

A Neural Network-Based Algorithm for Monitoring the Wholesale Power Prices around Ohio

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National
Association of
Regulatory
Utility
Commissioners

Ohio

**Public Utilities
Commission**

Preamble

- Ohio Statute requires the PUCO to carry out the following policy element:
O.R.C. 4928.02 (I) - *Ensure retail electric service consumers protection against unreasonable sales practices, market deficiencies, and market power.*
- In an ESP or an MRO, retail electricity prices may be tied to a wholesale index price such as the price at the Cinergy Hub or the PJM West Hub.
- Market power abuses are a concern to the PUCO, who is charged with developing competition in the state's retail electricity market.

Monitoring Tool

- An algorithm employing a neural network-based model has been developed by the PUCO staff to monitor the reasonableness of prices in wholesale electricity markets at two of the major hubs surrounding Ohio.
- The model builds a relationship between a day-ahead published index price (Cinergy or PJM West) and several independent variables (temperature, power plant production, type of day, historical wholesale prices of electricity and natural gas).
- The current monitoring accuracy is about 6% to 8% for the MAE% at both Cinergy (since 3/21/05) and PJM West (12/20/04) hubs.

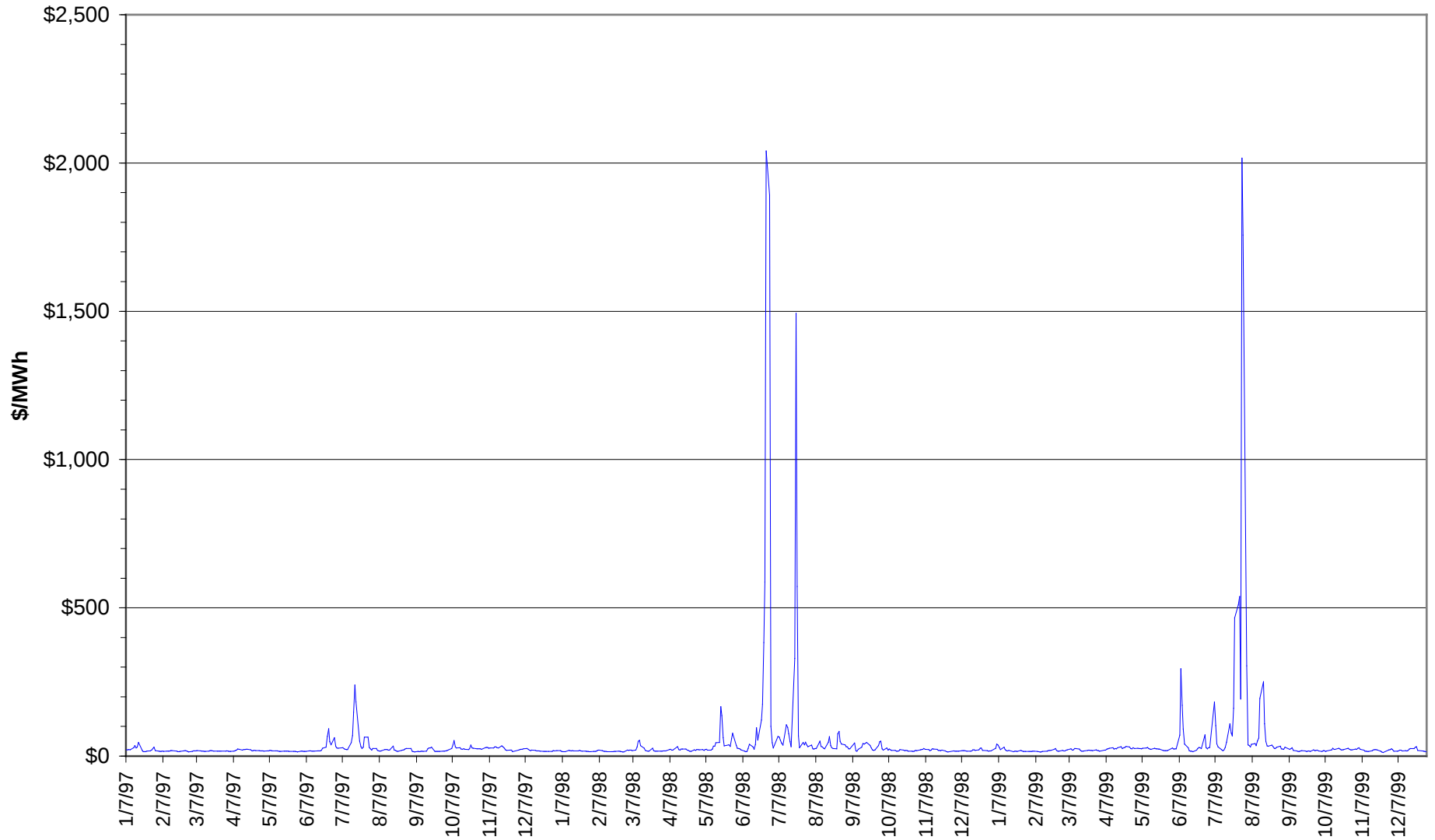
Application

- If day-ahead wholesale prices at either hub diverge “significantly” from the in-house model results → staff examines market conditions to determine whether the divergence can be reasonably explained by exogenous factors (e.g. an unplanned outage) → the PUCO decides whether or not to pursue an inquiry on this divergence with the market monitor of the Independent System Operator (ISO).

Motivation

- The significant impact of the wholesale power market on the retail power market (The California example).
- The price volatility in the wholesale power market in the late 1990s (The Cinergy Hub prices: \$20/MWh to \$2,000/MWh).
- The importance (cost) of short-term forecast accuracy in the power industry.
- The success of using neural network-based models in short-term energy demand/load forecasting (both natural gas and electric utility industries).

Day-Ahead Wholesale Power Prices at the Cinergy Hub (1/7/97 - 12/30/99)



Previous Work

➤ Model Development/Calibration

- Choueiki, M. H., and Mount-Campbell, C. A., "Training Data Development with the D-optimality Criterion", *IEEE Transactions on Neural Networks*, Vol. 10, No. 1, pp. 56-63, 1999.
- Choueiki, M. H., Mount-Campbell, C. A., and Ahalt, S. C., "Building a Quasi Optimal Neural Network to Solve the Short-Term Load Forecasting Problem", *IEEE Transactions on Power Systems*, Vol. 12, No. 4, pp. 1432-1439, 1997.
- Choueiki, M. H., Mount-Campbell, C. A., and Ahalt, S. C., "Implementing the Weighted Least Squares Procedure in Training a Neural Network to Solve the Short-Term Load Forecasting Problem", *IEEE Transactions on Power Systems*, Vol. 12, No. 4, pp. 1689-1694, 1997.

➤ Model Applications

- Choueiki, M. H., and Wang, D. L., "On the Robustness of Neural Nets for Predicting Price Abnormalities in Wholesale Power Markets", presented at the 2004 INFORMS Meeting, Denver, Colorado, October 24-27, 2004.
- Choueiki, M. H., "Forecasting Bulk Power Market Prices Using Simple Recurrent Neural Nets", presented at the 2003 INFORMS Meeting, Georgia, Atlanta, October 19-22, 2003.
- Choueiki, M. H., and Wang, D. L., "Forecast Competition Results in Predicting Monthly Natural Gas Sales in Ohio", presented at the 2000 INFORMS Meeting, San Antonio, Texas, November 5-8, 2000.
- Choueiki, M. H., "A Weighted Least Squares Training Procedure for Forecasting the Monthly Natural Gas Consumption in Ohio Using Neural Networks", presented at the 1999 INFORMS Meeting, Philadelphia, Pennsylvania, November 7-10, 1999.
- Choueiki, M. H., "Forecasting the Monthly Natural Gas Consumption in Ohio Using Neural Networks", presented at the 1999 INFORMS Meeting, Cincinnati, Ohio, May 2-5, 1999.

The Current in-house Monitoring Model

➤ Model Input

- Today's identifier (1-of-5 node coding)
- Today's high and low temperatures ($^{\circ} F$)
- Today's percent power plant production @ peak hour – 2:00pm (expensive, proprietary, and limited)
- Yesterday's spot market price of natural gas at the Henry Hub (in \$/MMBtu)
- Yesterday's wholesale price of electricity in the day-ahead market at the Cinergy or PJM West Hub (in \$/MWh)

➤ Model Output

- Today's wholesale power price at the Cinergy or PJM West Hub in the day-ahead market

➤ Historical Data

- December 30, 2002 – Present
- Training – 80%
- Cross validation – 20%

Definitions

- d_i is a binary variable that identifies the day type on day i
(1-of-5 node coding) --- ($d_i = 10000$ for Monday, $d_i = 01000$ for Tuesday, ..., $d_i = 00001$ for Friday)
- $t_{ij}^{\max}$ is the maximum daily temperature on day i in region j , $j = 1,2,3$
- $t_{ij}^{\min}$ is the minimum daily temperature on day i in region j , $j = 1,2,3$

$j=1$ represents the Columbus region

$j=2$ represents the Cleveland region

$j=3$ represents the Cincinnati region

Definitions (continued)

- p_{ik} is the percent production on day i for power plant k , $k = 1, 2, \dots, 23$, at 2:00 pm.

$$p_{ik} = \frac{\text{Plant } k \text{ generation on day } i}{\text{Plant } k \text{ capacity}} \times 100$$

Note: The 23 power plants that we collect daily data on constitute about 70% of Ohio's generation.

