A Report to the

Electric Reliability Council of Texas (ERCOT)

WIND GENERATION ASSESSMENT

Submitted by:

AWS TRUEWIND, LLC
255 FULLER ROAD, SUITE 274
ALBANY, NEW YORK

Michael Brower
Principal
Tel: 978-749-9591
Fax: 978-749-9713
mbrower@awstruewind.com

January 9, 2007

A REPORT ON THE ASSESSMENT OF THE WIND GENERATION POTENTIAL AND PATTERNS OF SELECTED AREAS OF TEXAS

1 INTRODUCTION

The two main goals of AWS Truewind's participation in this project were: (i) to assist ERCOT in identifying and characterizing the most promising Competitive Renewable Energy Zones (CREZs) where wind projects could be developed on a large scale in Texas, and (ii) to characterize the hourly, daily, and seasonal output of both existing and future wind projects in the proposed CREZs to enable ERCOT's assessment of potential transmission upgrades. The following sections describes the data sources we relied on to perform this analysis and the methods we employed. The findings of the analysis – including comparisons of the patterns of predicted plant output with ERCOT's loads, time correlations of plant output between CREZs, and implications for existing transmission and transmission upgrades – are discussed in "Analysis of Transmission Alternatives for Competitive Renewable Energy Zones," ERCOT System Planning (December 2006).

2 DATA SOURCES

The key data sources for our analysis are listed below.

- Wind Speed Maps. In the course of its consulting work, AWS Truewind has created proprietary wind maps of Texas using its MesoMap system.[1] The maps provide estimates of the mean wind speed at a resolution of 200 m for several heights above ground. By comparing the predicted speeds with data from over 60 meteorological stations in the state, we have estimated the error margin of the maps to be about 5% of the mean speed. The maps were the starting point for the selection and characterization of the Proposed CREZs.
- Simulated Wind Distributions and Time Series. In addition to wind speed maps, MesoMap produced files indicating, for each point, the amount of time spent in different ranges of wind speed in a typical year. These distributions, combined with modeled temperature data, allow us to estimate the annual generation of a turbine located anywhere in the state. From the MesoMap data it is also possible to extract a time series

[1] MesoMap is an integrated set of atmospheric models, computer systems, and meteorological and geophysical databases. The two main models are a mesoscale numerical weather prediction model (MASS) and a mass-conserving microscale wind flow model (WindMap). The main source of meteorological data is the reanalysis database produced by the National Centers for Environmental Prediction (NCEP); reanalysis data provide a snapshot of global weather conditions (including temperature, pressure, wind, atmospheric moisture, and other parameters) every 6 hours at multiple levels above the earth's surface. In its normal mode of operation, MesoMap simulates wind conditions in a region for a sample of 366 days from 1989 to 2004 at a resolution of 200 m. Aside from wind speed maps, MesoMap generates hourly wind speed, direction, temperature, and other weather parameters, which can be used to calculate turbine output for specific turbine models. The system runs on a distributed computer network consisting of about 130 processors. More information is available at www.awstruewind.com.

of hourly wind speed and temperature values. These data were used to create seasonal, monthly, diurnal, and other power output profiles.

- Wind Data from Tall Towers. At the start of the project AWS Truewind had wind data from some 64 masts in Texas. About 35 of these are tall towers instrumented for wind energy assessment, 17 have been operated by the Alternative Energy Institute (http://www.windenergy.org/), and the remaining 18 belong to AWS Truewind's clients. In addition, private developers affiliated with this project provided data from seven tall masts. The wind data were used to validate and adjust the mean wind speeds and speed distributions created by the MesoMap system, and to verify the modeled seasonal and diurnal behavior and correlations between regions.

