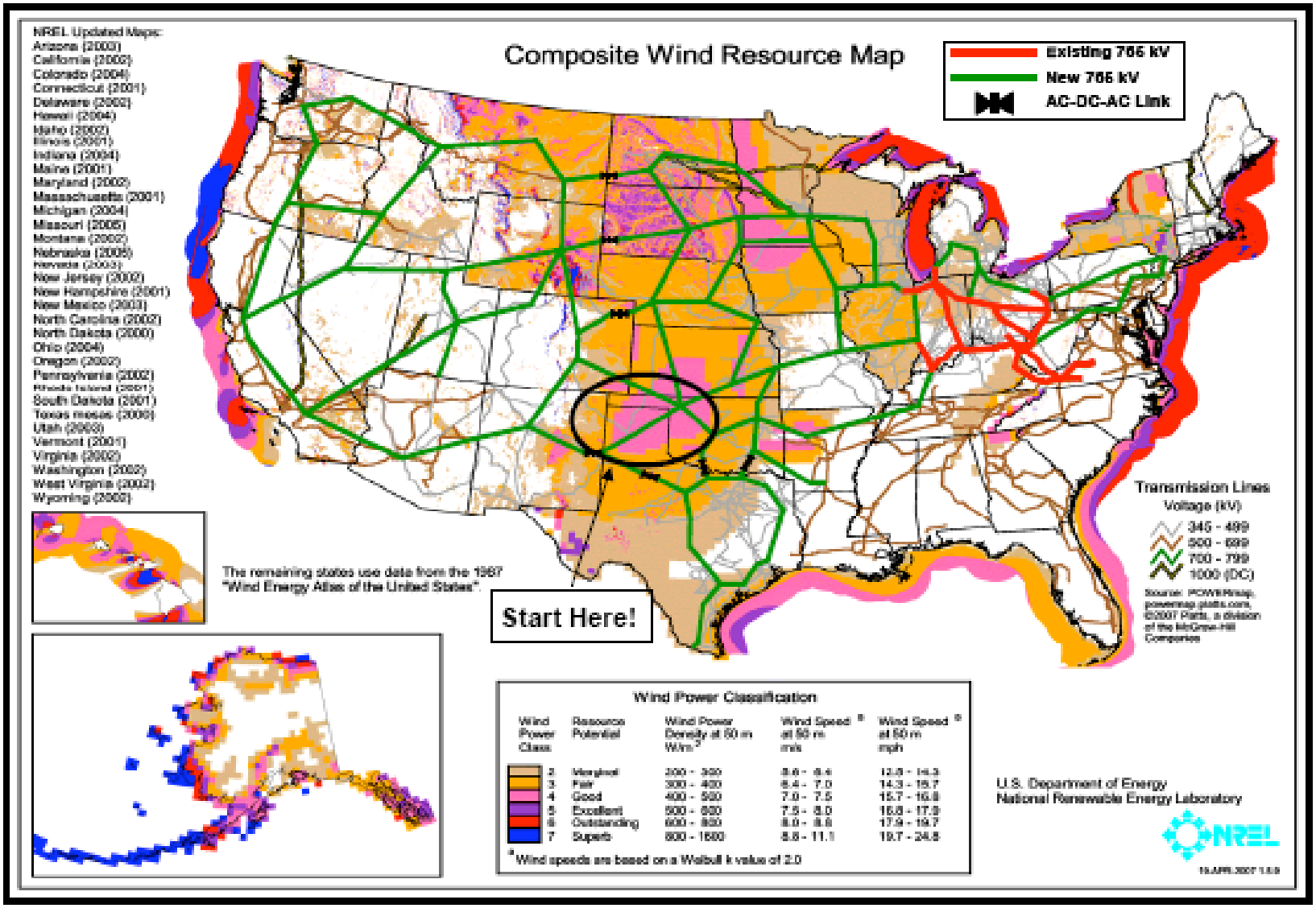
AEP – 765 kV Network Overlay



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Wind Energy Future ….

No fundamental barriers to achieving 20-30% electricity from wind

- US & China have rich land based resources

Land based wind already economically viable

RPS invaluable to initiate change

Tech investments can have huge payoff

- 1 c/kWh COE worth $12B/year in 2030

Grid integration technologies need investment

- forecasting, reserve, flexible gas turbines, smarter t&d

Offshore wind will be the end game with GW scale plants

- Need larger, lighter, higher tech turbines for marine environment
- Offshore infrastructure needs to be created

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Middlegrunden – Copenhagen Harbor