- g_i is the daily spot market price of natural gas (\$/MMBtu) at the Henry delivery hub on day i
- e_i is the day-ahead wholesale price of electricity (\$/MWh) at the Cinergy or PJM West hub on day i

GenscapeCSVtoSQL - Windows Internet Explorer

http://pucodev/maap/genscapecsvtosql.aspx?firstname=Dave

Yahoo! Search

GenscapeCSVtoSQL

Gas Electric Temperature Final Data Edit Data Add/Remove Plants to Display View Data

Genscape CSV to SQL

Good Morning Dave

Year: 2007

Month: June

File to Open 1:

File to Open 2:

File to Open 3:

File to Open 4:

File to Open 5:

File to Open 6:

File to Open 7:

File to Open 8:

File to Open 9:

Table to Update: PlantInfo

Submit

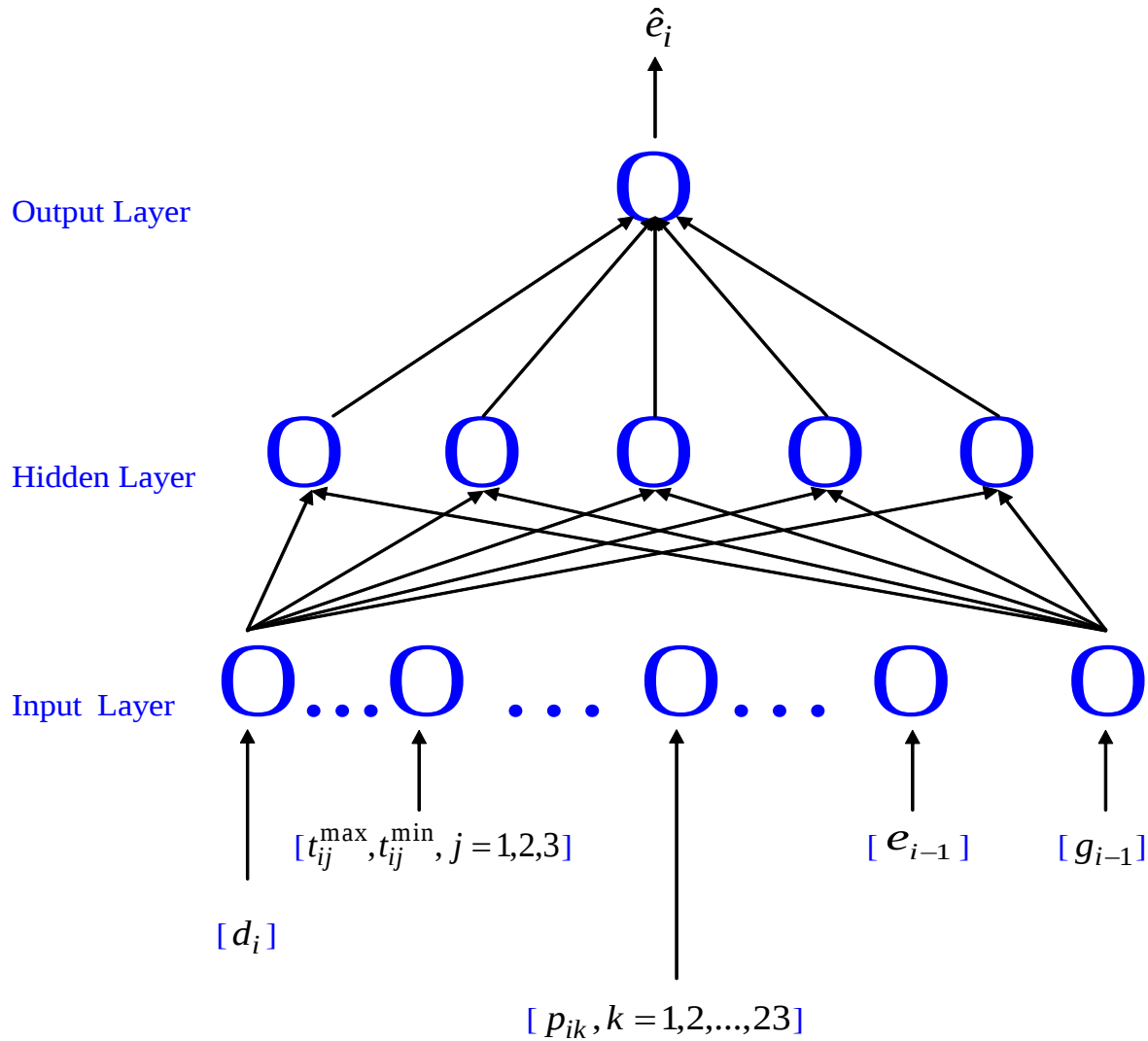
Last Date for Data Entered:
5/28/2007

Local intranet 100%

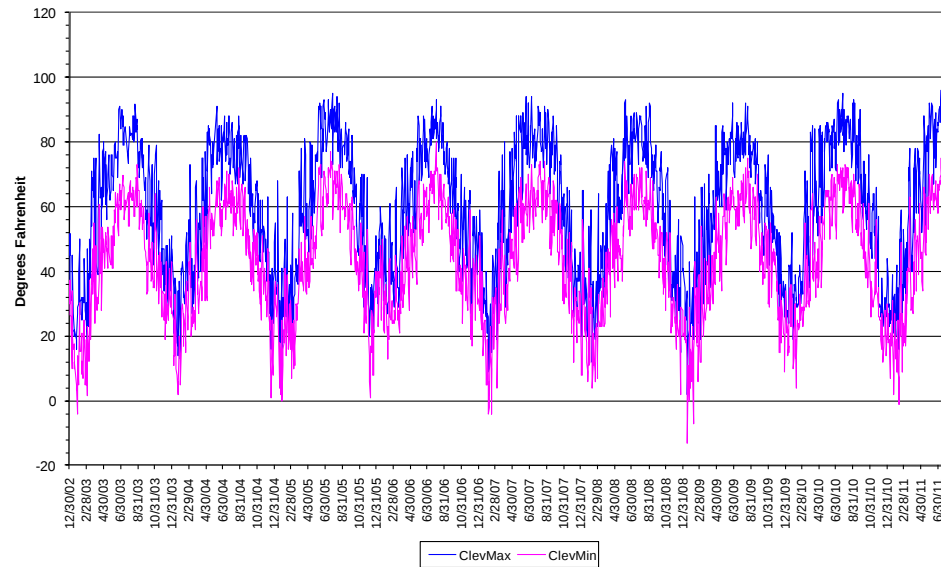
start 2 Microsoft Offic... GenscapeCSVtoSQ... 070327 Genscape Microsoft PowerPol... 7:53 AM

Model Architecture

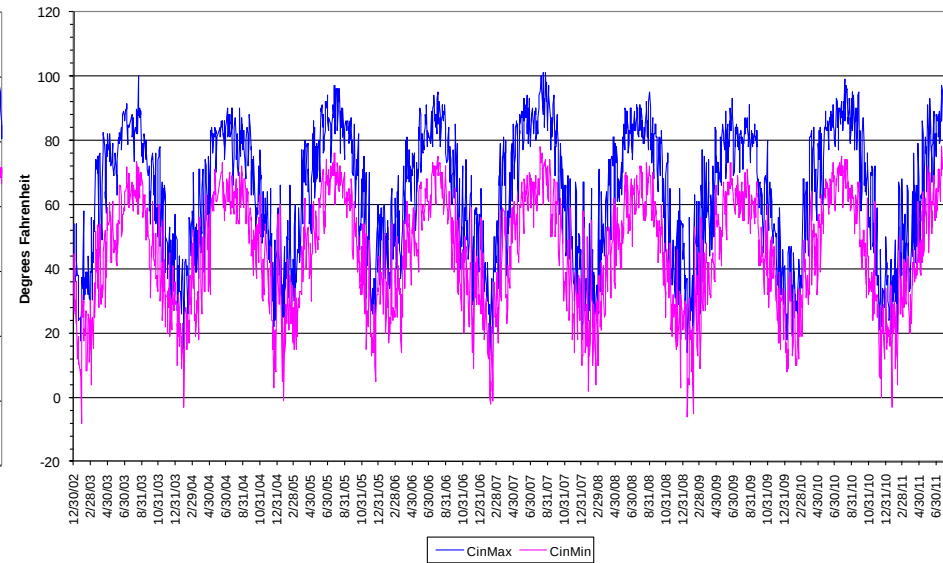
36x5x1 Architecture



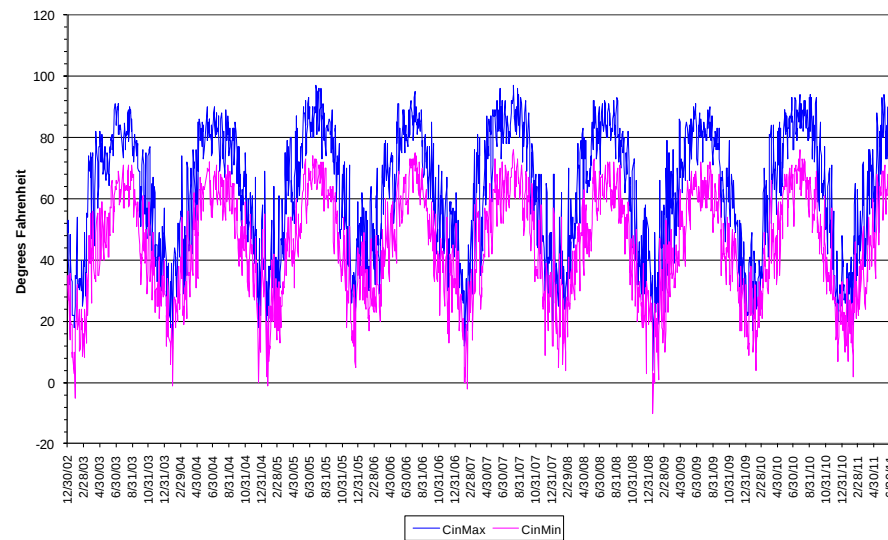
Daily Temperature in Cleveland
(12/30/02 - 08/05/11)



