Offshore Wind Energy: Prospects for Florida and the Gulf of Mexico

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FSU and COAPS
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Outline

- Sustainable Energy without the hot air
- US Energy Usage
- Renewables Conservation and Efficiency
- Offshore wind energy
- Florida, Gulf, East coast U. S. Offshore wind resources
- Research and operational needs
AT CURRENT DEMAND RATES, ENERGY USE WILL DOUBLE BY 2050

Figure 1. Concentration of important long-lived greenhouse gases in the atmosphere. Concentrations are given in parts per million (PPM) and parts per billion (PPB). Source: FAQ 2.1, Figure 1 in Forster et al., 2007

Figure 2. World primary energy demand from the International Energy Agency’s World Energy Outlook reference scenario for 2008 (Tanaka, 2008).

FROM OCEANOGRAPHY V23, 2010 THRESHER AND MUSIAL
CLIMATE MODELS OF GLOBAL MEAN TEMP RESPONSE TO CO₂

FROM MEINSHAUSEN ET AL 2009

LIMITING TEMP INCREASE TO < 2C REQUIRES LOWERING CUMULATIVE CO₂
“We have an addiction to fossil fuels and it's not sustainable”
USA  #1 Emitter of CO$_2$ since 2000

GHG emissions, year 2000

Data source: Climate Analysis Indicators Tool (CAIT) Version 4.0. (Washington, DC: World Resources Institute, 2007).

FROM MACKAY 2009

M. POWELL, FSU SEMINAR SEPT 9TH 2010
Efficiency improvements can cut demand

Renewables mostly Hydro and biomass Wind (0.5%) and solar (1%)

Wind is fastest growing renewable 30% rate/decade

Reducing Fossil fuel dependence can increase security and mitigate potential global warming
Fossil Fuels

CO₂ emissions (1996 IPCC Guidelines)

- **Coal**: 25 tons carbon /TJ, cheap, domestic
  - UCS Florida #2 importer of coal for energy generation, $1.6 B from other states, $32 M foreign coal

- **Natural Gas**: 14 tons carbon /TJ, recent discovery of large domestic supply in shale deposits
  - Extraction has high environmental cost, needs regulation
  - High price volatility

- **Oil**: 20 tons/TJ Transportation, heat, foreign sources threaten energy security
Fossil fuels carry significant long-term, subsidized environmental and health costs (NAS)

- Coal up to 12c / kwh
- Natural gas: “Fracking”, groundwater
- Petroleum: ~29c / gallon, $40B/y
- Favorable taxes, subsidies

BP $10B TAX CREDIT ON DEEPWATER HORIZON CLEANUP

MASSEY MINE WV

DEEPWATER HORIZON

DIMOCK PA

NAS 2009: HIDDEN COSTS OF ENERGY (HEALTH, ENVIRON, SECURITY, INFRASTRUCTURE)
US Energy Policy (stated)

- Cut carbon to 80% of 1990 levels by 2050
- 20% Renewable energy by 2020
- A mix of energy sources (including Fossil Fuels) will be required for some time

Currently in debate

- Renewable Portfolio Standard (RPS)
- Cap and dividend, cap and trade

NREL: 28 Coastal states use 78% of US Energy. 26 of them could supply 20% from wind by 2030
ONE 40 W LIGHT BULB ON FOR 24 H = 1 KWH

AMERICANS USE 250 KWH /PERSON PER DAY

FROM MACKAY 2009
Nuclear

- High Capacity factors, RELATIVELY CLEAN

- History of cost overruns (e.g. Areva in Finland where cost doubled, France), carbon intensive fuel

- Risks borne by ratepayers, profits go to shareholders. Fed loan guarantees put taxpayers at risk. FPL 30% rate hike request

- “Black Swan” potential (H. Andrew), Proliferation

- Lengthy license and construction phase ~ 10y

- Waste storage or recycling plans needed (e.g Sweden)