- GIS Data Layers: A variety of GIS data layers were used in the selection of Proposed CREZs. They include roads, administrative boundaries, designated federal and state forests and parks, military reserves, water bodies, populated areas, and topography. All of the data except elevations, residential, and water bodies were provided by ESRI, Inc., with the ArcGIS software. Elevations were obtained from the 30 m gridded National Elevation Dataset (http://edcwww.cr.usgs.gov/products/elevation/ned.html), and water bodies and populated areas were obtained from the 30 m gridded National Land Cover Database (NLCD 2001) (http://edcwww.cr.usgs.gov/products/landcover/nlcd.html).

3 METHODS

3.1 Initial Identification and Characterization of Proposed CREZs

The first step was to conduct a site-screening study for Texas using GIS-based tools developed by AWS Truewind for previous projects. The outcome was a map of potential wind project sites and a table summarizing their characteristics (e.g., location, rated capacity, mean speed, net capacity factor, distance to nearest road and transmission line, and cost of energy). The site selection procedure is described below.

- The wind speed map and speed and temperature distributions generated by MesoMap were combined to create a map of expected gross capacity factors for a generic large wind turbine (1.5-2.0 MW class). The generic wind turbine power curve was created by averaging the power curves from three leading turbine models: the GE 1.5sl (1.5 MW), Vestas V80 (1.8 MW), and Gamesa G80 (2.0 MW). The power curve was adjusted at each location to reflect the air density (estimated from the average temperature and elevation). A loss factor of 14%, which we judge to be typical for Texas projects, was then applied to convert from gross to net capacity factor.

- Exclusion zones were identified and mapped. The excluded areas included national and state parks and forests, other wilderness or protected areas, military reservations, areas within one mile of an inhabited area, water bodies, and terrain with a slope greater than 20%.

- We employed a computer program to select all sites in the state large enough to support a wind project of at least 100 MW capacity above a specified minimum net capacity factor outside excluded areas. The minimum capacity factor was adjusted to capture about 1200 sites representing over 130,000 MW of potential wind capacity in diverse regions of Texas.

Next, we reviewed the site map and identified groups of sites meeting the basic requirements for a CREZ. The requirements included: similarity of wind resource (mean speed and seasonal/diurnal patterns); sufficient wind generation potential (at least several hundred megawatts, and typically several thousand megawatts); and adequate geographic diversity (coverage of all counties of active interest to stakeholders). Note that access or proximity to the existing transmission grid was not considered.

This preliminary review resulted in a map of 25 CREZs, shown in Figure 1. In this map, it should be noted, the CREZ outlines encompass many individual 100+ MW sites with a minimum buffer of 5 km between and around the sites. Three (CREZs 1, 3, and 4) have over 11,000 MW, while two (CREZs 16 and 22) have less than 500 MW. The average capacity is about 5400 MW.

For each Proposed CREZ, we constructed a supply curve indicating the average net capacity factor as a function of cumulative generating capacity. Based on these curves, we divided each CREZ into up to four groupings of 1000 MW each. Maps of the 1000 MW and 4000 MW CREZ outlines are provided in Figures 2 and 3, respectively.

3.2 Modifications to Proposed CREZs

The Proposed CREZs were submitted to the stakeholders to solicit their suggestions for improvement. Some project developers informed us that the wind resource estimates in certain regions appeared to be too low. We asked the developers to provide data or independent reports supporting these claims. After reviewing the information provided for several sites, we concluded that the concerns were mostly valid, and determined that the average wind speeds should be increased by 5% in CREZs 3, 14 and 25 and by 8% in CREZ 21. These changes increased the net capacity factors of the sites in those CREZs by roughly 8-14%. The supply curves were then recalculated. The revised curves are presented in ERCOT's report.

3.3 Characterization of Plant Output

ERCOT asked that we provide hourly simulated wind output data for all sites in the 4000 MW CREZs for its transmission analysis. To do this we relied on a mix of modeled and measured data to characterize the output of wind projects. The main source of data was the dynamic (time-varying) weather simulations performed for a representative sample of historical days by the MesoMap system. The advantage of relying on a model for this purpose is that it allowed us to consider sites anywhere in the state, regardless of the availability or proximity of wind measurements. In addition, we have shown in previous studies that the model captures the essential characteristics of the wind resource, including its dynamic behavior and correlations between distant sites. To ensure that typical seasonal and daily patterns are faithfully represented, however, we used high-quality data from tall towers to adjust the model output. This blended approach struck a compromise between the flexibility offered by models and the accuracy offered by direct observations.