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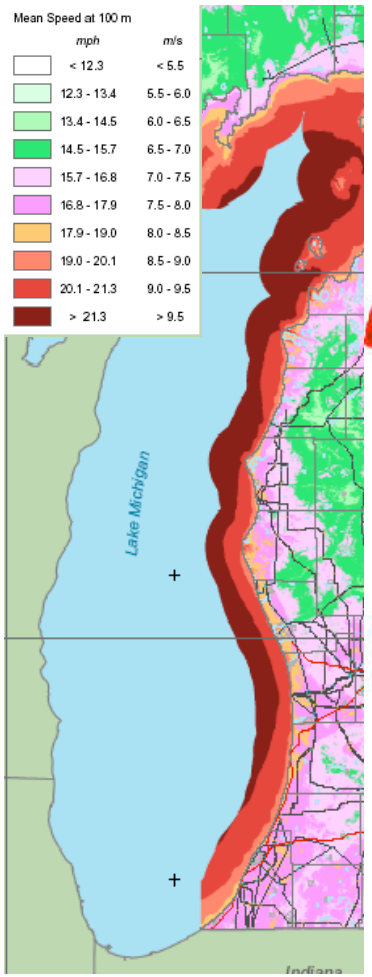
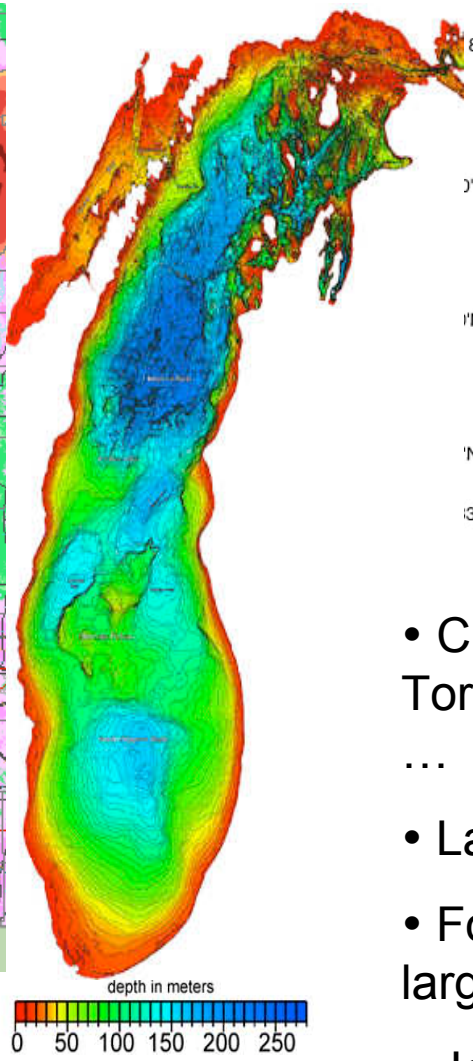
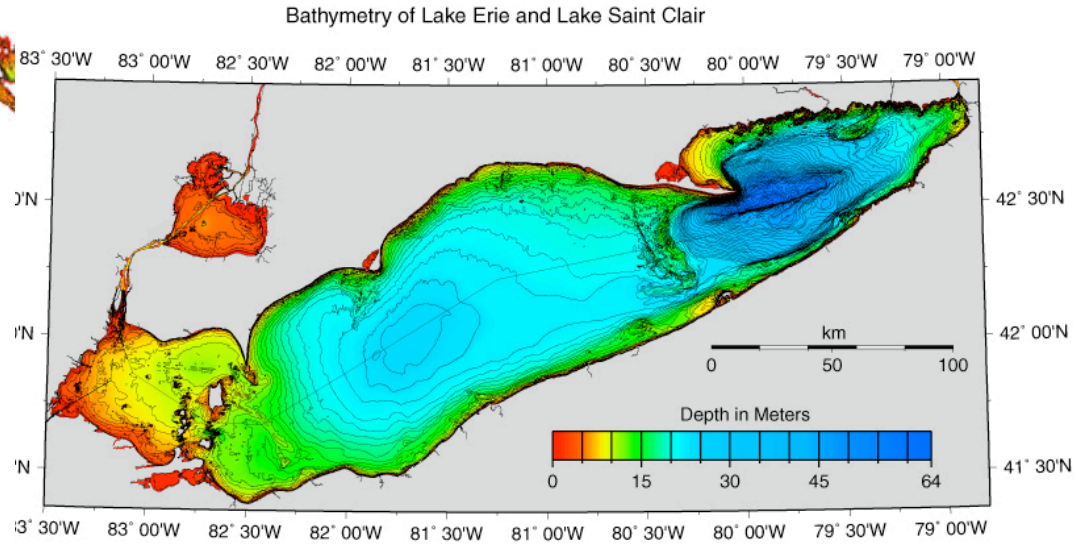
Offshore in the Great Lakes







- Close to large load centers in US & Canada – Toronto, Cleveland, Detroit, Chicago, Milwaukee, …
- Lake Erie shallowest at 15-30 m
- Foundation technology 50-70 m would enable large deployment
- Ice loading on foundations?