Daily Temperature in Cincinnati
(12/30/02 - 08/05/11)



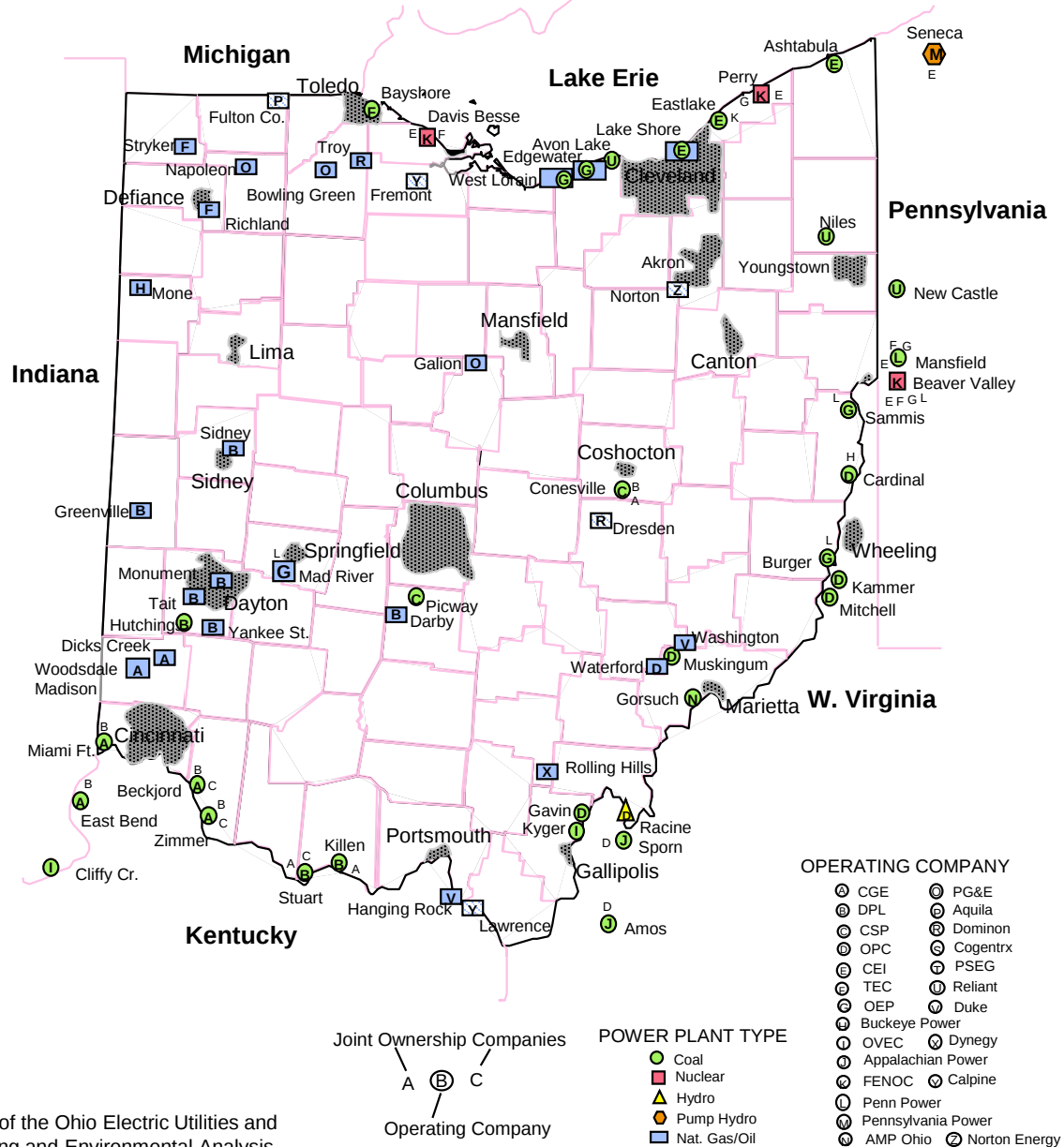
Daily Temperature in Columbus
(12/30/02 - 08/05/11)



OHIO ELECTRIC UTILITIES

Generating Facilities

(2005)

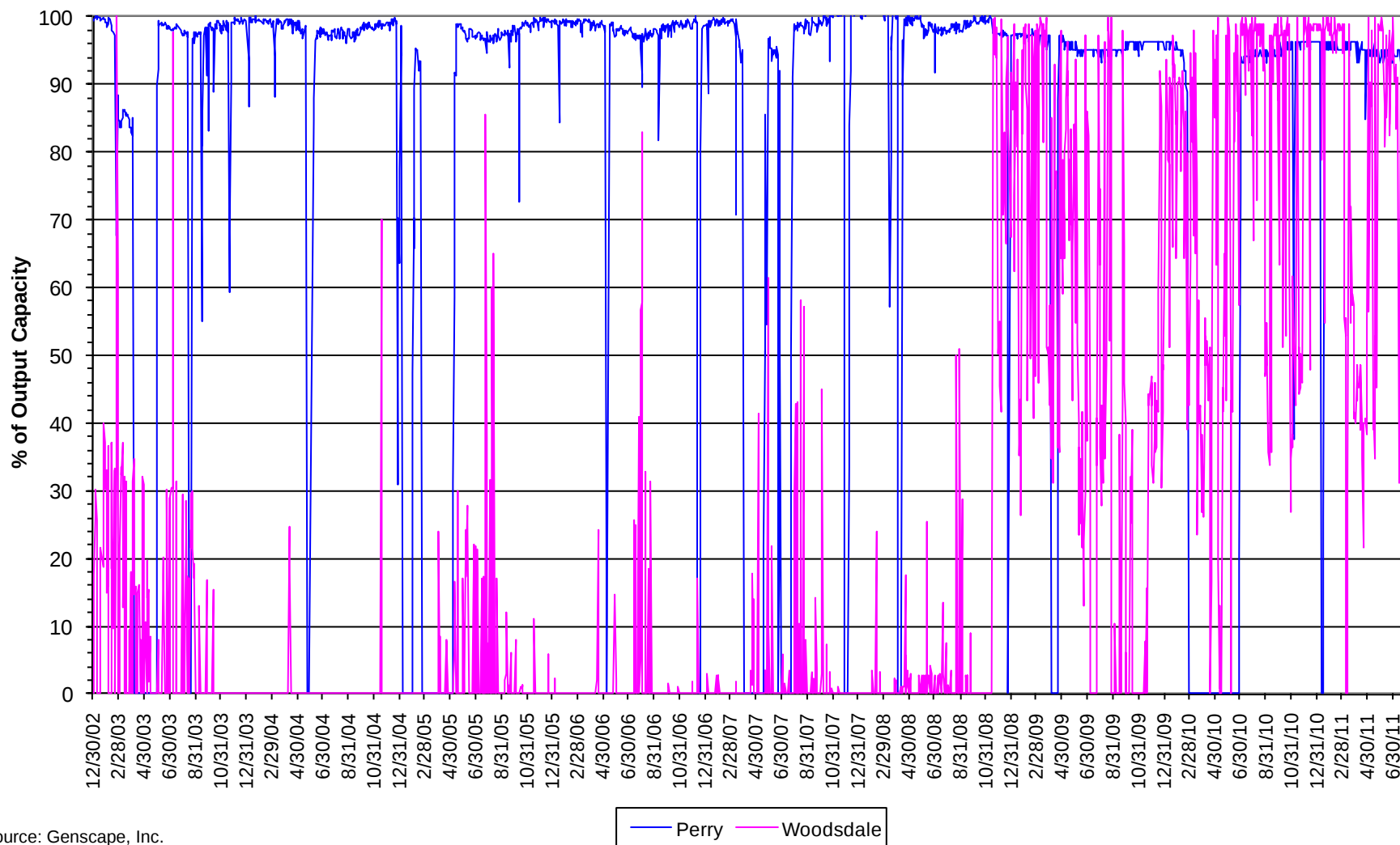


Source: Long-term Forecasting Reports of the Ohio Electric Utilities and PUCO, Division of Facilities, Siting and Environmental Analysis.