Once the Proposed CREZs were defined and characterized, we extracted from the MesoMap model runs an hourly time series of wind speed, direction, and temperature data for a point near each site. Each time series represented a "typical year" (365 days, 8760 hours) sampled from 15 years (1990-2004). The speeds for each site were then scaled so that the mean matched the estimated mean extracted from the Texas wind map (adjusted as necessary as described in Section 3.2).

Next, we converted the wind speed, direction, and temperature data to plant output. The method we used accounted for variations in speed, air density, wake loss (as a function of direction), and other losses (such as electrical losses), as well as random fluctuations related to turbulence. For each site, the following steps were carried out:

- The average diurnal and monthly speeds were adjusted to match patterns observed at tall towers in the region. The adjustments, which were modest, did not materially affect changes in speed from one hour to the next or correlations in speed between sites.
- A direction-dependent loss factor was then subtracted from the speed in each hour to represent the effect of wake interference between turbines as well as other, non-direction-dependent losses such as blade soiling. The loss factor ranged from 4% to 9% depending on the direction of the wind relative to the prevailing (most frequent) direction.
- The speed was adjusted up or down by a random factor related to the turbulent kinetic energy (TKE) predicted by the model for that hour. The TKE is a measure of the gustiness of the wind, and thus, this adjustment allowed the output to fluctuate in a realistic fashion according to how gusty the conditions were expected to be.
- The speed was transformed to power using a generic power curve, which had been adjusted to the predicted air density for each hour. The power curve was a composite of three leading turbine power curves chosen to match the IEC class of the site.[2] The turbine models for each class were as follows:

  Class I (>8.5 m/s): GE 1.5sl, Vestas V80, Gamesa G80

  Class II (7.5-8.5): GE 1.5sle, Vestas V82, Gamesa G87

  Class III (<7.5 m/s): GE 1.5xle, Vestas V100, Gamesa G90

  (The speed ranges are defined for the standard sea-level air density of 1.225 kg/m^3.)
- The output was adjusted by a random loss factor ranging from 0% to 8%, with an average of 4%, representing fluctuations in losses associated with turbine down time. The combined wake and non-wake losses averaged about 14% for all projects and ranged from 12% to 16%.

The resulting output data were provided to ERCOT in comma-delimited files, one for each Proposed CREZ. Within each file, a time series of data was provided for each project site in the CREZ; however the precise locations of the sites were not specified. This approach allowed ERCOT to pick and choose sites in each CREZ to create the scenarios to be assessed in its analysis of transmission upgrades.

---

2 Turbines are designed for sites that fall within a range of wind conditions defined by the IEC class. At a standard sea-level air density of 1.225 kg/m^3, a site is Class I if its mean speed exceeds 8.5 m/s, Class II if it exceeds 7.5 m/s, and Class III if it is below 7.5 m/s. The speed threshold is adjusted according to the air density: a lower air density means the speed threshold for a particular IEC class can be increased, so that, for example, a Class II turbine could be used at a site that, at standard density, would be Class I.

4 RESULTS AND CONCLUSIONS

AWS Truewind employed its MesoMap system and a variety of other tools to identify 25 CREZs encompassing over 1200 potential wind project sites totaling over 130,000 MW, and to produce data files characterizing the hourly output of up to 4000 MW of capacity in each CREZ for a typical historical year. The simulated output was adjusted to match observed seasonal and daily patterns according to tall tower data obtained by AWS Truewind from various parts of the state. The results have been used by ERCOT, in consultation with stakeholders in the transmission planning process, to provide a focus and basis for the study of possible transmission upgrades designed to enable the expansion of wind energy projects in Texas.