- Rate payers in Florida already paying $7 /mon for $20B Progress plant for 2016

INFO FROM NRC, FPSC, VERMONT LAW SCHOOL VS MIT STUDY

M. POWELL, FSU SEMINAR SEPT 9TH 2010
All renewables are diffuse

<table>
<thead>
<tr>
<th>Power per unit land area</th>
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<tbody>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Plants</td>
</tr>
<tr>
<td>Solar PV panels</td>
</tr>
<tr>
<td>Tidal pools</td>
</tr>
<tr>
<td>Tidal stream</td>
</tr>
<tr>
<td>Rain-water (highlands)</td>
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<tr>
<td>Concentrating solar power (desert)</td>
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</tbody>
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To make a difference, renewable facilities have to be country-sized
EXAMPLE SCALE OF THE RESPONSE NEEDED TO SUPPLY ENERGY FROM CLEAN SOURCES

FROM MACKAY 2009

2100 GW of wind (60-fold increase)
525 one-gigawatt nuclear power stations (five-fold increase)
NREL’s 20% Wind by 2030 projects 300 GW of new wind capacity (54 GW from offshore) capable of removing 25% of co2 emissions from electric power (18% coal, 50% Nat. gas displacement)

- Both onshore and offshore Florida wind farms 5-10 GW
Coming to America

- Cape Wind Approved
- TX Gulf Coast operating
- Offshore Wind projects announced in ME, NJ, MD, DEL, VA, NC, OH, TX
- NJ moving very fast
- GA, SC assessing feasibility
Offshore Wind Energy

- Proven technology in harsh environments
- Wind farms operating in Denmark, UK, Germany, Ireland, Sweden, Finland, Norway, Japan, Netherlands
- Under construction in China, Italy
Wind Energy Costs

- NREL 20% WIND BY 2030
- COST ~ AVG $.06-.14
Operation and Maintenance costs

- More expensive than onshore
- Costs ~$20 per MWH or 2c per kwh
- Maintenance planned for summer (low seas)

![Comparison of O&M costs](chart)

Source: IEA
How do they work?

- Wind energy converted into rotational energy of a shaft which drives a gearbox and/or generator.
- Wind across blades generates lift and rotation.
- Power generated depends on horizontal flux of kinetic energy which is proportional to $V^3$.
- 1 MW can power 250 homes for a year.
- A “Wind farm” may have 50-100 turbines and may take several months to a year to build.
~ 40-50% of mean flow energy is extracted so wind decreases after passing the turbine (Betz limit 59.3%)

A meandering wake is generated

Eddies create load buffeting for downstream turbines

Wind deficit of 30% 3 rotor diameters downstream

Sfc dissipation ~ 1 w/m2

Heat, moisture fluxes enhanced

large scale roughness increased

HORNS REV WIND FARM, DENMARK

BARTHELMIE, 2003

WUBOW, 2007
Bigger turbines ahead

- RePower 5 MW turbine
- World’s largest in use 125 m blade sweep diameter
- 150 ft depth, 100 m high hub
- Off N. Scotland, Belgium
- 8-12 rpm, winds up to 30 m/s
- 1 MW in 6 m/s, 5 MW in 14 m/s

- GE and Siemens moving toward direct drive turbines (no gearbox)
10 MW Giant offshore Turbines

- Clipper (US) and Sway (NOR) are building 10 MW prototypes for testing in 2011
- SWAY to be testing floating downwind turbine in 2012
- Clipper to test fixed offshore turbine in UK in 2012
Offshore Wind

**Advantages**
- close to load centers
- stronger, more stable resource
- transportation
- less NIMBY

**Limitations**
- costs ~ 1.5 times onshore
- harsh environment
- protected areas and military training
- Avian migration, navigation, marine mammals
Challenges

