Assessing California's Offshore Wind Energy Potential

Horns Rev Wind
Farm, Denmark
Source: http://www.hornsrev.dk

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Overview

- Why move wind power offshore?
- Limits/advantages to offshore development
- Existing and proposed projects
- Turbine support technologies
- CA offshore wind assessment methodology

Overview (cont.)

- Shallow water areas in CA
- Modeled wind resource
- Validation of modeling results
- CA wind energy resource estimate
- Example CA offshore wind park
- Public acceptance of a CA wind park

Why Move Wind Energy Offshore?

- Lower surface roughness over water
- “Reduced” visual impact
- Wildlife impact much lower
- Fewer limitations on transmission
- Shipping restrictions greatly reduced
- Possible to install **larger** turbines, **higher**

Limits of Offshore Development

- Tough installation of turbines
- More $$$/energy (about 2-3 times more per kWh)
- Increased maintenance costs
- Deep water tower support technology not mature
- Underwater transmission more $$$
- NIMBY issues
- Unprecedented in the US
  - regulatory uncertainty
  - affected communities

So why bother?

Transmission limitations +

Expensive electricity rates +

Zero fuel risk +

Majority of populations being on coast +

Global warming

=

Render offshore wind a viable energy resource

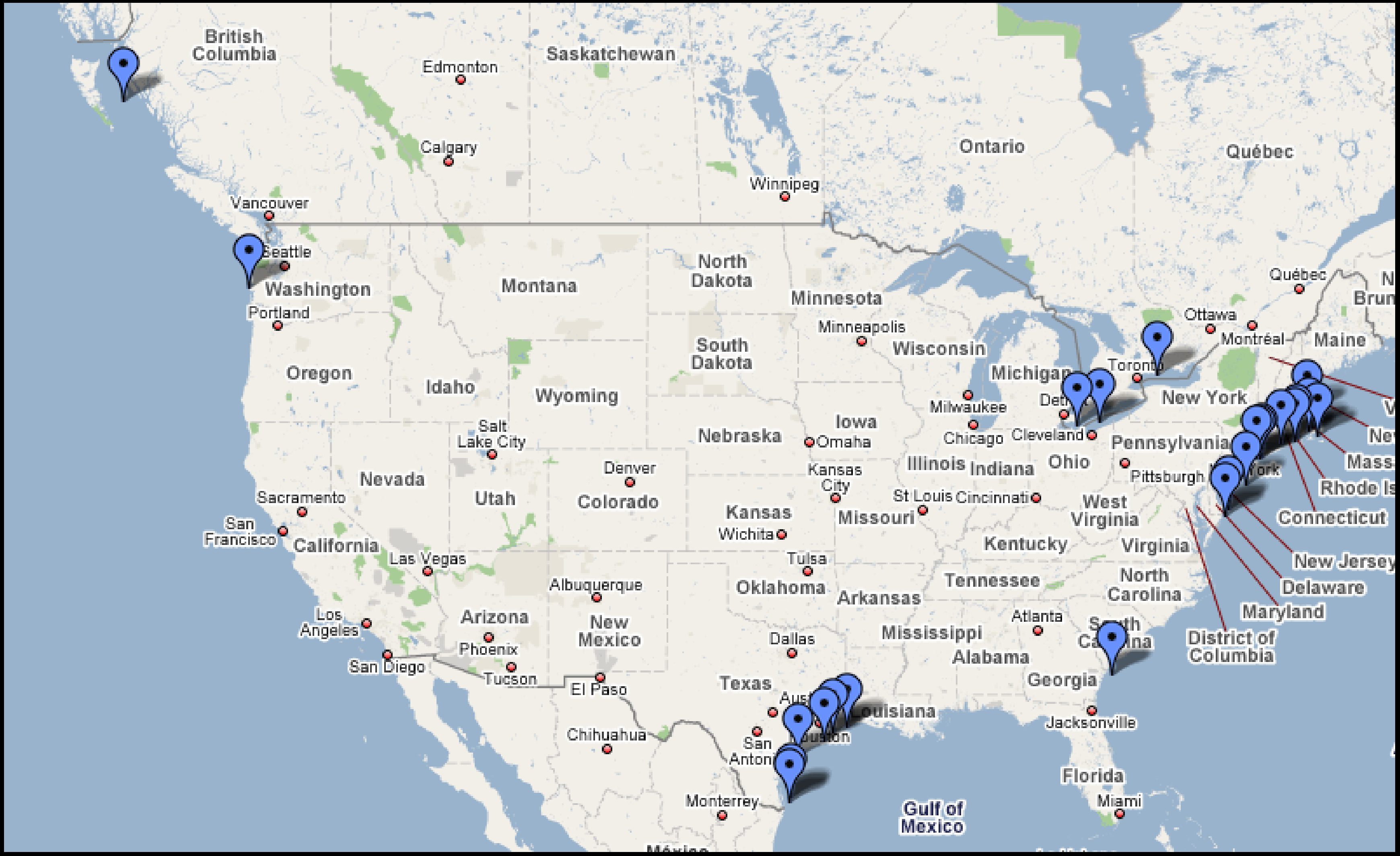
Existing Offshore Wind Turbines

- About 1,100 MW installed by 2007 (EWEA)
  - Compared to 94,000 MW total (GWEC)
  - Mostly in the North and Baltic Sea

Map source: EWEA

Proposed N. American Projects

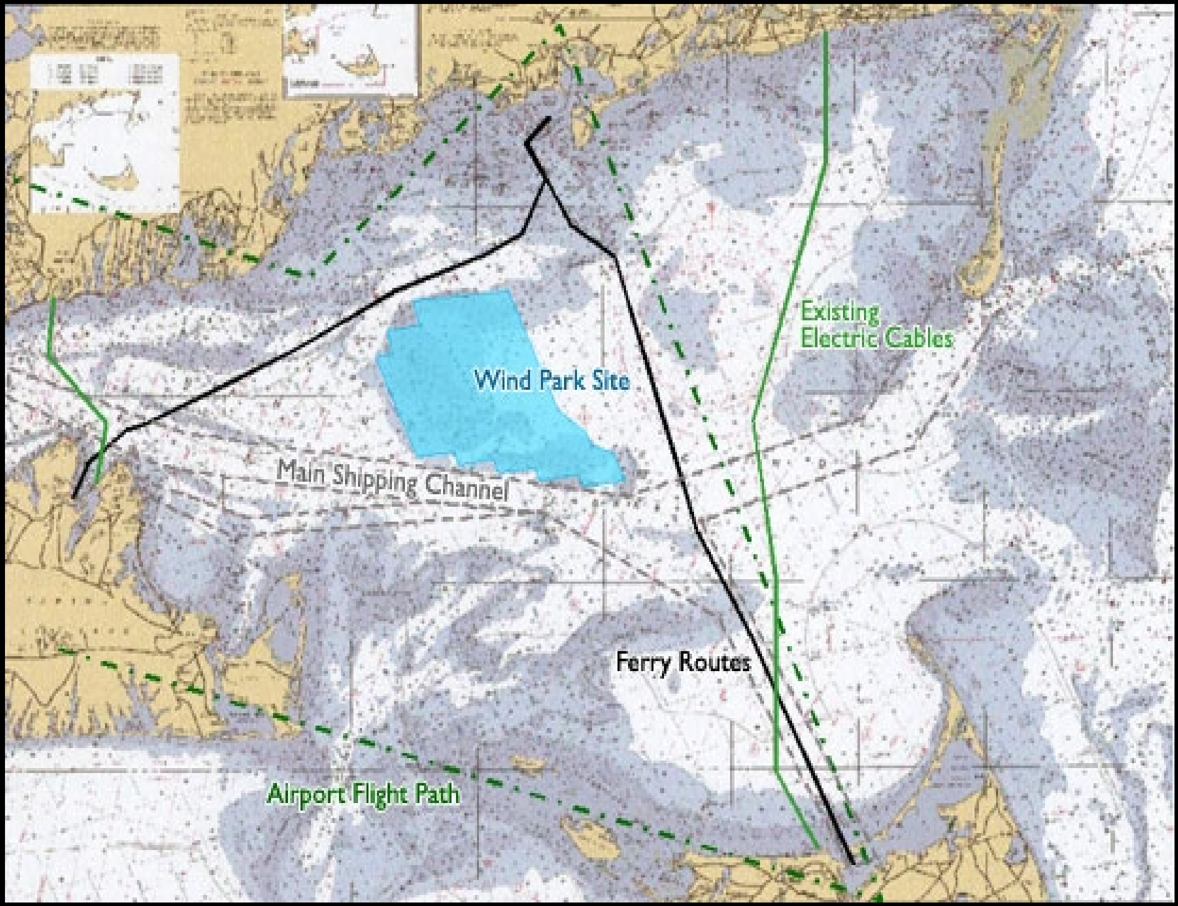
NOTE: Zero installed capacity!!!