Ohio Power Plants

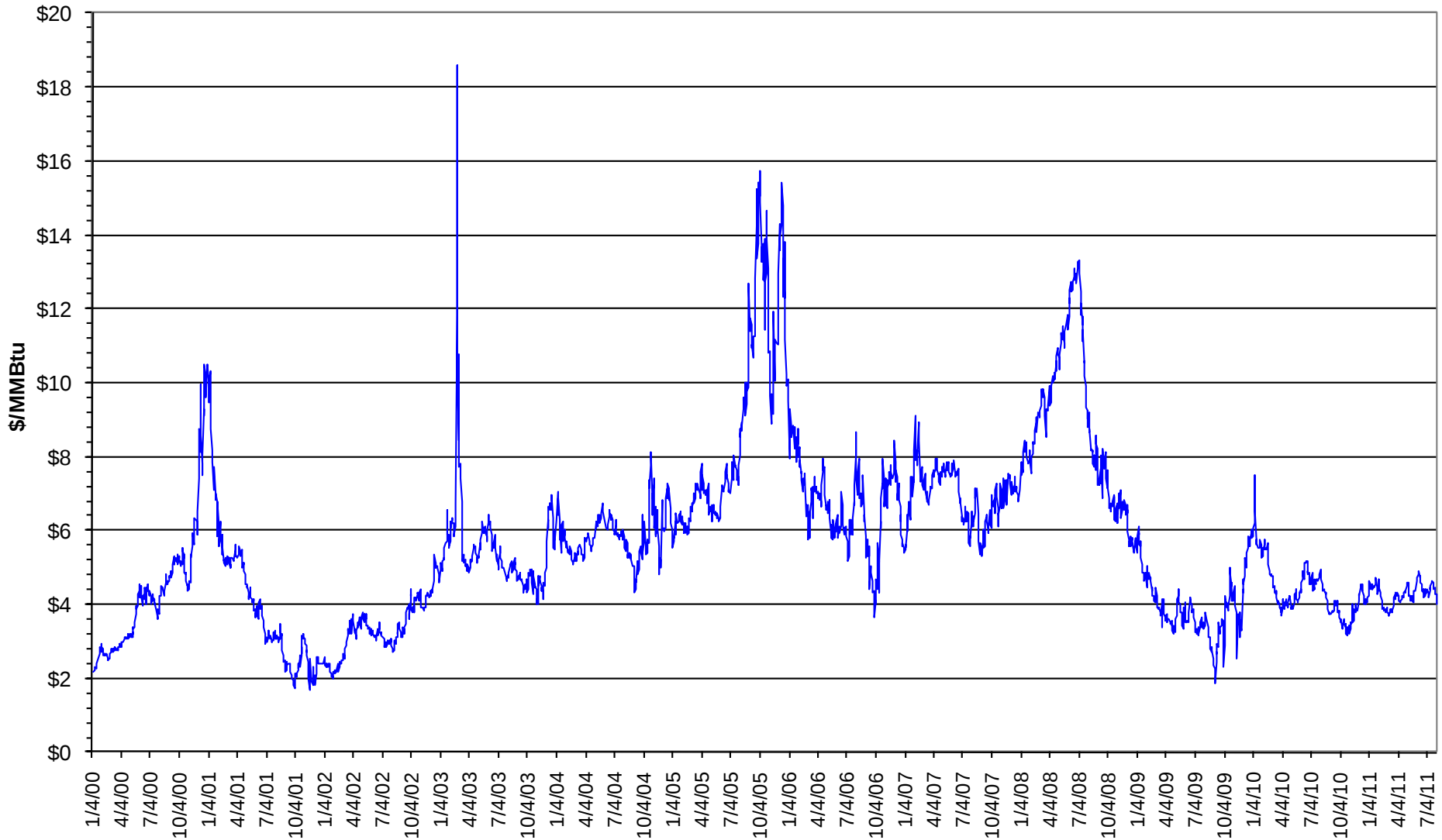
Plant Name	Fuel Type	Total Capacity MW
Ashtabula	Coal	440
Bayshore	Coal	655
Beaver Valley	Nuclear	1847
Big Sandy - Riverside	Coal/Gas	2246
Bruce Mansfield	Coal	2741
Clifty Creek	Coal	1304
Conesville	Coal	2176
Davis Besse	Nuclear	946
EastBend	Coal	648
Eastlake	Coal	1289
Fort Martin	Coal	1152
Harrison	Coal	2052
J M Stuart	Coal	2451
Killen Station	Coal	686
Kyger Creek	Coal	1085
Mountaineer	Coal	1300
Muskingum River - Washington Energy	Coal/Gas	2149
Perry	Nuclear	1272
R E Burger	Coal	423
Seneca	Hydro	466
W H Sammis	Coal	2468
W H Zimmer	Coal	1425
Woodsdale	Gas	489

Daily % of Output Capacity at Two Power Plants in Ohio (@2:00 pm)
(12/30/02 - 08/05/11)



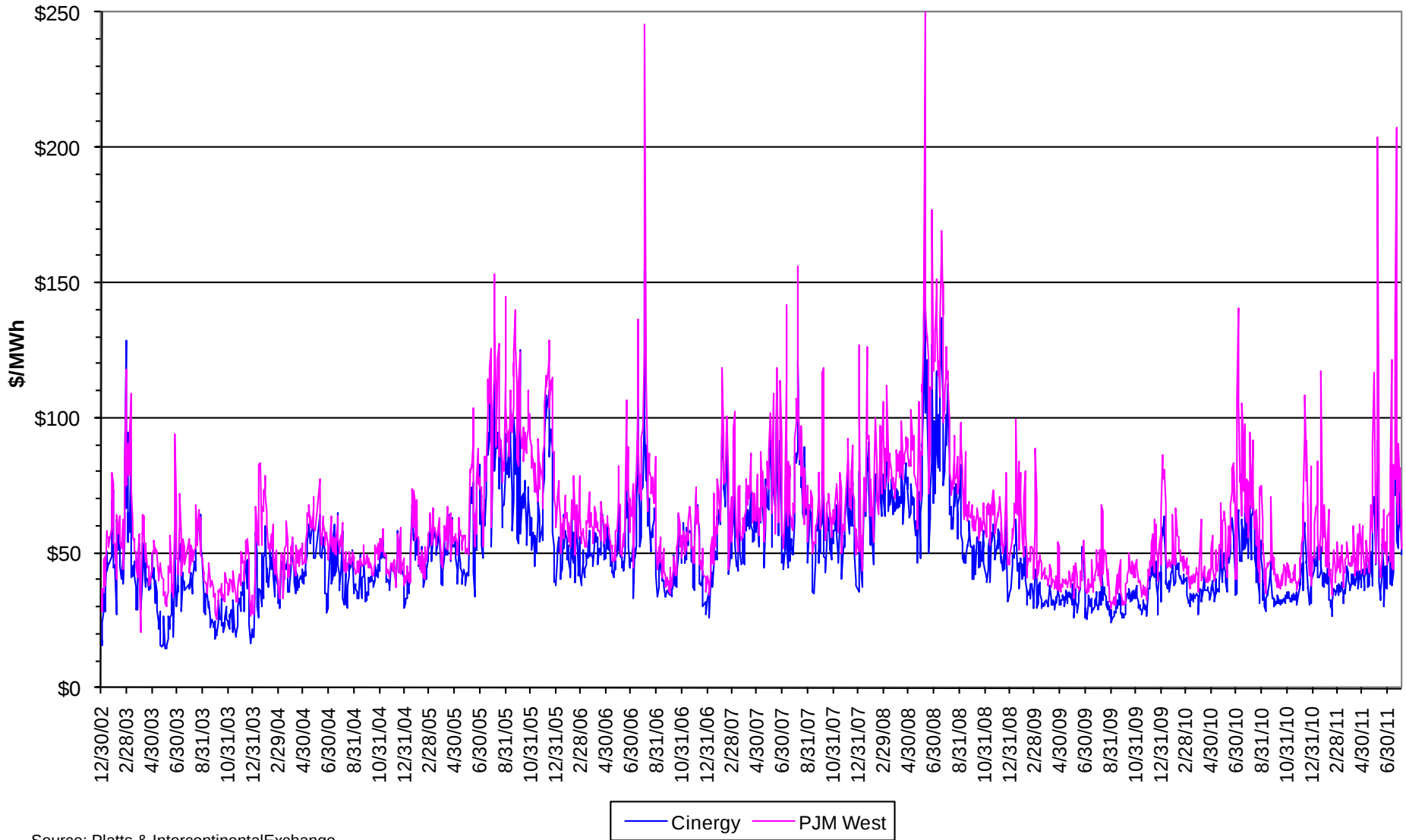
Source: Genscape, Inc.

Daily Spot Gas Prices at the Henry Hub (1/4/00 - 08/05/11)