- Decrease Costs: lighter, stronger design, floating structures, direct drives, higher efficiencies and capacity factors
- Avian impacts: minimal, Audubon supports wind energy
- Marine mammals and fisheries: monitoring during construction
- Military training areas: Navy Norfolk has identified areas for wind development
- Marine Spatial Planning: GIS planning, stakeholder inputs, avoid protected areas
- Load balancing, integration, transmission
- Resource assessment
- Severe weather
- Intermittency
Load balancing, integration, transmission

- Load balanced by supply
- Reserve supply is kept available
- Load and supply must be forecasted on time scales of min to years
- Existing reserves are capable of integrating up to 20% wind in most areas
- NREL: MN 25% wind (5.7 GW) required only additional 7% more reserve
- Regional load balancing is needed
• Wind is not dispatchable (but can be on reserve)

• Load net of wind must be balanced

• Short term changes (RAMPS) can be expensive (low CF Gas turbines)

• Short term forecasts needed: 5 min, 1 h, 24 h (for day ahead market)

• HRRR and Ensemble runs used for inland US
Transmission: Costly but ends up saving over long term due to lower wholesale power e.g Iowa-Dakotas -> Midwest $18B for 16 GW Wind + 5000 miles of transmission can save ~ $500 M/y if Natural gas is $5/therm
Intermittency

- Base loads need dependable resource
- Capacity at any one site can have large swings
- Distributed wind farm networks can provide a stable resource
- Wind forecasting critical for load management
- Ramping events (large and rapid wind changes) are critical for forecasting

FROM KEMPTON ET AL., 2010 PNAS
Capacity Factor: GE 3.6 MW Turbine

For each hour’s mean wind speed:

Compute the hypothetical power generated by a GE turbine e.g. 1.0 MW at 17 mph

Divide by rated value for the capacity factor e.g. $1 / 3.6 = 28\%$
Synoptic scale distributed wind farm networks can provide a stable resource.

FROM KEMPTON ET AL., 2010 PNAS: A MONTH OF SIMULATED WIND GENERATION

TOP: CAPACITY FACTOR OFFSHORE MIAMI (S2) AND CAPE COD (S10) AND EAST COAST GRID

BOTTOM: HOURLY CHANGE IN CAPACITY FACTOR

AN EAST COST SYNOPTIC NETWORK ALWAYS PRODUCES, WITH “GRADUAL” RAMPING IS A GULF COAST SYNOPTIC SCALE NETWORK FEASIBLE?
Wind Resource Maps

- Mesoscale models with imbedded flow models
- Wind maps have large uncertainty
- Measurements and modeling needed
- TX, Iowa, CA, WA, OR have largest installed wind generation
- Iowa (20%), S. Dakota, N. Dakota, Minnesota use wind for > 10% of their energy needs
- Florida onshore relatively weak

Resource Assessment

- Mesoscale Models
  - Nested models used to recreate wind climate at turbine level
  - Initialized and nudged to NARR over coarse domain, 72 five day runs -> 1y

- Flow Models (Wind Analysis and Application Program- WAsP)
  - Uses roughness, stability, and reference measurements to estimate PBL top wind climate, then downscales to nearby site

- Offshore assessment could benefit from coupled models and ensembles

Figure 4. Simulation domains of the MMS model

JIMENEZ 2007, WIND ENERGY
Example: Wind Turbine Design Safety requirements IEC 61400-1

- At least 1 year data required
- Wind profile adj to hub ht. (sfc roughness, stability)
- Wind PDF fit (critical for estimating extremes) big limitation for TC risk
- Turbulence intensity for winds > 10 m/s, turbulence modeling
- 50 and 1 year return period mean and gust winds, directional, vertical wind shear, combined extreme gust with direction change
- Wake effects, air density
- Correlate with longer term data
NREL Offshore wind map

- NREL and AWS Truewind release in July 2010
- Combination of buoy, tower and satellite wind obs, modeling up to 50 nm offshore
- No offshore resource mapping for FL, MS, AL due to lack of earlier preliminary maps
Complex coastal circulations

- Doppler Lidar measurements off New England (Y. Pichugina 2010)
- Nocturnal offshore low level jet structures at turbine heights
- Most offshore platforms measure winds at 5-10 m
- Coupled models needed to properly account for air-sea stability effects, sea breeze, pre and post frontal flows
What about Georgia?