Map credit: OffshoreWind.net

Proposed – Nantucket Sound

- Developer *Cape Wind*
  - 420 MW
  - 130 turbines
  - 2 rounds of EIS (under the Corps and MMS)
  - Draft EIS released by MMS in January

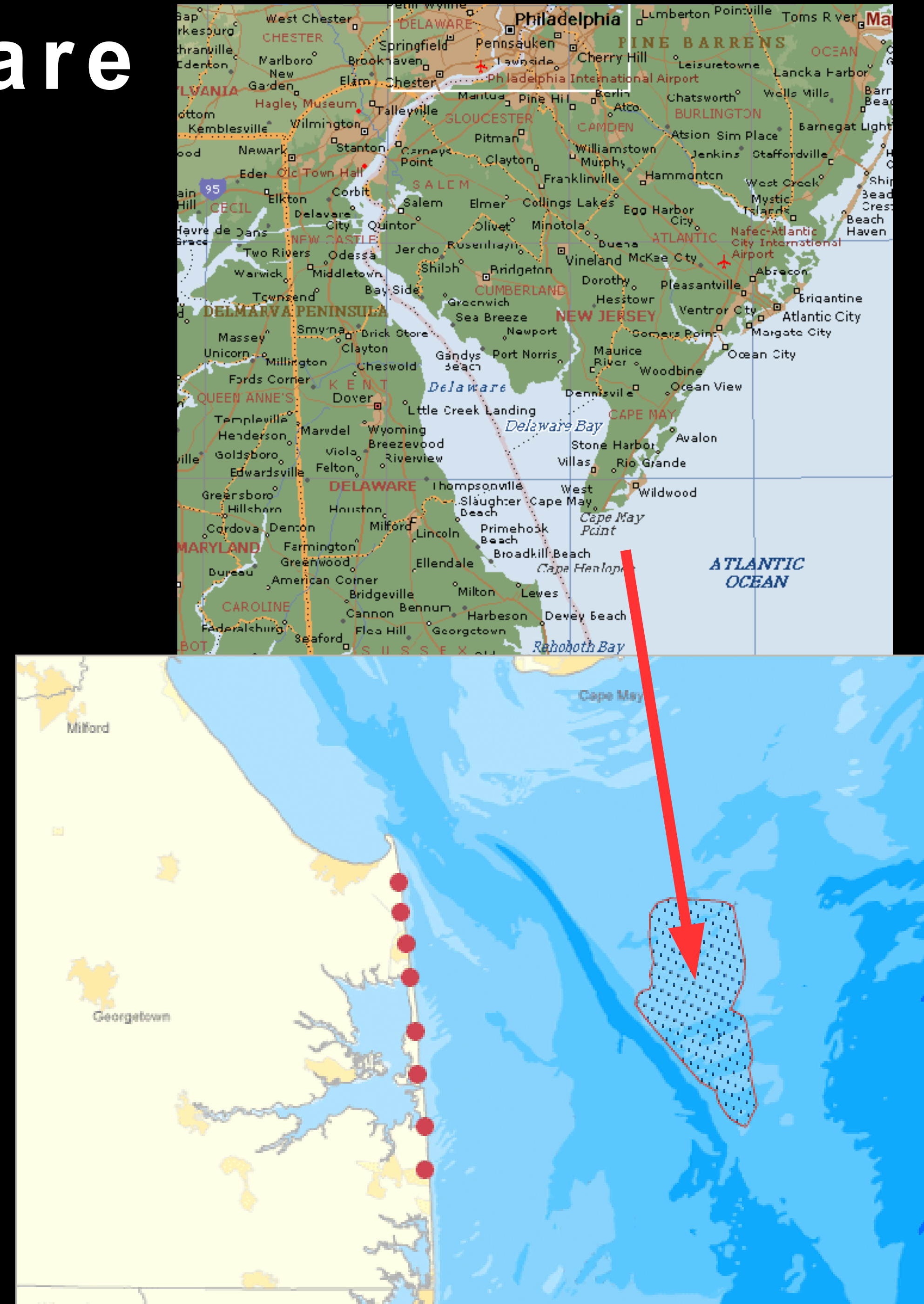


Map source: http://capewind.org

The nation's first proposed offshore wind-energy project cleared its most formidable hurdle yesterday as the US Minerals Management Service declared that the wind farm off Cape Cod would have little lasting impact on wildlife, navigation, and tourism. -Boston Globe, Jan 15, 2008

Proposed - Delaware

- Developer *Bluewater Wind*
  - 450 MW capacity
  - 150, 3 MW turbines
  - closest turbine 11.9 miles (19 km)
  - competitive bid process
  - 10.6 cents/kWh + 0.6 cents/kWh capacity credit



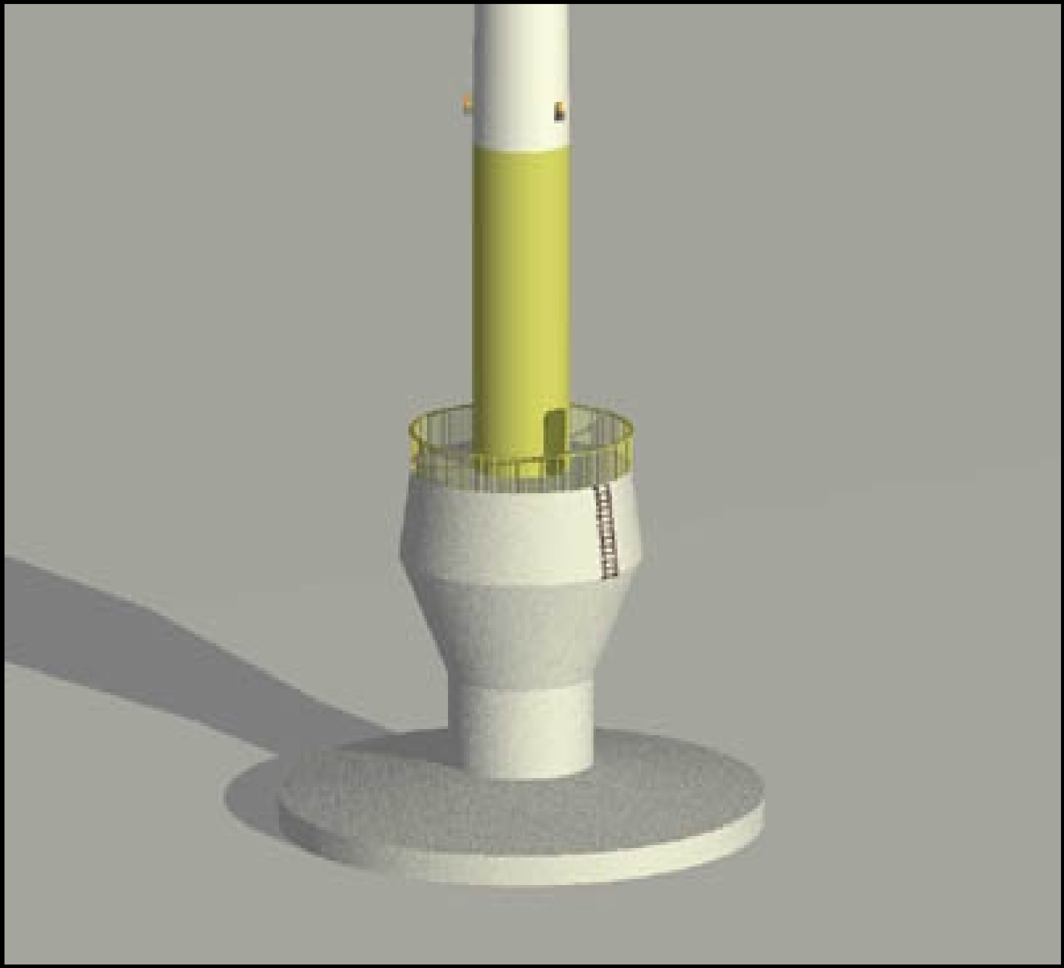
Map source: Bluewater Wind

Wind Turbine Tower Support Technology

- Offshore conditions harsh
  - Need to design for large waves, hurricanes, and even earthquakes
  - Only shallow waters currently (45 m depth max)
- Tower support types
  - Gravity Base
  - Monopile
  - Multileg (suction piles)
  - Floating towers (lots of variations)

Gravity Base Structures

- Extremely shallow water (~ 5 meters)
  - Large, flat base supports turbine load
- Middelgrunden, Denmark
  - 2-6 meters
  - 40 MW, 2MW turbines