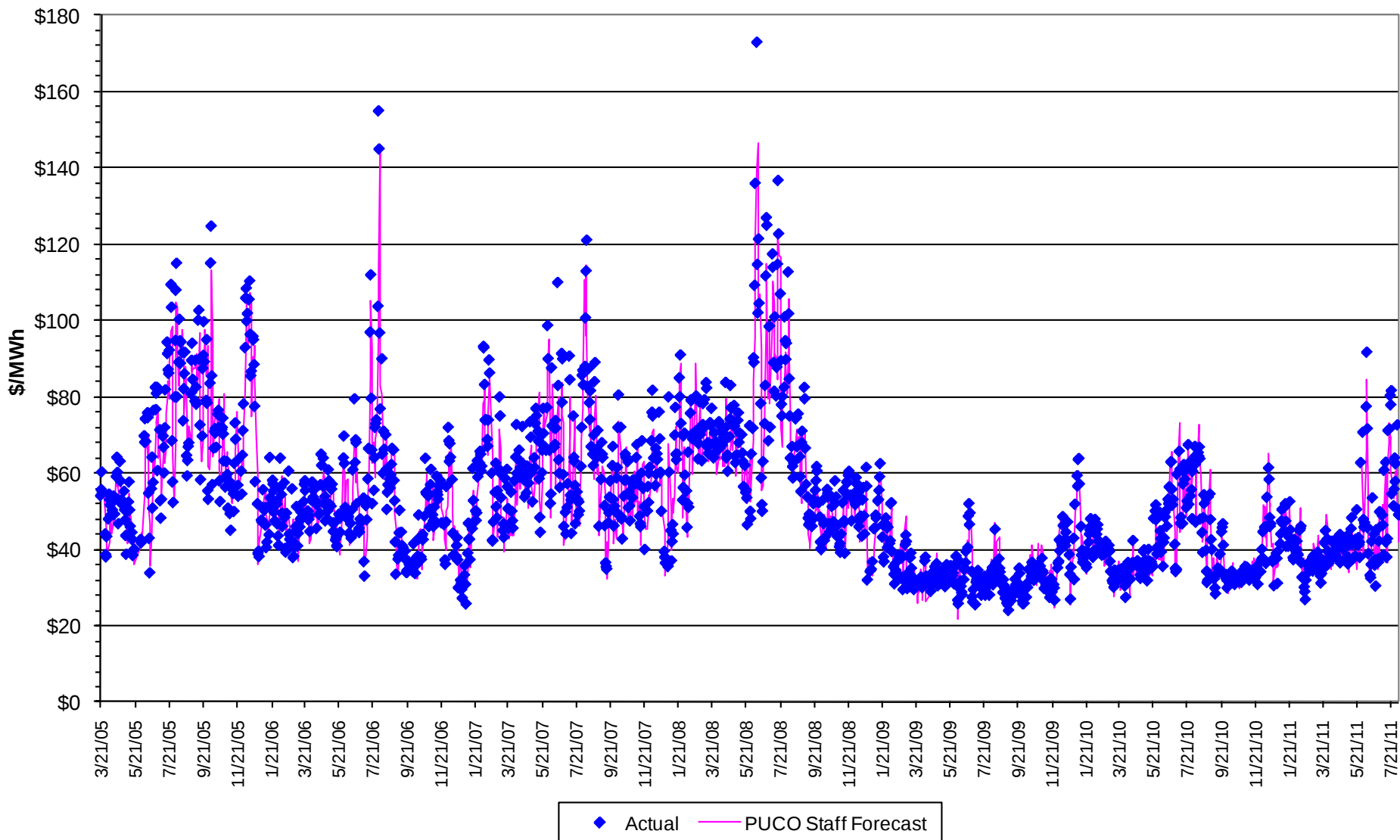
Source: Platts & IntercontinentalExchange.

Day-Ahead Wholesale Power Prices at the Cinergy and PJM West Hubs (12/30/02 - 08/05/11)



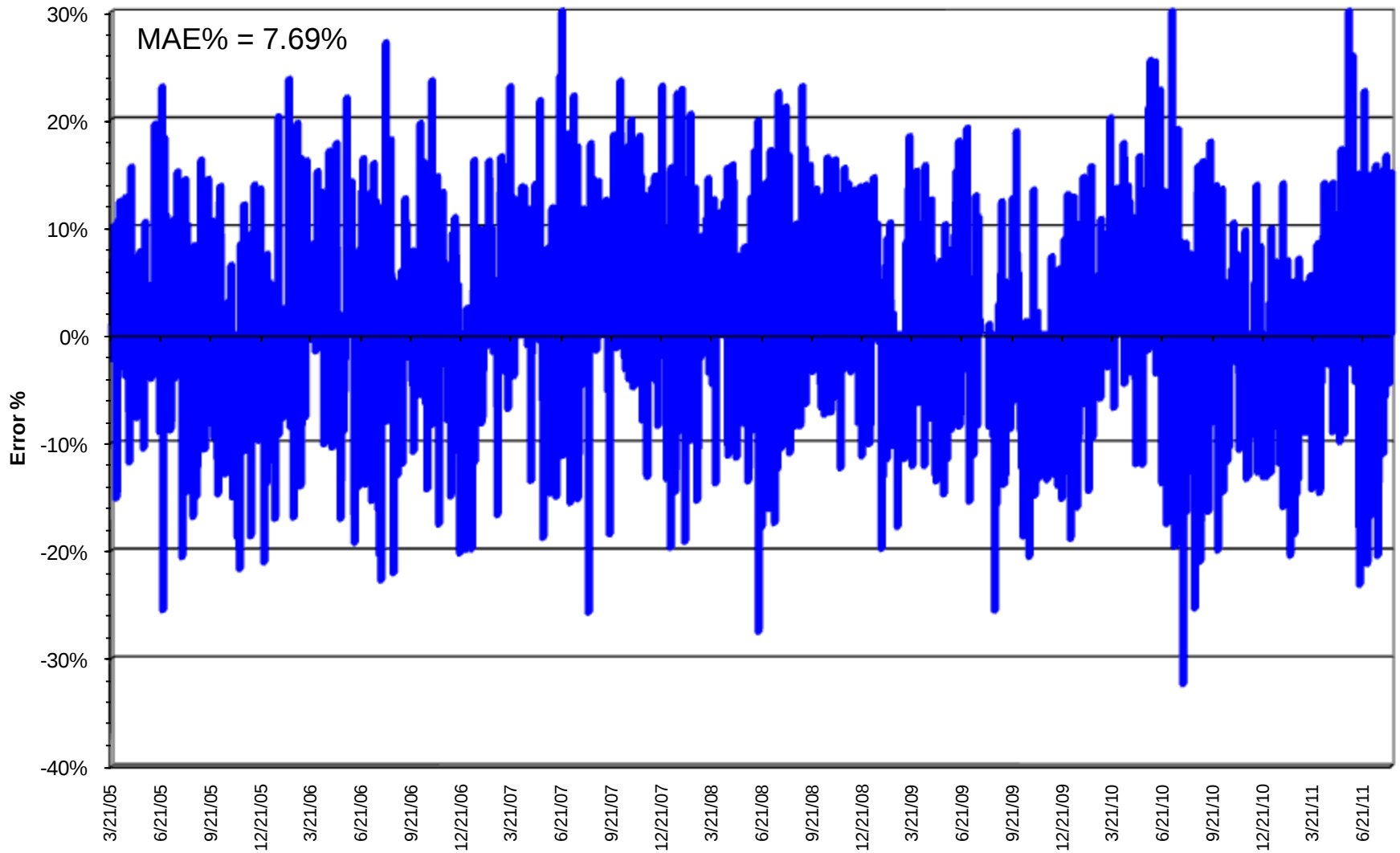
Source: Platts & IntercontinentalExchange.

Day-Ahead Wholesale Power Prices at the Cinergy Hub (03/21/05 - 08/05/11)

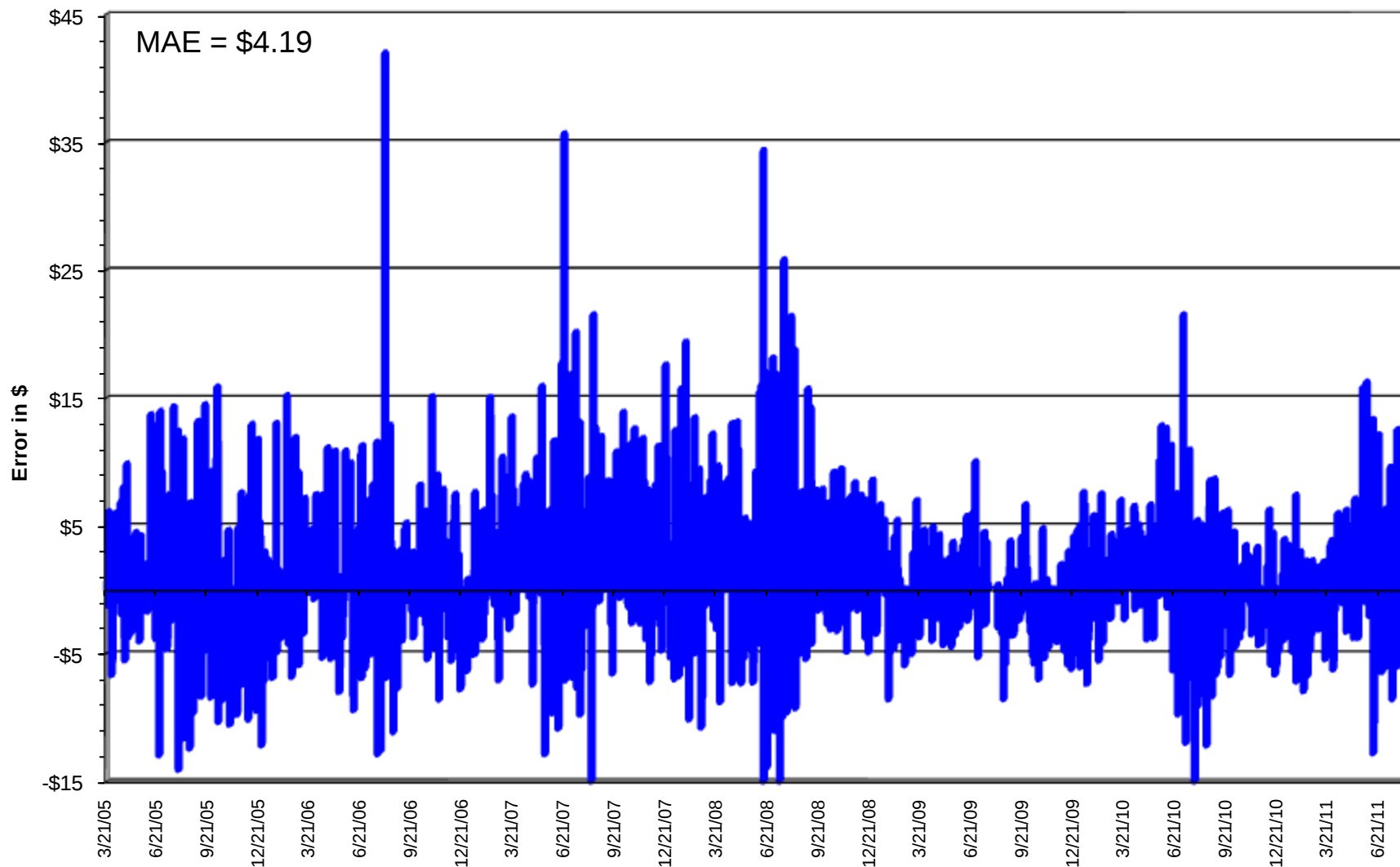


Source: Platts, IntercontinentalExchange and and PUCO, Division of Planning & Market Analysis.