- Few Data at turbine heights
- Most winds measured at 3-10 m
- NREL and AVS Truewind constructed map
- Georgia Tech and Skidaway Study validate map based on observations
- Bureau of Ocean Energy (old MMS) has received lease proposals off Savannah for collecting tower data
South Carolina offshore wind

- Sodar ($50K) placed in Winyah Bay off Georgetown SC on 8-4
- Clemson and Coastal Carolina to analyze data against buoys and tower to evaluate accuracy
- Conduct energy forecasts to determine site feasibility
- Sodar cheaper than offshore conventional anemometer tower $4M or buoys ($400k)
Florida’s Wind Energy Industry

- GE’s Offshore turbine generators are made in Pensacola
- Siemens US Wind Energy HQ in Orlando
- FPL NextEra largest wind developer in US (Juno Beach)
- MMS has received lease proposals offshore Boca Raton and Ft. Lauderdale but not for wind (hydrokinetic)
Florida Wind

- Class 4 winds viable for offshore wind energy
- 2005 DOE FL Wind Initiative: Class 4 “Good” winds offshore
- 2008 PSC study by Navigant ~ 130 GW available
- Above studies based on very limited data
- FPL St. Lucie doomed by poor planning, nimby cancelled 2008
Wind Resource Mapping

- Measurements Needed
- Accurate height adjustment
- Depends on meteorology and oceanography of the sea surface
- Complex coastal circulations
- Let’s examine a few locations
FLORIDA NEEDS AN ACCURATE WIND RESOURCE MAP

- **FSU IESES Pilot Study**
- **Air Force Navigation towers with NOAA and FSU instruments supported by Northern Gulf Institute**
- **Tower measurements ~30 m**
- **Estimate winds for hub height near 100 m using boundary layer and air-sea interaction theory**
- **Compute annual and monthly mean winds**
- **Compute what a GE Turbine would produce at the site**
- **Compare capacity factors and wind energy classes to existing wind farms**
High towers are best

- Tower data analysis
- K tower 1 year fall 2008-2009
- C tower 2 years 2008, 2009
- QA/QC process

- Height adjustment: air-sea temperature difference determines stability (mixing) and sea state ocean roughness determine how speeds change with height

30 M

TURBINE HUB IS ALMOST 3 X HIGHER (~100 M)
Mean Winds at turbine height

C TOWER
7.1 M/S
31% CF
100 M
2008

K TOWER
6.6 M/S
25% CF
85 M
2009
Seasonal wind variation

HIGHEST WINDS IN OCTOBER
WEAKEST IN SUMMER
Seasonal Power and Capacity variation

US annual mean wind capacity factor is 23% for onshore wind.

C Tower (June-July out for maintenance) hourly power.

K Tower hourly power.

C Tower hourly capacity.

K Tower hourly capacity.

M. Powell, FSU Seminar Sept 9th 2010
Time of day variation in summer

Wind highest 5-7 am
NW Florida:
25 miles Offshore Pensacola
NOAA Buoy 42012
26 m water depth

42012
APRIL-DEC 2009
6.9 M/S AT 100M
28% CF
S Central Florida:
22 miles Offshore Sarasota
USF Buoy 42013, 3m Zan
25 m water depth
28% Mean Capacity factor

2008-SEPT 2009
6.7 M/S
28.4% CF
Florida Keys
Near Dry Tortugas
NOAA CMAN station at Pulaski Shoals 27% mean Capacity Factor

PLSF1
2009
6.6 M/S
27% CF

M. POWELL, FSU SEMINAR SEPT 9TH 2010
SE Florida: near Miami
NOAA CMAN station at FWYF1
44m high (144 ft)
4 miles SE Key Biscayne
18 miles from FPL Nuclear plant
28% mean Capacity Factor