Source: http://offshorewindenergy.org

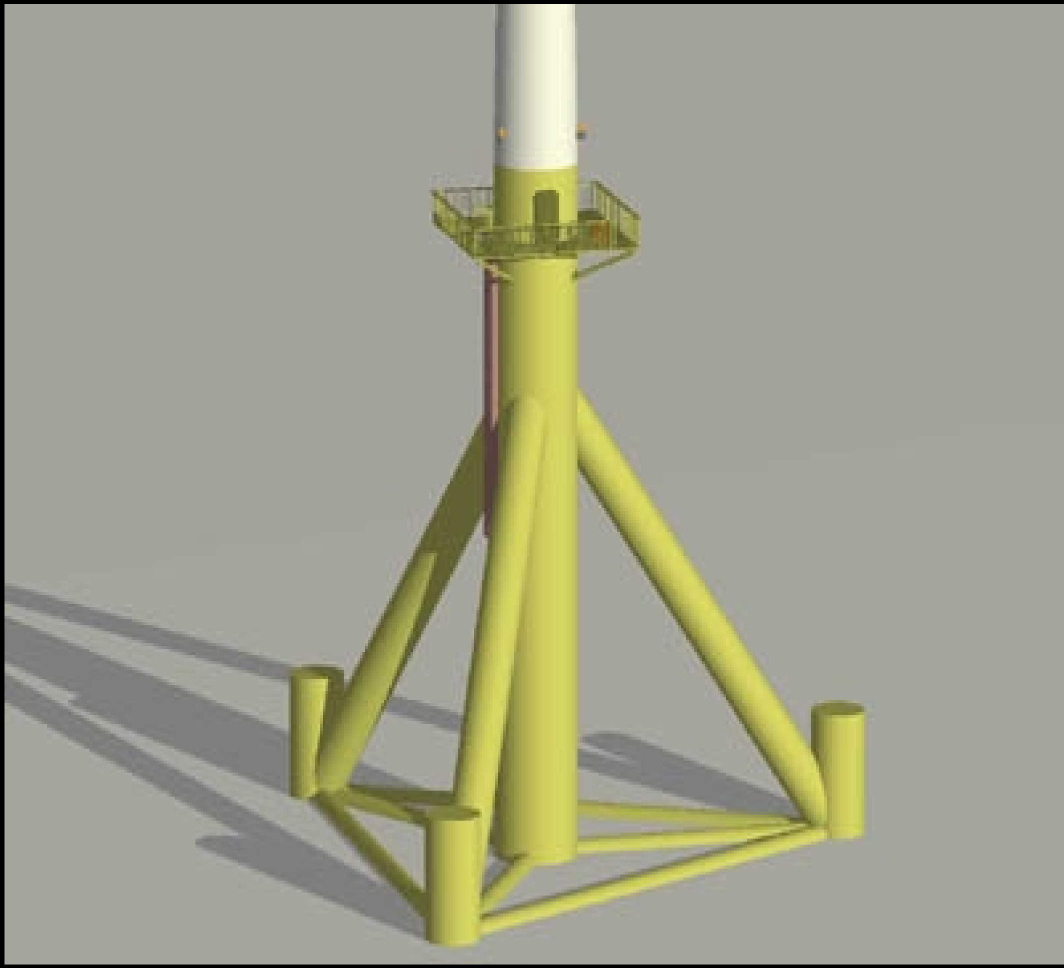
Monopile Towers

- Some potential for CA
  - up to 20 meters depth
- Pounded into sea floor
- Horns Rev, Denmark
  - 80, 2 MW Vestas turbines
  - 160 MW capacity

Source: http://offshorewindenergy.org

Multileg Support Structure

- Use suction piles (water jackets) to anchor into sea floor
- Beatrice, Scotland
  - 45 meters depth
  - 2 test platforms installed
  - Using *Repower 5M* 5MW turbines



Source: http://offshorewindenergy.org

Floating Support Structure

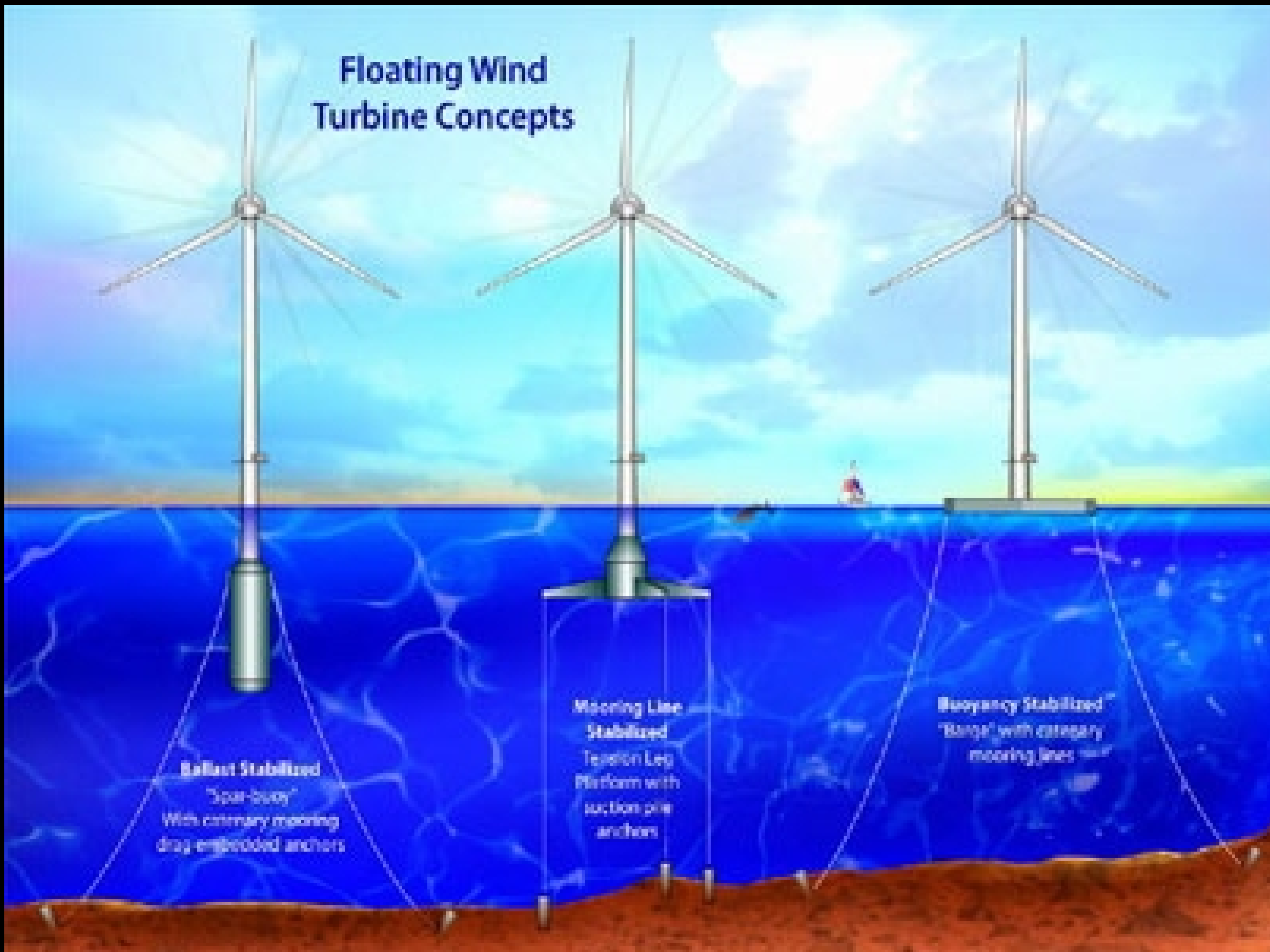
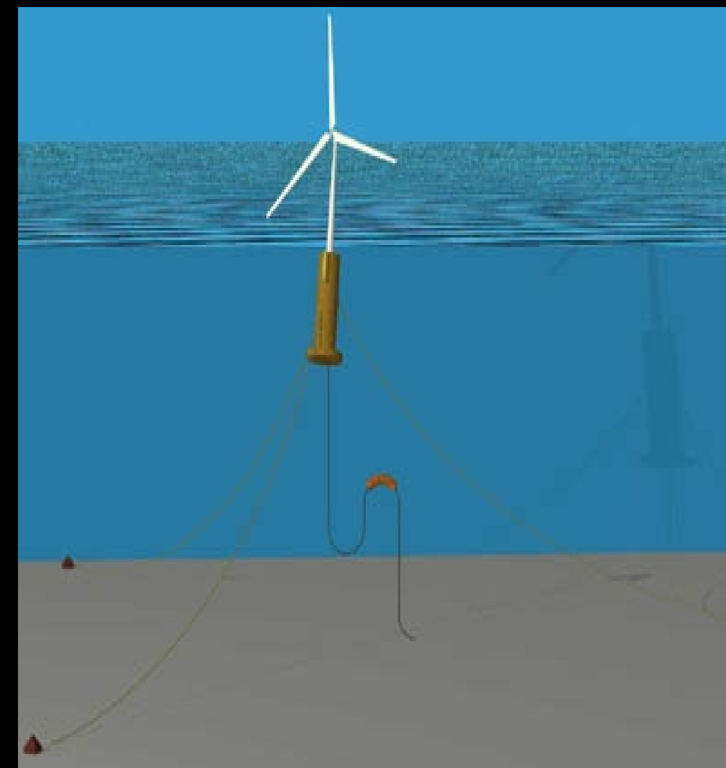


Image source: Sclavounos/MIT, NREL



Source: http://offshorewindenergy.org

Out to 200 meters in 15 years?