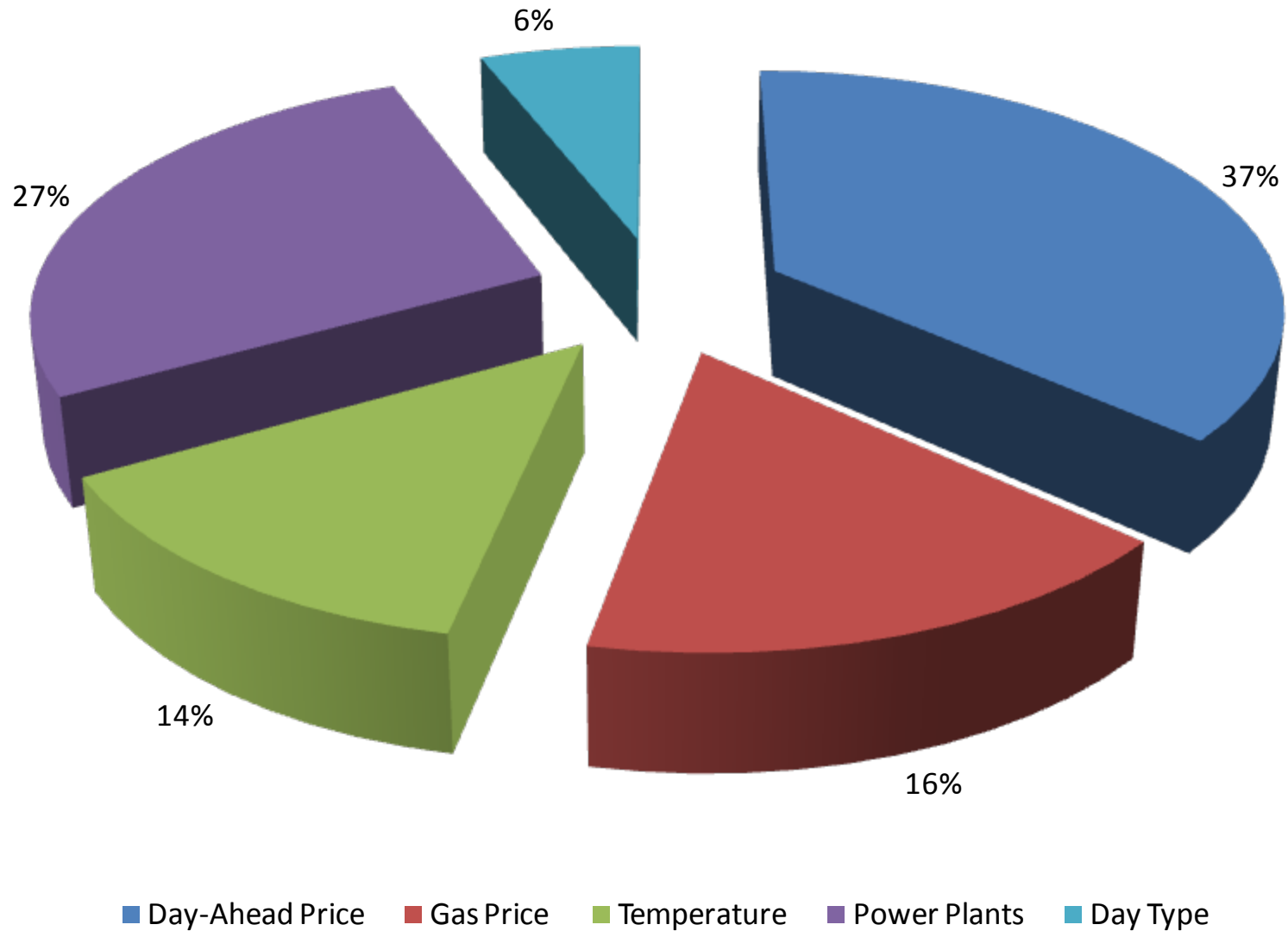
Daily Forecast Error Percent (Cinergy Hub)
(03/21/05 - 08/05/11)



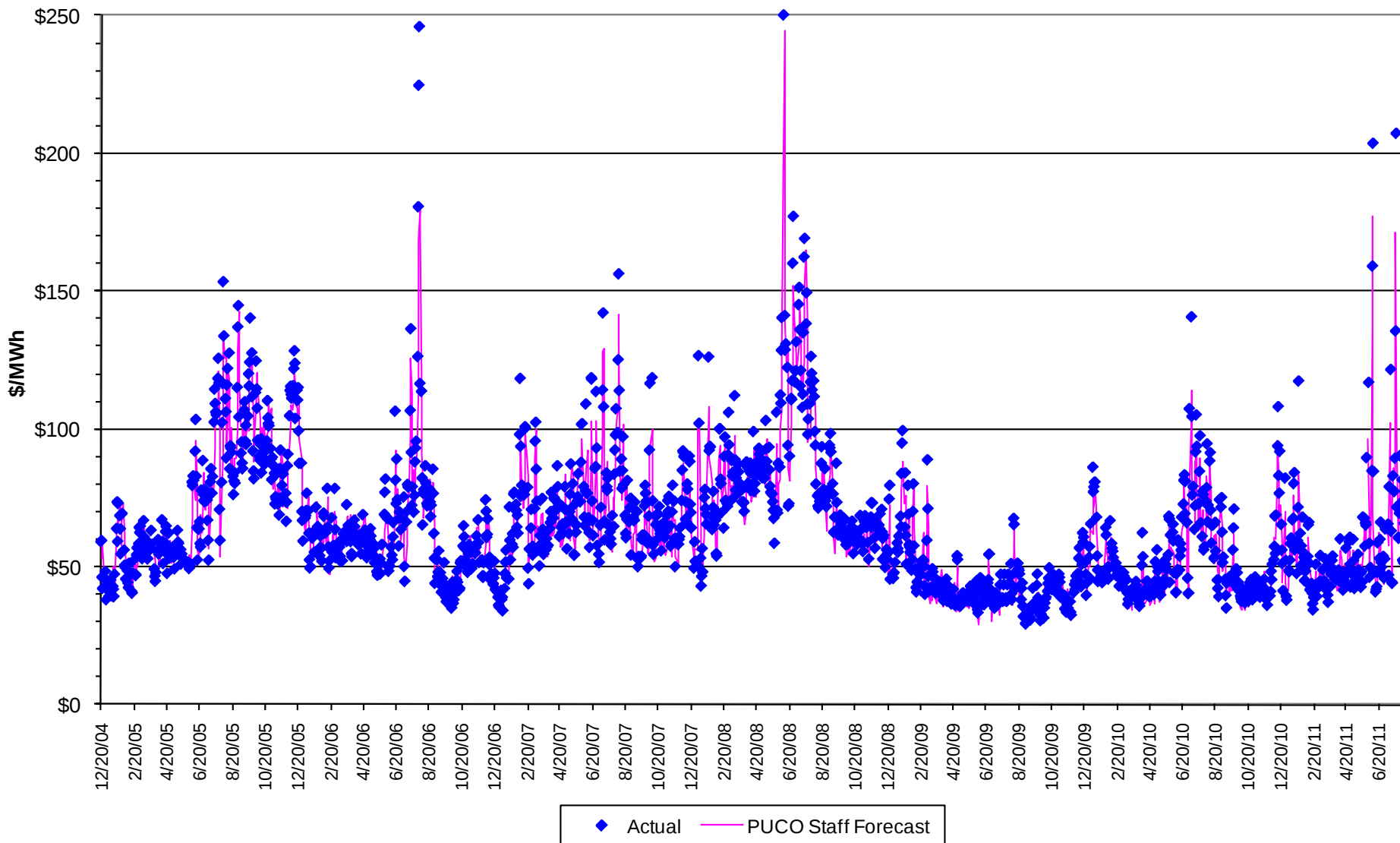
Daily Forecast Error in Dollars (Cinergy Hub)
(03/21/05 - 08/05/11)