FWYF1
2009
6.8 M/S
28% CF
E Central Florida:
near Cape Canaveral
NOAA moored buoy 41009
5m Anem. ht, 44 m depth
23 miles from Cape Canaveral
30% mean Capacity Factor

41009
2009
7 M/S
30% CF
NE Florida:
40 nm Off St. Augustine
NOAA Buoy 41012, 5m Za
37 m depth
31 % mean capacity factor

Overlay Plot

41012
2009
7.1 M/S
31% CF

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Gulf Coast Wind Energy

IBERDROLA’S PENASCAL WIND FARM NEAR CORPUS CHRISTI

- 84 Turbine farm on TX Gulf coast
AL Offshore
64 nm S Dauphin Island
NOAA Buoy 42040, 10 m Za
164 m depth
27 % mean capacity factor

42040
2007
6.7 M/S
27% CF

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TX Coast
22 nm E Galveston
NOAA Buoy 42035
14 m depth
27% mean capacity factor

42035
2007
6.8 M/S
27% CF
TX Coast
50 nm SE Corpus Christi
NOAA Buoy 42020
85 m depth
39 % mean capacity factor

42020
2009
8 M/S
39 % CF

Mean Log law Capacity
per 10 min period

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East Coast

- DOE-DOI (BOEMRE) Joint agreement for Offshore wind and hydrokinetic renewables
- DOI and 10 Atlantic coast states formed Atlantic Offshore wind energy consortium
- 13 states have task forces
- So far Florida limited to gulf stream hydrokinetic
Cape Wind

Nantucket Sound

NOAA Buoy 44020
10 m depth
39.8% mean capacity factor

44020
3-2009 TO 2-2010
8.2 M/S
40% CF
85 M

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NC Offshore
Frying Pan Shoals, SE Cape Fear
NOAA Buoy 41013, 5 m Za
23 m depth
42.5 % mean capacity factor

41013
2008
8.4 M/S
85 M

\[\text{Mean Log law amp. it pe 10 min pe Ibd)\]

M. POWELL, FSU SEMINAR SEPT 9TH 2010
SC Offshore
41 nm SE Charleston
NOAA Buoy 41004, 5 m Za
38 m depth
39.5 % mean capacity factor

41004
2008
8.1 M/S
85 M

Mean log law app. ft
per 10 min per end
GA Offshore
Gray's Reef 40 nm SE Savannah
NOAA Buoy 41008
18 m depth
33 % mean capacity factor

Graph showing wind speed distribution and mean capacity factor over time.
Is Offshore Wind Power Feasible in the Gulf and offshore Florida?

- A proper wind resource study is needed: Observations, modeling, remote sensing
- Preliminary examination indicates:
  - Already feasible off South TX (Corpus Christi to Brownsville)
  - Capacity factors off Gulf coast and FL are similar to existing inland farms but about 8-12% lower than where E. coast offshore farms are being planned
  - New technology developing larger turbines with higher low wind production
  - Synoptic scale distributed networks could help make Gulf and FL wind farms workable
  - Perfect capacity factors not possible. Ability to take “Peaker” plants offline can save on fuel and pollution costs.
  - Integration requires accurate Wind forecasting on all scales
Questions?
Research Needs:

- Further buoy and tower data analysis
- Additional observations in critical locations
- Boundary layer turbulence
- Satellite wind mapping, Reanalysis assessment
- Regional, Mesoscale, Seasonal Modeling
- Forecasting ramp events and network resources
- Marine spatial planning and GIS mapping
- Optimal wind farm network distribution analysis
- Hurricane Risk Assessment
• One 40 w bulb = consumes 3456 kJ in a day

• 1 kw-h = 3600 kJ

• In one day, a 40 w bulb will consume ~1 kw-h
Avian impacts are minimal compared to other mortality sources

Figure 5-2. Anthropogenic causes of bird mortality
(per 10,000 avian deaths)

Source: Erickson et al. (2002)