Future of Turbine Supports?

- California/West Coast has unique constraints
  - foremost, water is deep
  - BUT seismic loads are most significant
  - bottom founded will be more expensive
- Floating tension leg and spar design might end up being cheaper
- Thanks to Chris Barry, USCG for this insight

Challenges of Offshore Installation

- Requires specialized boats
- Rough weather and tides can cause delays
- First US project will have to build these boats
- Merchant Marine Act of 1920 a big problem!

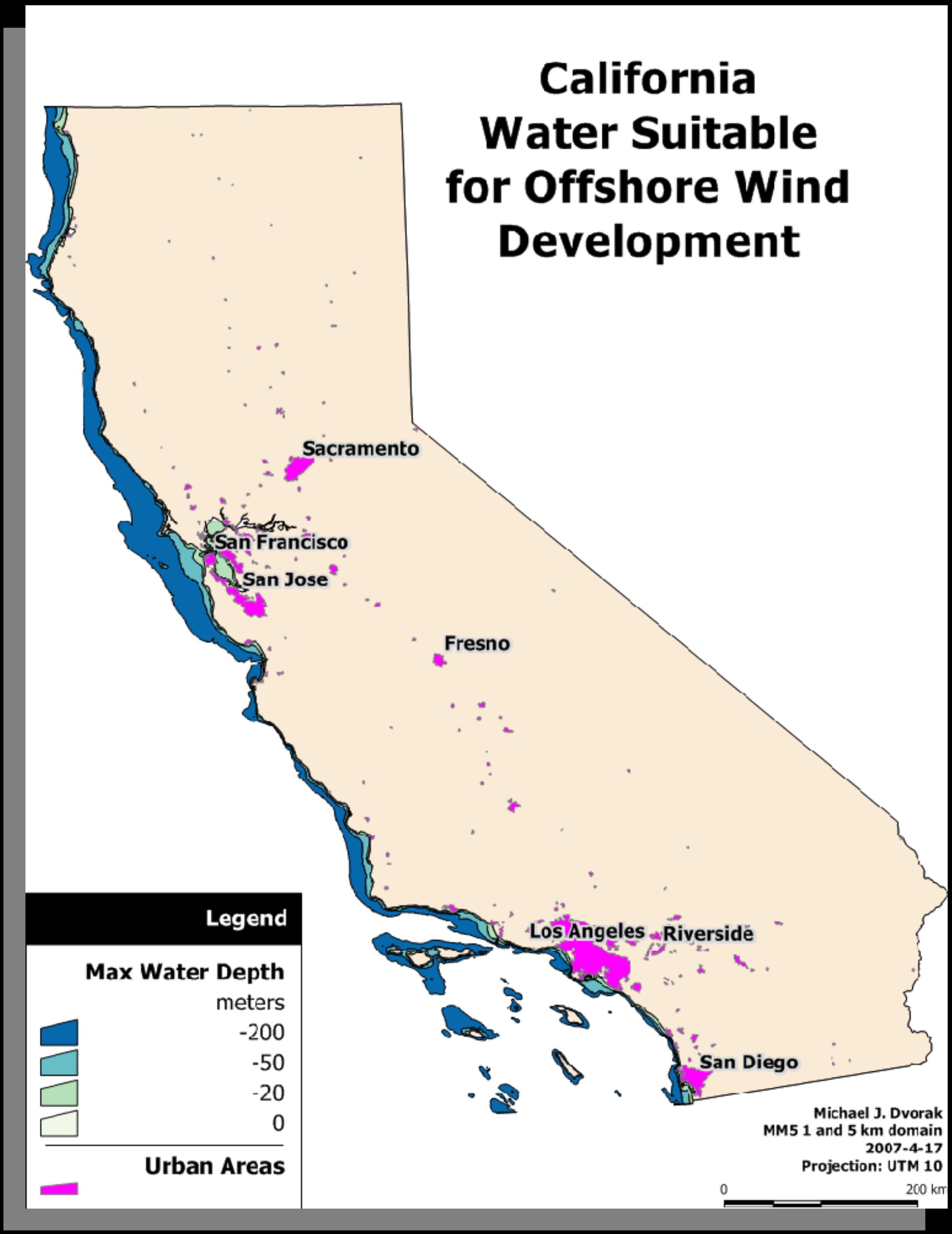
Photo credit: BBC

Photo credit: Talisman Energy

Overview of California's Offshore Wind Energy Assessment

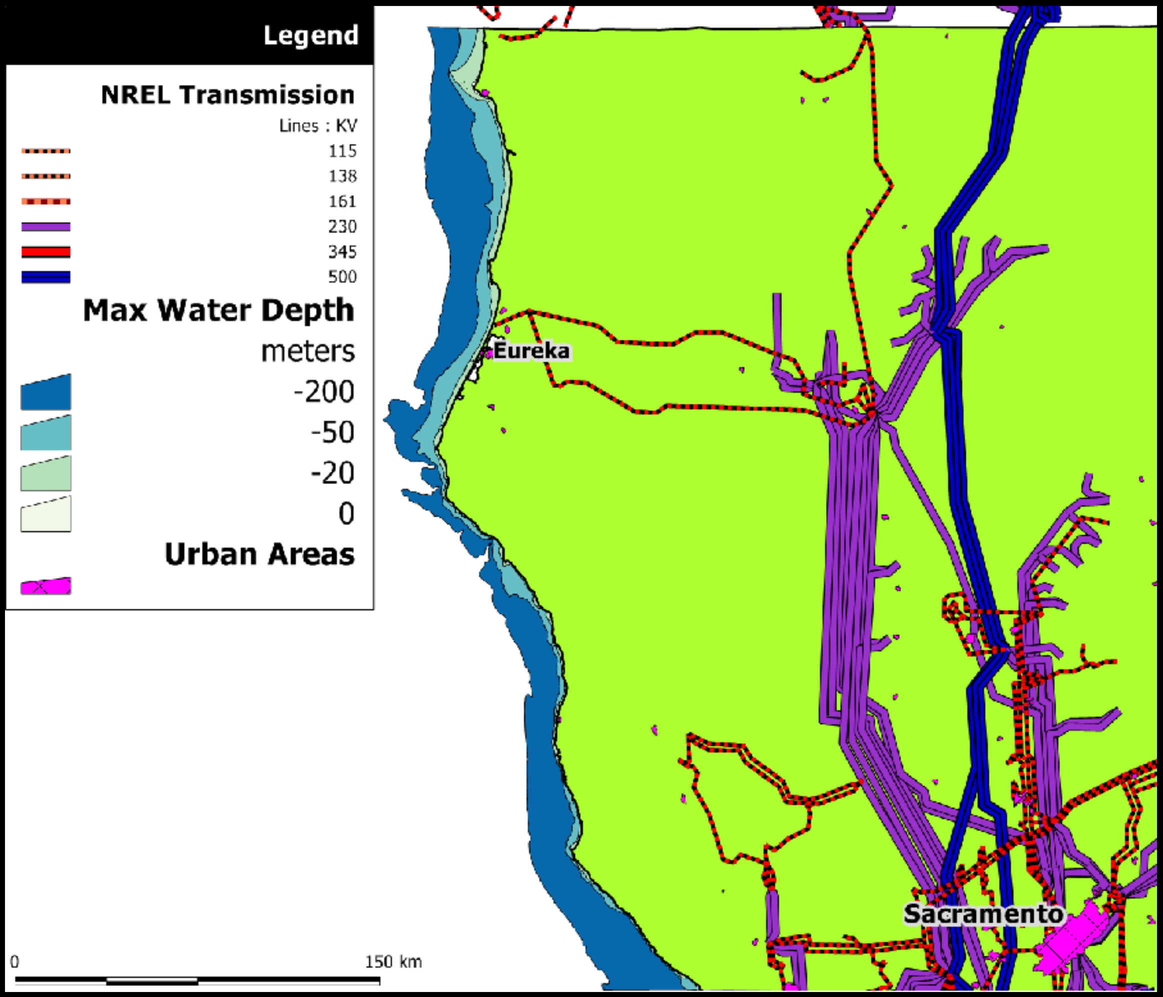
- Evaluated the bathymetry (water depth) for tech and economic feasibility
- Modeled the winds using a mesoscale weather model (8 seasonal months over 2 years)
- Checked the accuracy of the model using offshore buoy wind data
- Picked a turbine, to calculate energy and power numbers