Figure 1. Proposed Competitive Renewable Energy Zones

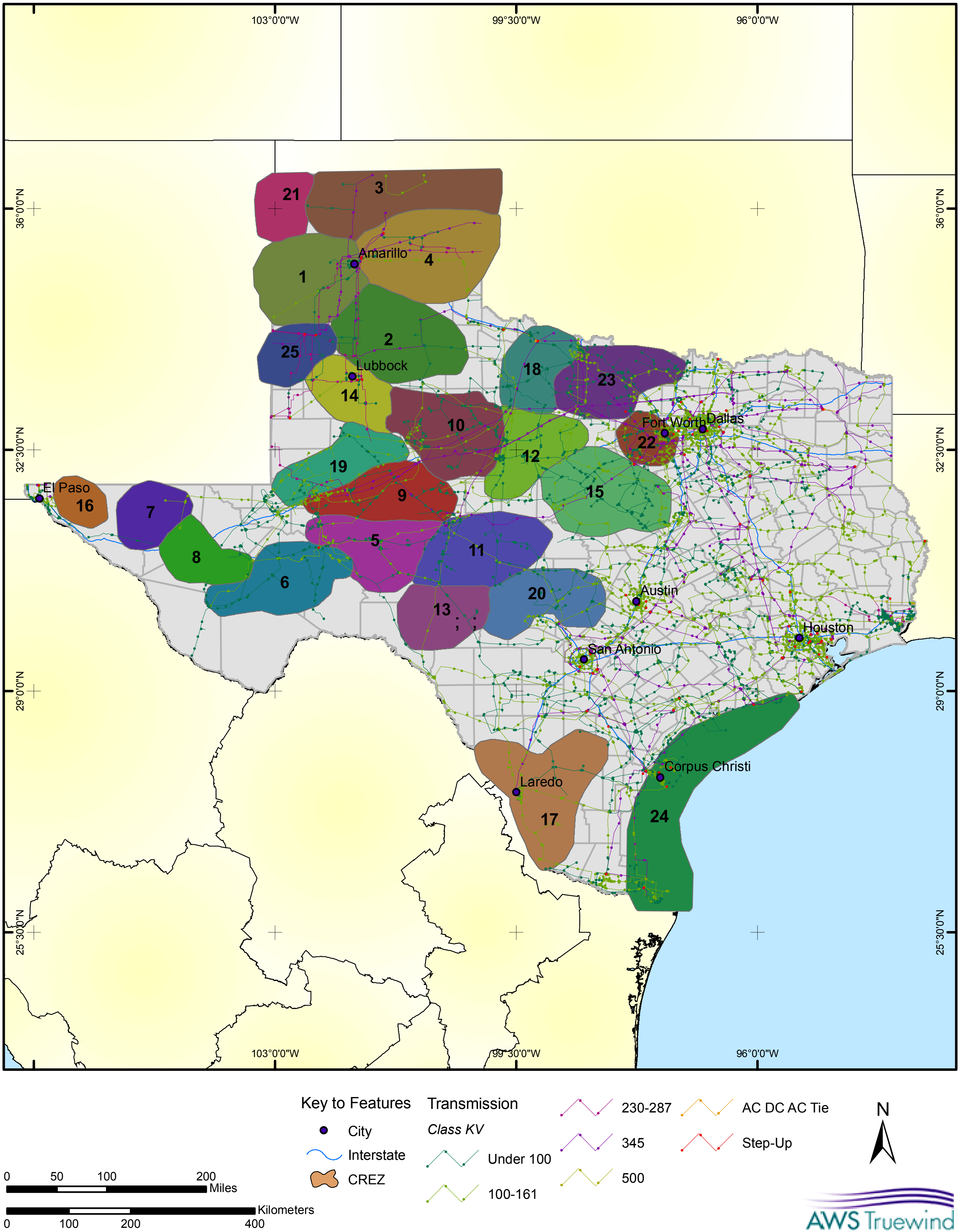

Figure 2. Proposed Competitive Renewable Energy Zones