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The Offshore Projects


160 MW Vestas Offshore Farm – Horns Rev, North Sea


40 MW Bonus Middlegrunden Farm in Copenhagen Harbor


10 MW GE Wind at Utgrunden, Sweden


90MW Vestas Barrow, UK


176 MW Siemens/Bonus

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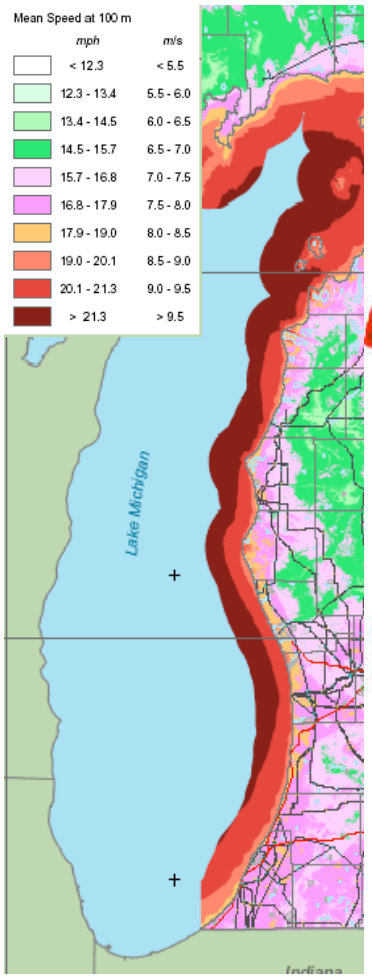
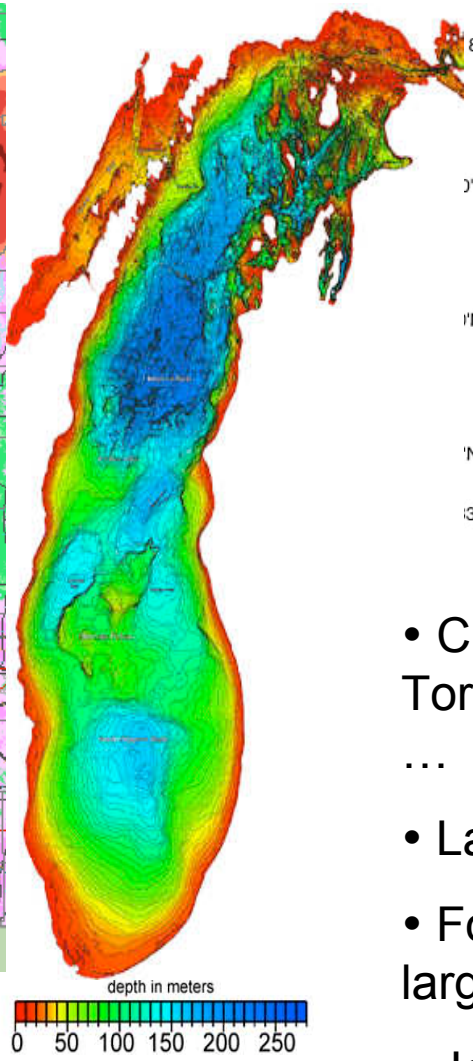
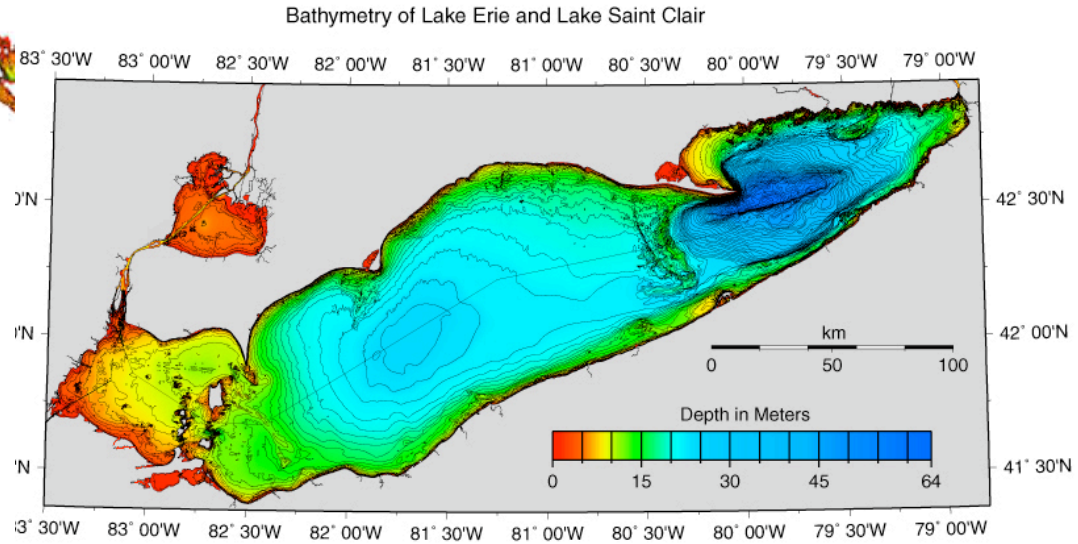
Offshore in the Great Lakes







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