Bathymetry Data



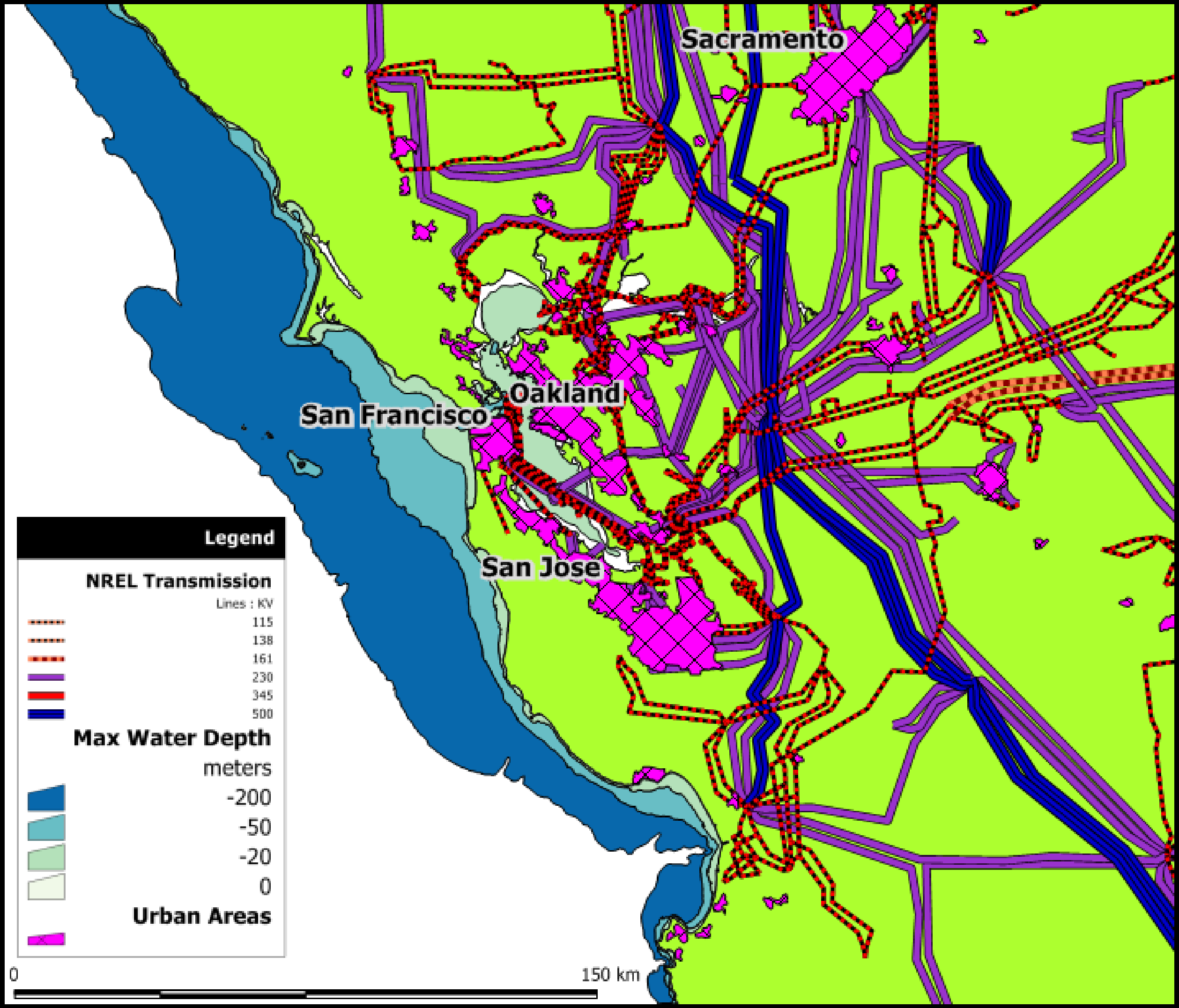
- *Nat. Geophys. Data Center* 3-arc second Coastal Relief (~30 m)
- Similar breaks to Dhanju, et al.
  - breaks at 20 m for monopiles
  - 20-50 m for multi-leg support
  - 50-200 m for floating platforms

Northern CA



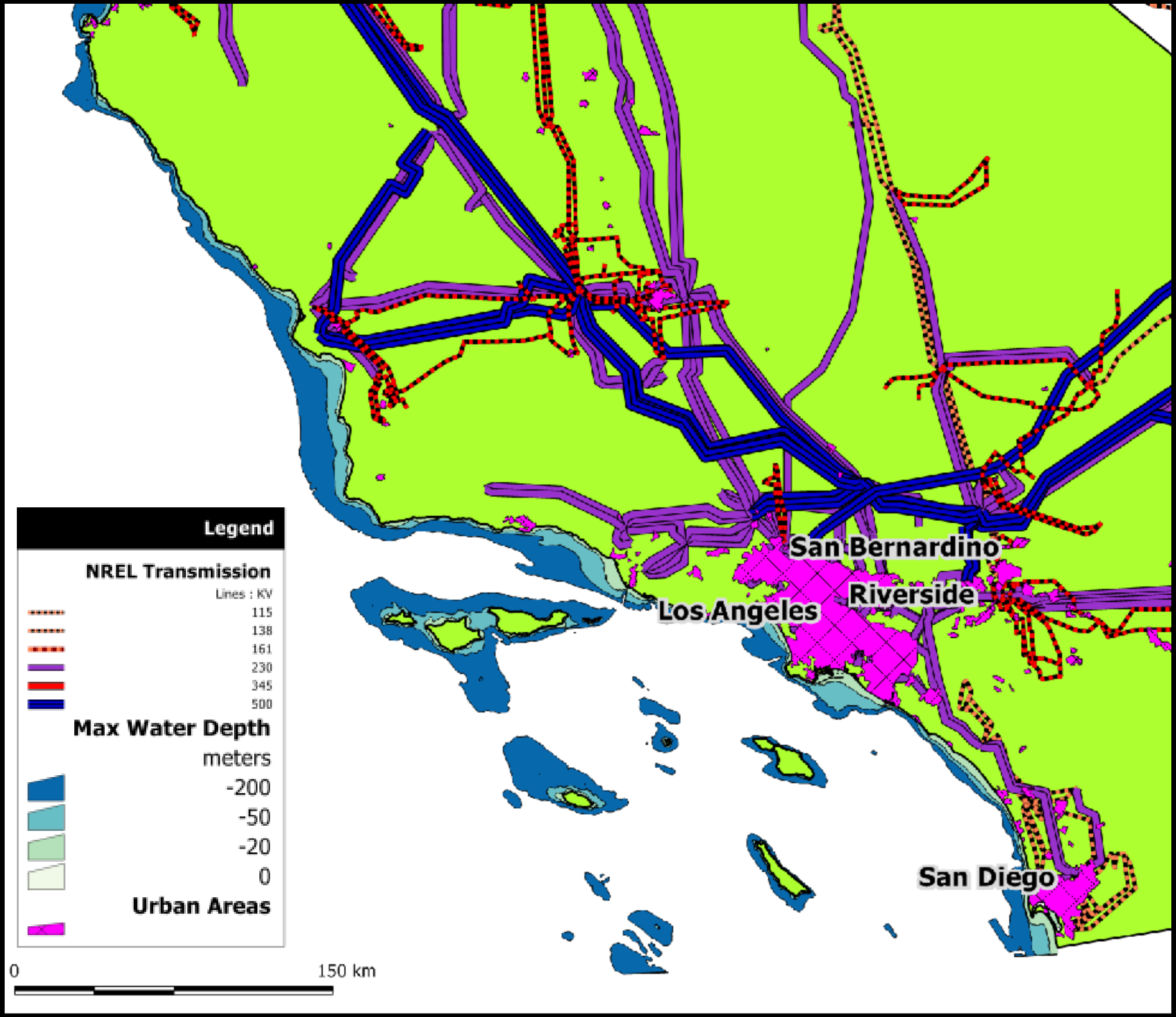
- Harsh weather and terrain keep populations low
- Small amount of transmission near coast
- Site of potential wind farm (later)