1000 MW

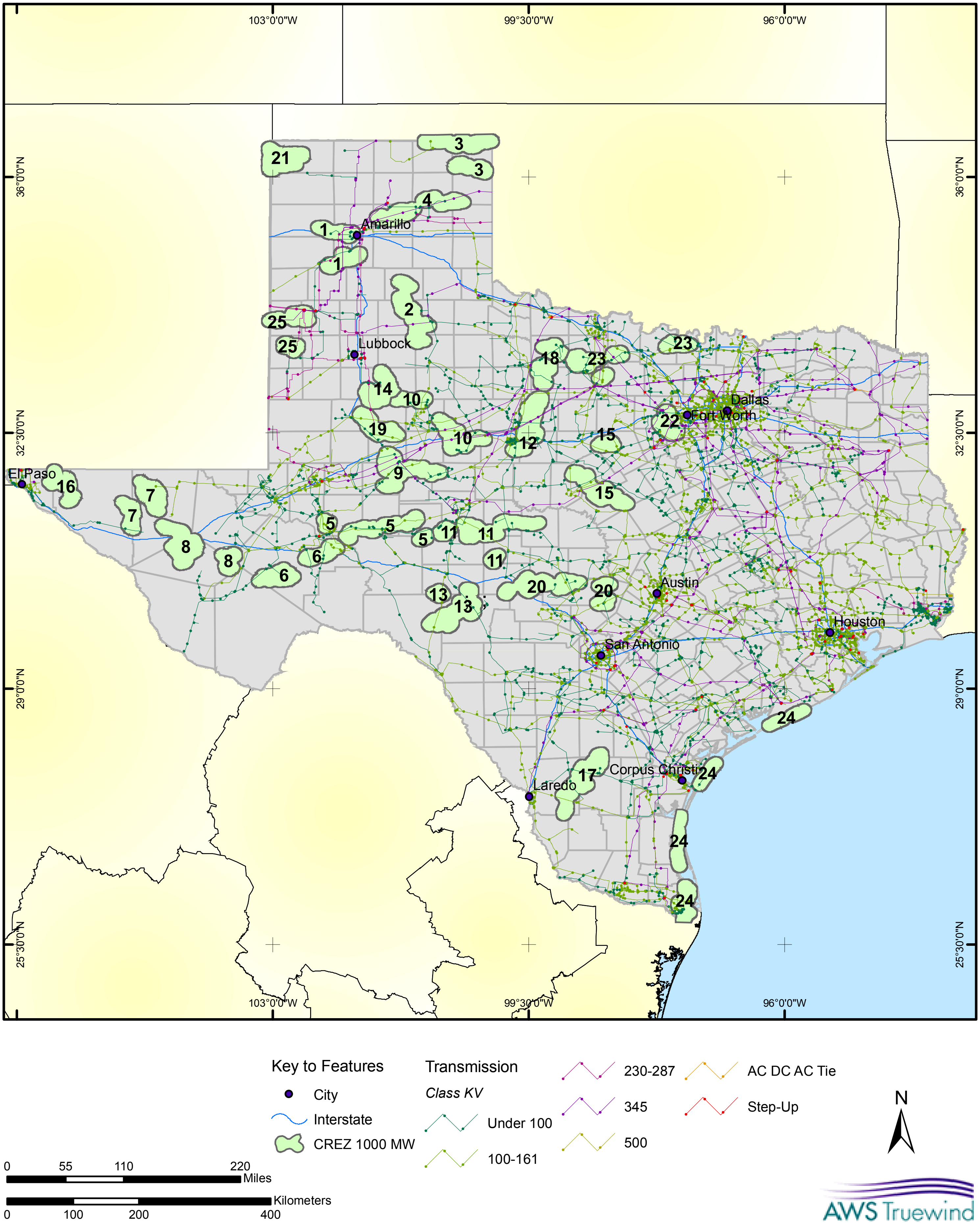

Figure 3. Proposed Competitive Renewable Energy Zones

4000 MW