Impact Analysis of Neural Network Model Input Into Cinergy Hub

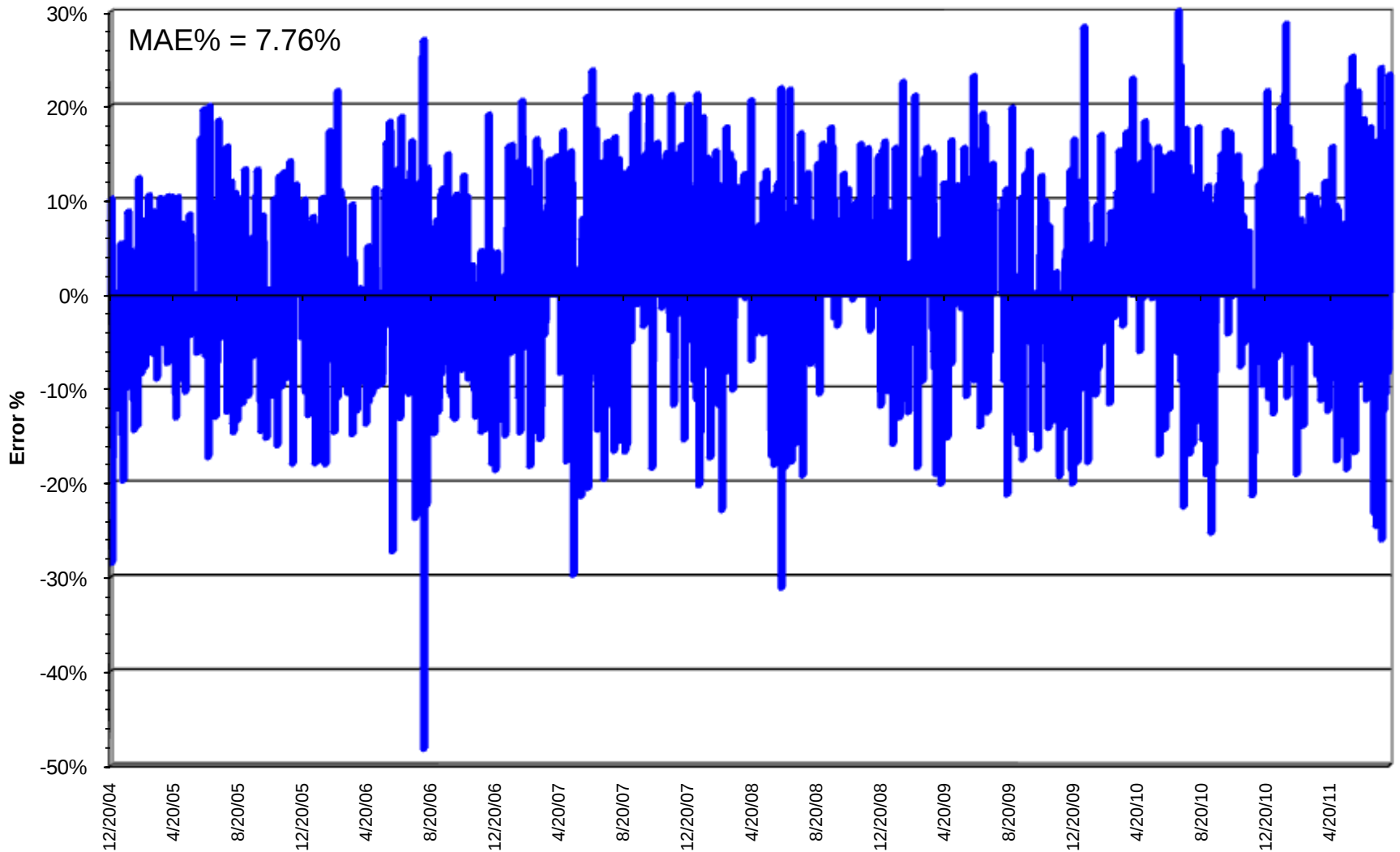


Day-Ahead Wholesale Power Prices at the PJM West Hub (12/20/04 - 08/05/11)

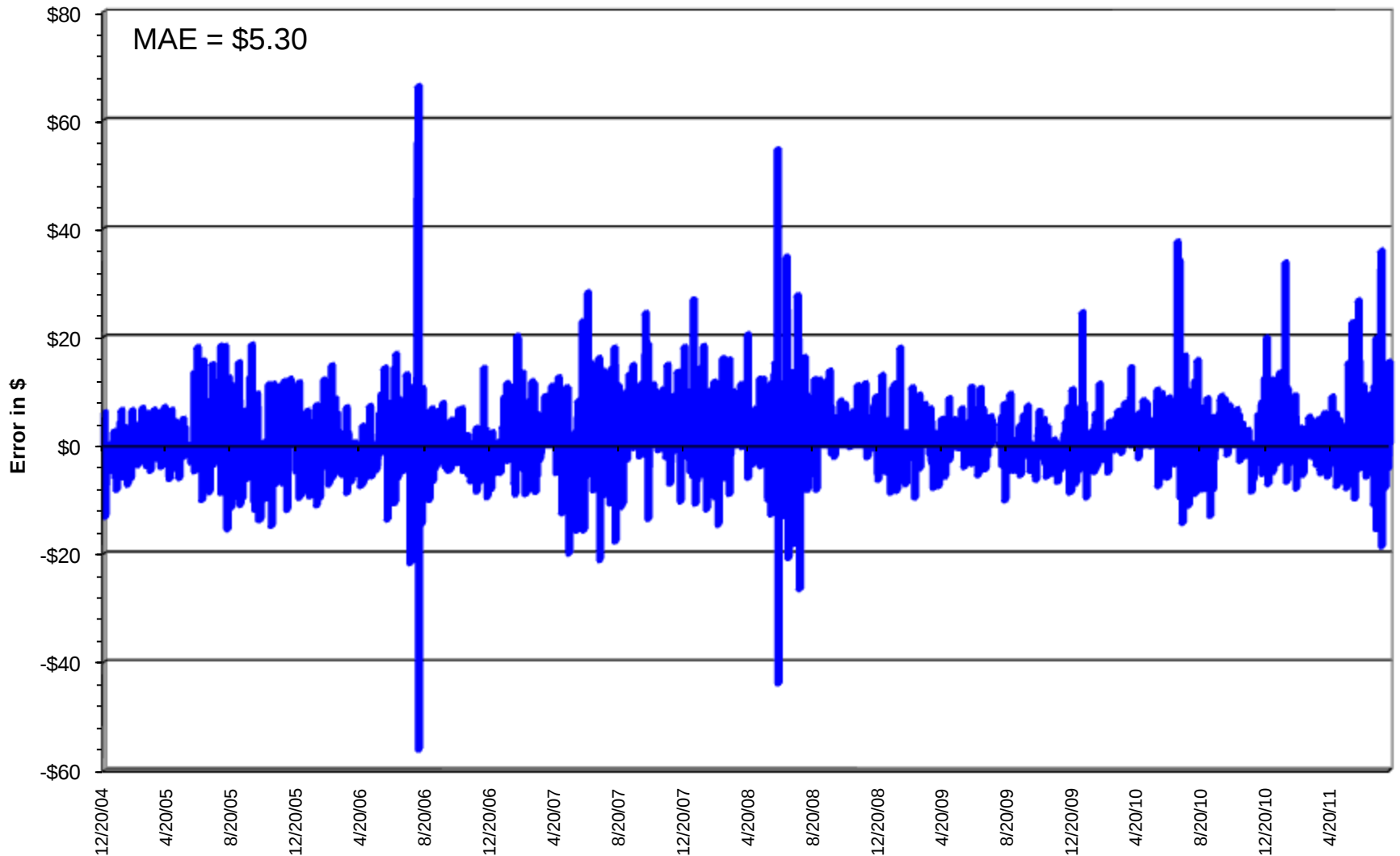


Source: Platts and PUCO, Division of Planning & Market Analysis.

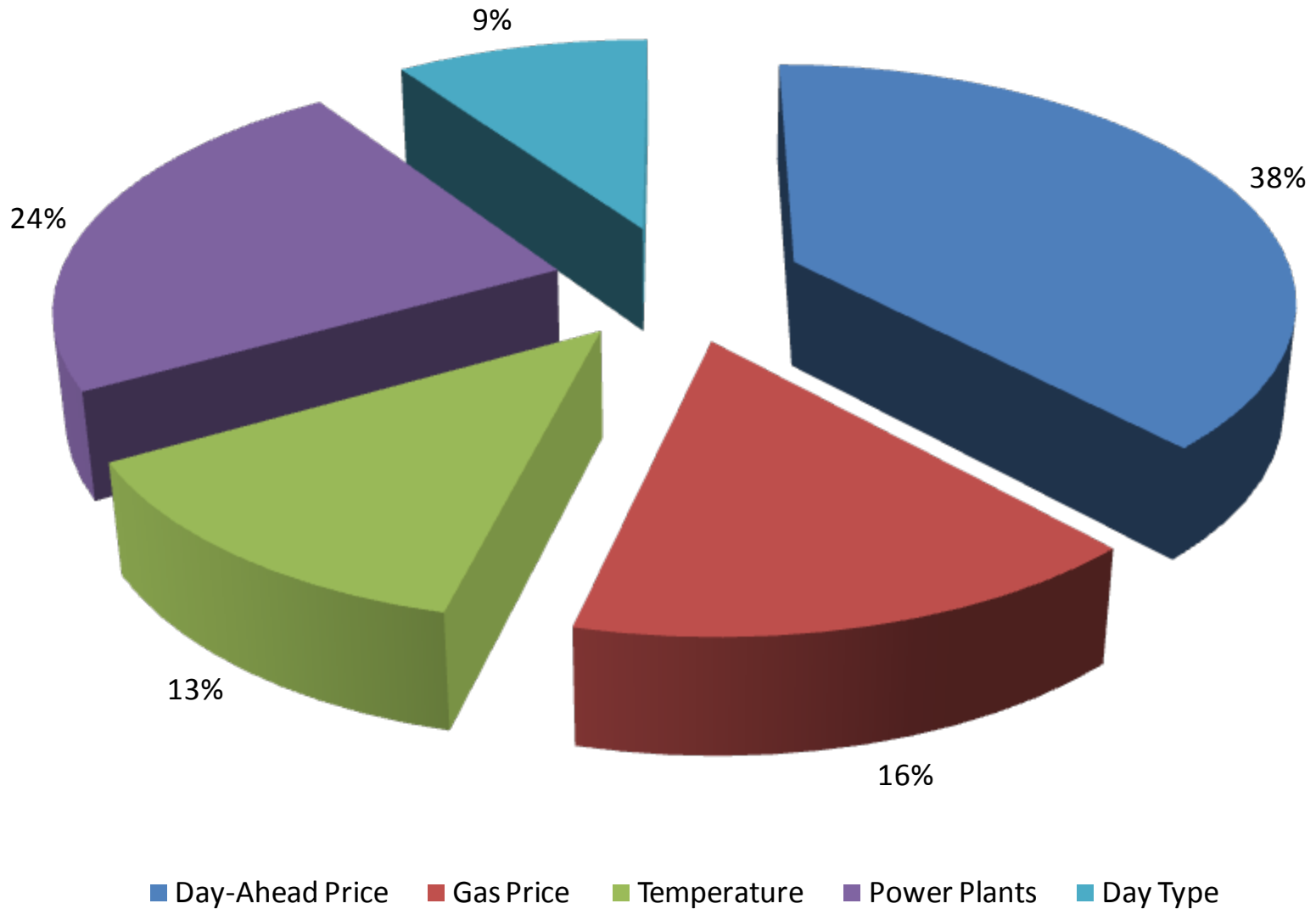
Daily Forecast Error Percent (PJM West Hub)
(12/20/04 - 08/05/11)