San Francisco Bay Area



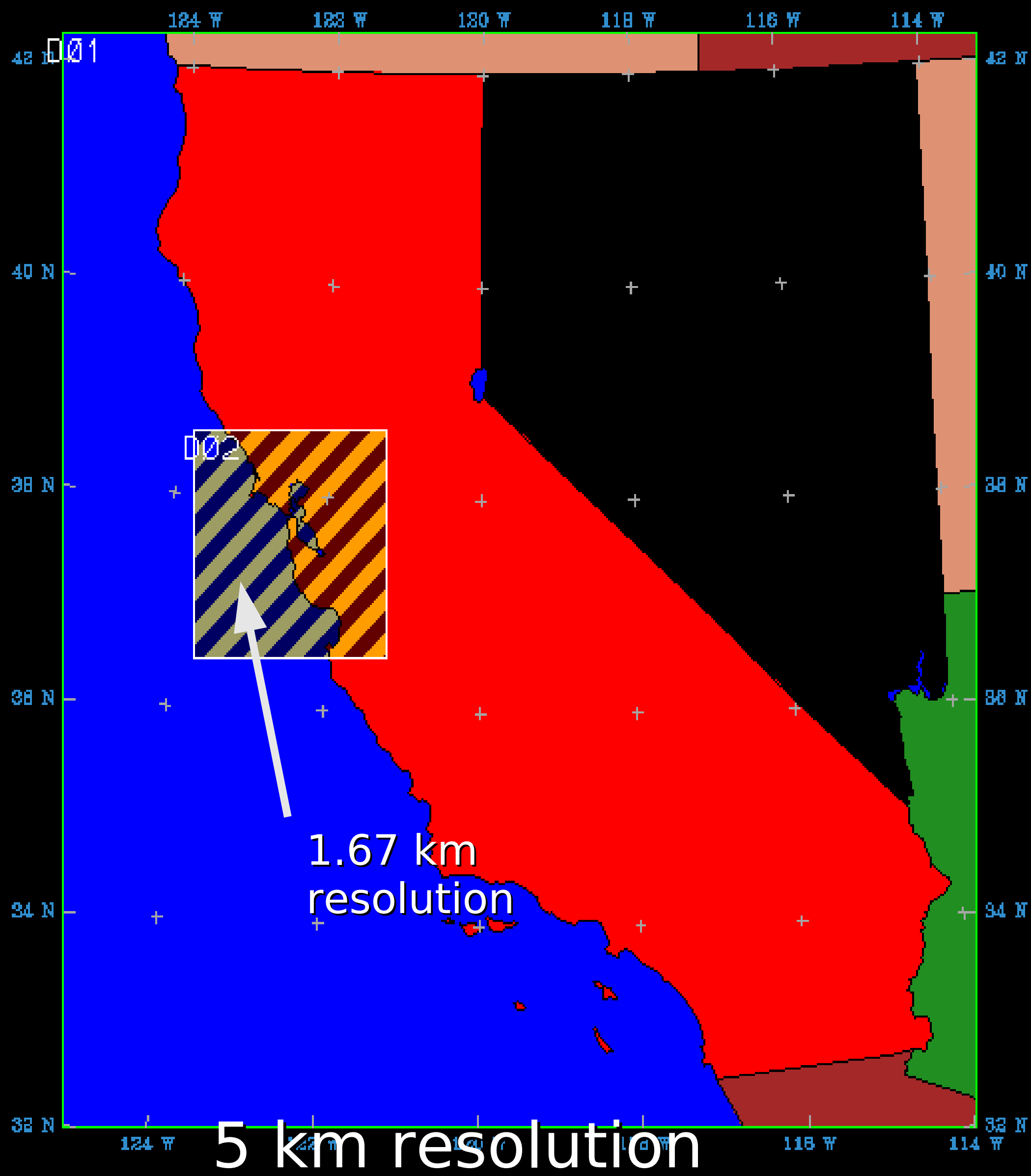
- Bay itself is shallow
- Transmission access near Bay inlet
- High urban electricity demand

Southern California



- Lots of grid access
- Existing oil and gas may quell NIMBY issues
- Lots of urban electric load

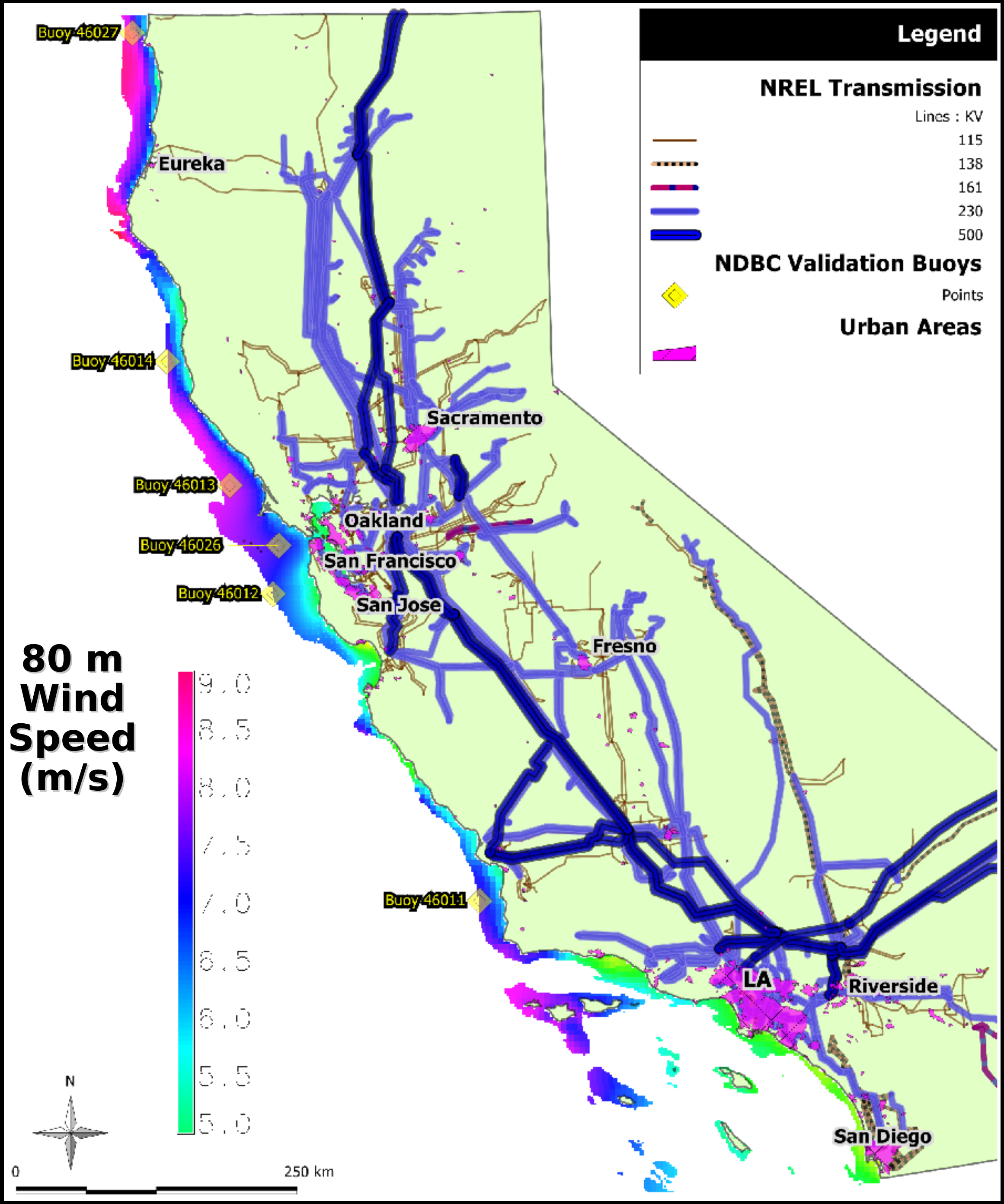
Modeled Winds



- Penn State/National Center for Atmos. Research **Mesoscale Model V5** (**MM5**)
- 2 domains
  - 5 km resolution over all CA
  - 1.67 km resolution over Bay Area
- Restarted every 7 days

Modeled 2005/2006 80 m Wind

- Winds only shown out to 200 m depth
- Combination of Jan, Apr, Jul, Oct 2005 and 2006 results
- Transition from blue to pink is the 7.5 m/s cutoff



Model Validation

Image source: NOAA NDBC

- NOAA National Data Buoy Center (5 m height)
- Used 6 offshore buoys in the 0-200 m depth zone
- Compared all available buoy data to MM5 10 m winds (including 2006 JJA)
- Should meet the following criteria to show “skill” (E is the RMSE) (2002, Pielke, R.A.)

(1) $\sigma \approx \sigma_{obs}$

(2) $E < \sigma_{ob}$

~~(3) $E_{UB} < \sigma_{obs}$~~

Error Results – Domain 1

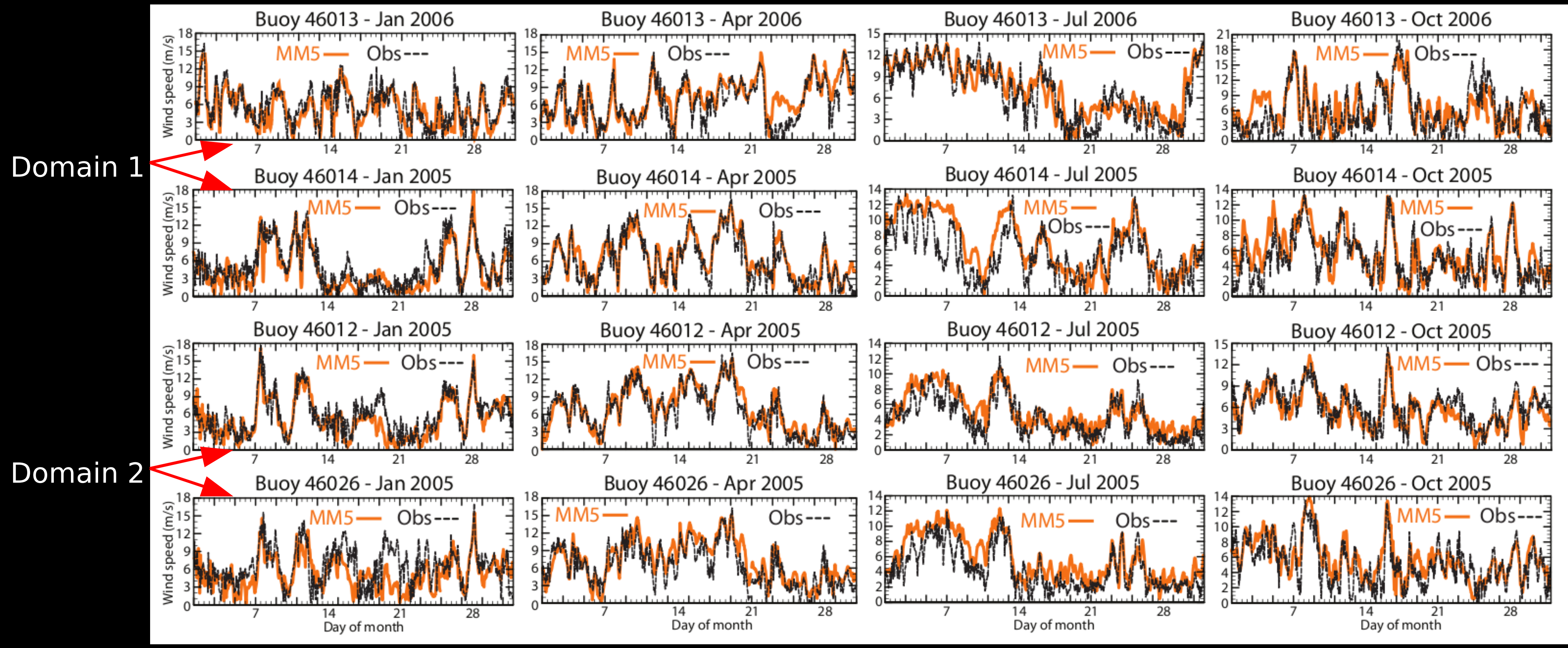
Domain 1 (5.00 km resolution)											
year	**2005**				**2006**						**Wt**
month	**Jan**	**Apr**	**Jul**	**Oct**	**Jan**	**Apr**	**Jun**	**Jul**	**Aug**	**Oct**	**avg**
avg mm5 (m/s)	4.94	6.81	6.91	6.04	5.30	6.56	7.67	6.84	6.27	4.88	**6.21**
avg buoy (m/s)	6.60	7.15	5.63	6.04	6.18	6.81	7.05	6.25	5.69	4.98	**6.22**
stddev mm5 (m/s)	3.02	3.37	3.14	2.82	2.99	2.91	3.34	2.66	2.16	2.49	**2.88**
stddev buoy (m/s)	3.38	3.84	3.49	3.04	3.18	3.41	3.94	3.37	3.14	2.95	**3.36**
RMSE (m/s)	2.98	1.99	2.59	2.19	2.29	2.21	2.43	2.52	2.35	2.28	**2.38**
bias (m/s)	-1.65	-0.34	1.28	0.00	-0.89	-0.25	0.62	0.59	0.58	-0.10	**-0.01**
NGE	43%	31%	67%	44%	37%	37%	48%	58%	59%	53%	**48%**
NB	-16%	5%	54%	17%	-7%	10%	31%	36%	41%	20%	**19%**
count	3575	3458	3424	4224	2848	3688	3318	3463	3411	3953	**35362**

Error Results – Domain 2

Domain 2 (1.67 km resolution)

year	2005				2006						Wt
month	**Jan**	**Apr**	**Jul**	**Oct**	**Jan**	**Apr**	**Jun**	**Jul**	**Aug**	**Oct**	**avg**
avg mm5 (m/s)	5.30	7.44	6.20	5.97	5.35	6.88	7.32	6.14	5.49	4.24	**6.03**
avg buoy (m/s)	6.99	7.58	5.50	6.49	6.16	7.01	6.81	6.55	5.65	4.46	**6.33**
stddev mm5 (m/s)	2.92	3.60	3.00	2.71	2.94	3.02	3.71	2.83	2.37	2.42	**2.95**
stddev buoy (m/s)	3.23	3.85	3.32	2.96	3.08	3.38	3.77	3.23	2.95	2.63	**3.24**
RMSE (m/s)	3.16	1.96	1.89	2.05	2.31	2.19	2.18	1.97	1.95	2.03	**2.17**
bias (m/s)	-1.70	-0.14	0.71	-0.52	-0.81	-0.13	0.51	-0.41	-0.17	-0.22	**-0.30**
NGE	41%	28%	45%	32%	37%	33%	40%	34%	39%	49%	**38%**
NB	-13%	7%	32%	2%	-5%	10%	21%	5%	14%	12%	**8%**
count	2166	2083	2079	2160	2128	2105	2000	2140	2104	1973	**20938**

Validation of MM5 Winds with Offshore Buoys



CA Offshore Energy Estimation Method

- REpower 5M turbines
  - 5.0 MW rated power
  - 126.0 m diameter swept area
  - 4D x 7D spacing
  - Area req'd per turbine: 0.44 km^2
- Assumed a 33% exclusion zone
- Used 7.0 and 7.5 m/s cutoff
- Summed all areas <=20 m, 20-50 m and 50-200 m
- Calculated number of turbines per area

Capacity Factor Calculation

$$CF = 0.087 \times V_m - \frac{Pr(kw)}{D^2(m)}$$

- Equation* assumes Rayleigh distribution of winds.
- Within 1% accurate energy output for Repower 5M turbine using power curve.

*Masters, G.M. (2004) *Renewable and efficient electric power systems.*
** Hoste, G., Jacobson, M.Z., Archer, C.L. (2007) *unpublished.*

Usable Surface Area and Average Wind Speeds

ocean depth	cutoff speed (m/s)	Northern CA area (km^2)	Northern CA spd (m/s)	SF Bay Area (offshore) area (km^2)	SF Bay Area (offshore) spd (m/s)	Southern CA area (km^2)	Southern CA spd (m/s)	total area (km^2)
0-20 m	≥7.0 m/s	126	7.72	14	7.15	139	7.65	294
	≥7.5 m/s	67	8.05	0	N/A	106	7.76	181
20 – 50 m	≥7.0 m/s	641	7.66	141	7.20	396	7.60	1193
	≥7.5 m/s	391	7.93	8	7.52	215	7.84	629
50 – 200 m	≥7.0 m/s	3832	8.09	3829	7.67	2886	7.57	10563
	≥7.5 m/s	3298	8.22	2491	7.90	1476	7.88	7281

- Average wind speed calculated based on bathymetry depth class
- Northern California has the best shallow water winds
- Other areas, better winds as depth increases

Turbine Nameplate Capacity and Annual Energy Output

		Nameplate Capacity (MW)			
ocean depth	cutoff speed (m/s)	Northern Calif.	SF Bay Area	Southern Calif.	total
0-20 m	≥7.0 m/s	950	106	1,048	**2,103**
	≥7.5 m/s	505	0	799	**1,304**
20 – 50 m	≥7.0 m/s	4,831	1,063	2,984	**8,878**
	≥7.5 m/s	2,947	60	1,620	**4,627**
50 – 200 m	≥7.0 m/s	28,878	28,856	21,749	**79,483**
	≥7.5 m/s	24,854	18,772	11,123	**54,750**

		Annual Energy Output (TWh)				
ocean depth	cutoff speed (m/s)	Northern Calif.	SF Bay Area	Southern Calif.	total (TWh)	avg power (GW)
0-20 m	≥7.0 m/s	2.97	0.28	3.22	**6.5**	**0.74**
	≥7.5 m/s	1.7	0	2.52	**4.2**	**0.48**
20 – 50 m	≥7.0 m/s	14.87	2.9	9.05	**26.8**	**3.06**
	≥7.5 m/s	9.68	0.18	5.21	**15.1**	**1.72**
50 – 200 m	≥7.0 m/s	98.38	89.07	65.47	**252.9**	**28.87**
	≥7.5 m/s	87.13	61.23	36.11	**184.5**	**21.06**