Daily Forecast Error in Dollars (PJM West Hub)
(12/20/04 - 08/05/11)



Impact Analysis of Neural Network Model Input PJM West Hub

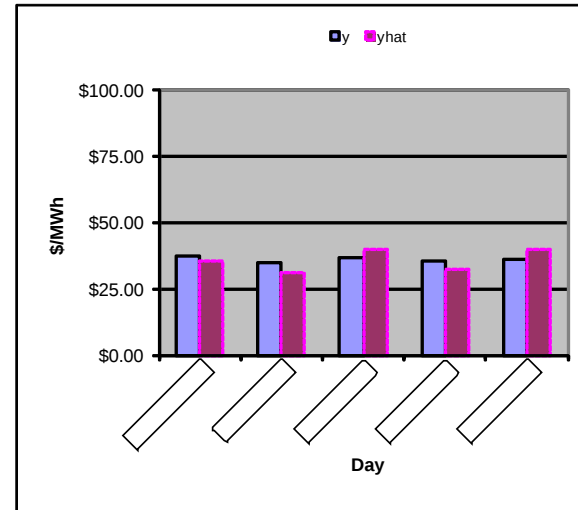


Day-Ahead Wholesale Prices at Cinergy

Forecast Data: week of 10/31/2011

<u>obs.</u>	<u>y</u>	<u>yhat</u>	<u> error </u>	<u> error% </u>	<u>error</u>	<u>error%</u>
10/31/2011	\$37.42	\$35.38	\$2.04	5.44%	\$2.04	5.44%
11/1/2011	\$34.83	\$31.36	\$3.47	9.95%	\$3.47	9.95%
11/2/2011	\$36.49	\$39.58	\$3.09	8.46%	-\$3.09	-8.46%
11/3/2011	\$35.60	\$32.18	\$3.42	9.61%	\$3.42	9.61%
11/4/2011	\$36.09	\$39.72	\$3.63	10.05%	-\$3.63	-10.05%

|Error| **|Error%|**
\$3.13 8.70%

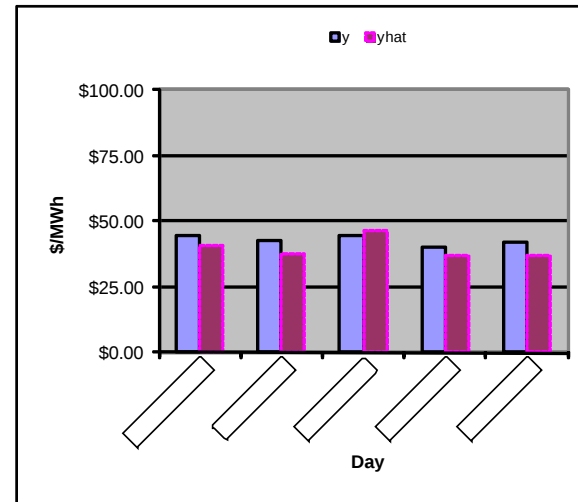


Day-Ahead Wholesale Prices at PJM West

Forecast Data: week of 10/31/2011

<u>obs.</u>	<u>y</u>	<u>yhat</u>	<u> error </u>	<u> error% </u>	<u>error</u>	<u>error%</u>
10/31/2011	\$44.43	\$41.13	\$3.30	7.43%	\$3.30	7.43%
11/1/2011	\$42.98	\$37.90	\$5.08	11.82%	\$5.08	11.82%
11/2/2011	\$44.82	\$46.33	\$1.51	3.37%	-\$1.51	-3.37%
11/3/2011	\$39.93	\$36.78	\$3.15	7.88%	\$3.15	7.88%
11/4/2011	\$41.79	\$37.33	\$4.46	10.68%	\$4.46	10.68%

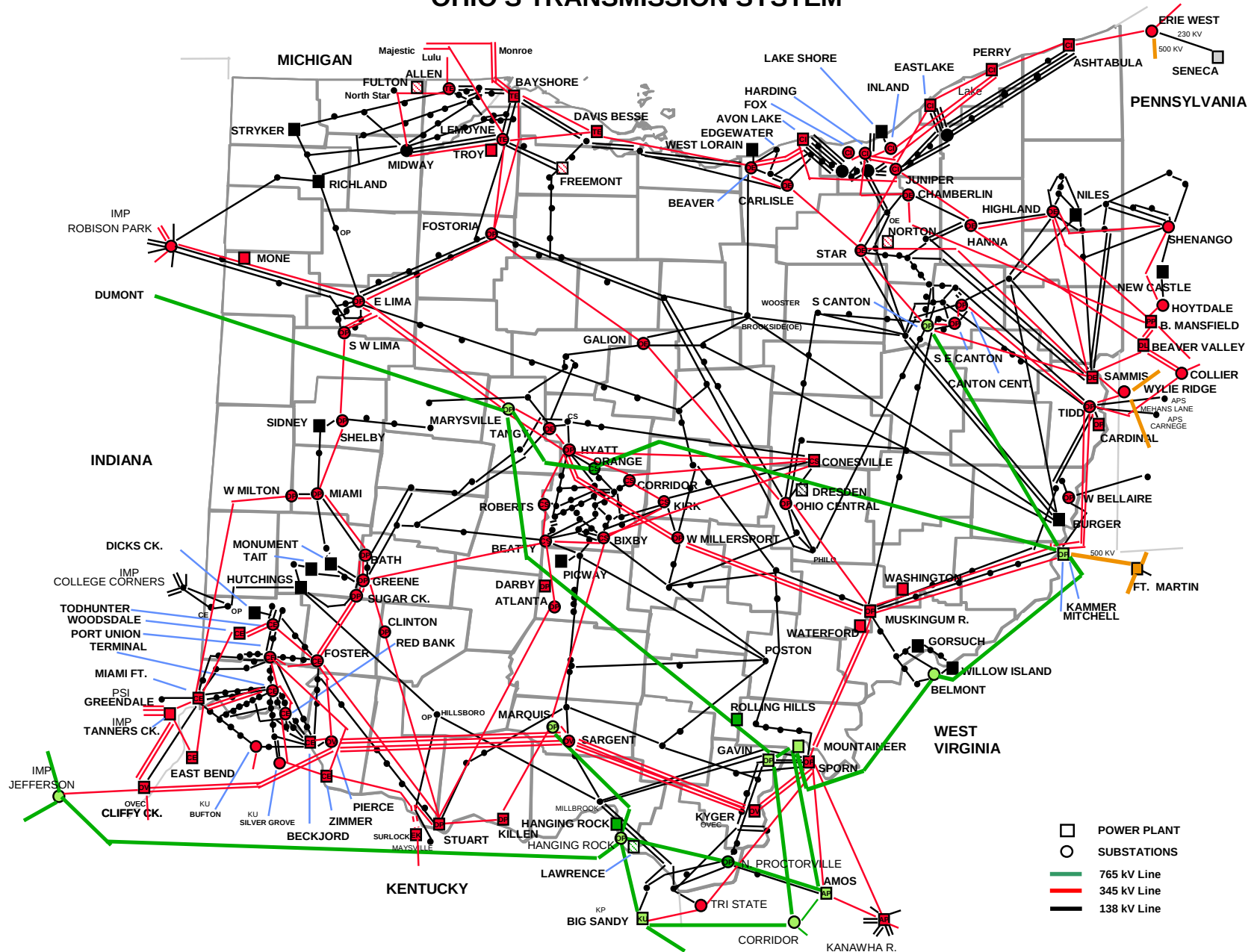
|Error| **|Error%|**
\$3.50 8.24%



Current Research

- We are currently researching the impact of transmission constraints on the behavior of the wholesale electricity market.
- In specific, we are in the process of mining for two or three transmission line bottlenecks in and around Ohio that are impacting wholesale electricity prices in the day-ahead market.
- Our objective is to explicitly represent transmission line congestion in the neural network model.

OHIO'S TRANSMISSION SYSTEM



Source: Long-term Forecasting Reports of the Ohio Electric Utilities and PUCO, Division of Facilities, Siting and Environmental Analysis.