Proposed *Cape Mendocino Wind Park*

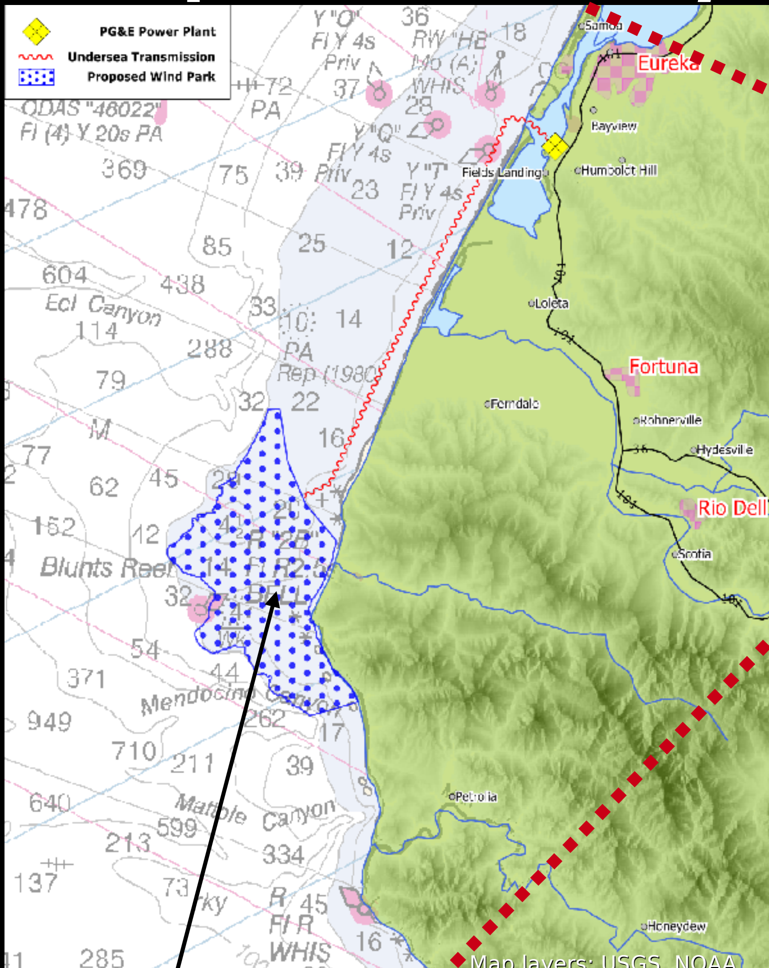
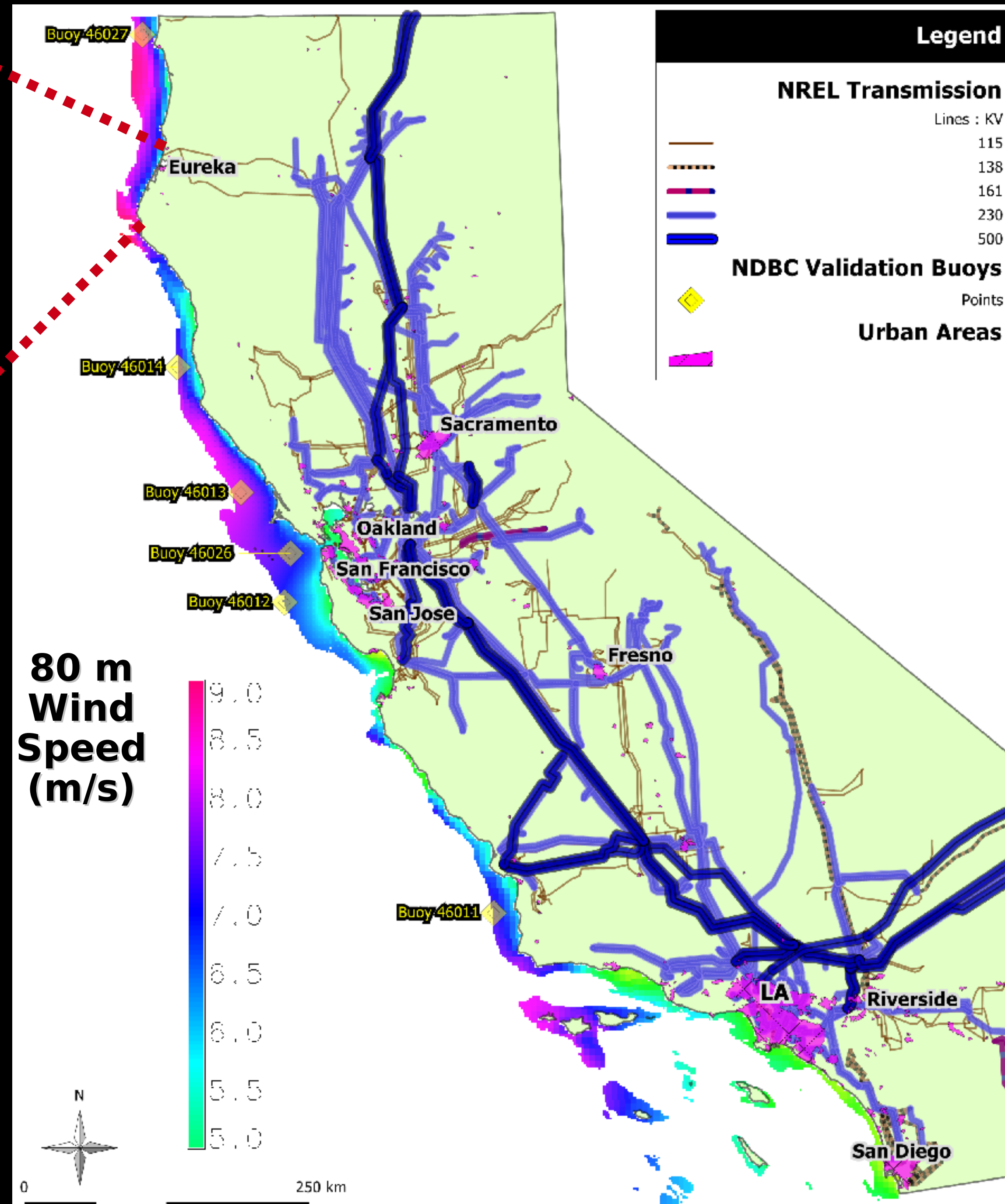
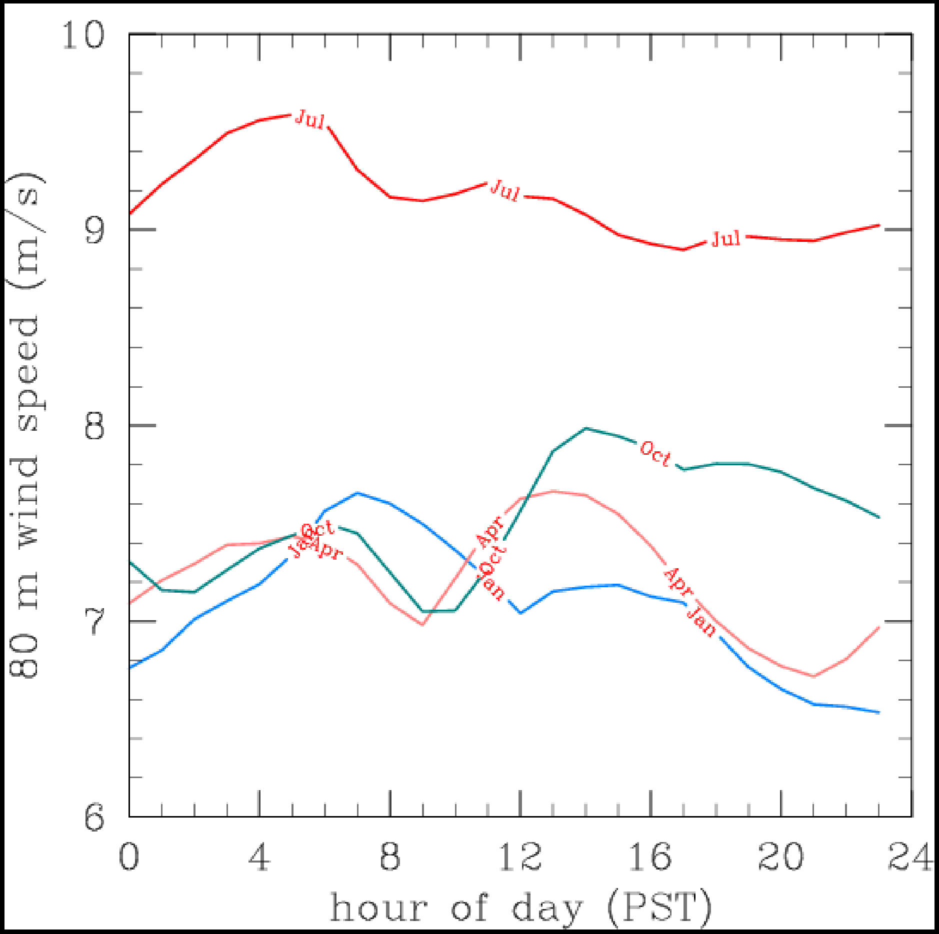


Photo credit: GE

- 278-GE 3.6 MW turbines (1000 MW)
- 420 MW avg output
- 2% of CA's current carbon emitting generation



Peak Wind Power Output?



- Group 2005 and 2006 modeled winds speeds by hour (average)
- Steady breeze persists throughout the summers months

Public Acceptance in N. California?

- *Small* research project over holiday break
- Placed a replica turbine in the waters off Eureka
- Evaluated public response

No complaints about the aesthetics!!!*

*Results not scientifically based.

Public Acceptance in N. California?

Conclusions

- Between 63% and 86% of CA's electricity needs could be provided with offshore wind energy alone.
- Despite the steep bathymetry off the CA coast, significant development potential exists for offshore wind
- Northern CA has the best 80 m wind resource but has the least transmission capacity

Conclusions (cont.)

- Northern CA's resource could be developed today, using existing turbine support technology
- The San Francisco Bay Area will require the development of floating turbine support structures
- Southern CA's wind resource is significantly reduced during the summer months

Thank You

Questions?