Syllabus Section I

Power Market Restructuring: Current Context and Historical Events

**Important Acknowledgement:** These notes are an edited abridged version of a set of on-line lecture notes prepared by Professor Tom Overbye, ECpE, University of Illinois, 2008

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EE/Econ 458 focuses on the restructuring of wholesale power markets, using the U.S. as the primary source of illustrations.

Particular attention will be focused on U.S. restructuring efforts in the Midwest (MISO), New England (ISO-NE), New York (NYISO), mid-Atlantic States (PJM), California (CAISO), Texas (ERCOT), and the Southwest Power Pool (SPP).

First, however, it is important to consider this restructuring movement within the larger context of the energy delivery system as a whole.
Electric Systems in Energy Context

- Electricity is used primarily as a means for energy transportation.
  - Other sources of energy are used to create it, and once created it is usually converted into other forms of energy before actual use.

- About 40% of US energy is transported in electric form.

- Concerns about CO₂ emissions and the depletion of fossil fuels are becoming main drivers for change in the world energy infrastructure.
Measurement of Power

- **Power**: Instantaneous consumption of energy

- **Power Units**

  \[\text{Watts (W)} = \text{voltage times current for DC systems}\]

  \[\begin{align*}
  \text{kW} & \quad 1 \times 10^3 \text{ Watts} \\
  \text{MW} & \quad 1 \times 10^6 \text{ Watts} \\
  \text{GW} & \quad 1 \times 10^9 \text{ Watts}
  \end{align*}\]

- Installed U.S. generation capacity is about 900 GW (about 3 kW per person)
**Measurement of Energy**

- **Energy**: Integration of power over time; energy is what people really want from a power system

- **Energy Units**:
  
  Joule = 1 Watt-second (J)
  
  kWh = Kilowatt-hour (3.6 x 10^6 J)
  
  Btu = 1054.85 J (British Thermal Unit)

**Note on Unit Conversion**: 3413 Btu ≈ 1 kWh

- Annual U.S. electric energy consumption is about 3600 billion kWh (about 13,333 kWh per person, which means on average each person uses about 1.5 kW of power each hour).
Sources of Energy – U.S. 2005

About 86% Fossil Fuels

CO₂ emissions (millions of metric tons, and per quad):

Petroleum: 2614, 64.0
Natural Gas: 1178, 53.0
Coal: 2142, 92.3

What is a Fossil Fuel? A Quad?

- A **fossil fuel** is a hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter from a previous geologic time.

- **1 Quad** = 293 billion kWh (actual)

- **1 Quad** = 98 billion kWh (used, taking losses into account)

- **1 Quad** = 1015 Btu (**heat** value)
Electric Energy by Fuel Sources, US 2006

Source: Energy Information Administration (EIA) State Electricity Profiles, 2006
Electric Energy by Fuel Sources, Calif. 2006

- **Coal**: 1.0%
- **Gas**: 49.8%
- **Hydroelectric**: 22.2%
- **Petroleum**: 1.0%
- **Nuclear**: 14.7%
- **Renewable**: 11.3%

Oregon is 71% Hydro, while Washington State is 76% Hydro

**Source:** EIA State Electricity Profiles, 2006
Electric Energy by Fuel Sources, Illinois 2006

- **Coal**: 47.6%
- **Gas**: 2.9%
- **Hydroelectric**: 0.1%
- **Petroleum**: 0.1%
- **Nuclear**: 48.9%
- **Renewable**: 0.4%

**Source:** EIA State Electricity Profiles, 2006
Global Warming and the Power Grid: What is Known -- CO$_2$ in Air is Rising

Value was about 280 parts per million (ppm) in 1800, 384 in 2007

Rate of increase has been about 3 ppm per year

Source: http://cdiac.ornl.gov/trends/co2/sio-mlo.htm
As is Worldwide Temperature

Baseline is 1961 to 1990 mean

Source: http://www.cru.uea.ac.uk/cru/info/warming/
Change in U.S Annual Average Temperature

Source: http://www.sws.uiuc.edu/atmos/statecli/Climate_change/ustren-temp.gif

Data Source: Climate Research Unit, University of East Anglia, UK
But Average Temperatures are Not Increasing Everywhere Equally

Source: http://www.sws.uiuc.edu/atmos/statecli/Climate_change/iltren-temp.jpg
## World Population Trends

<table>
<thead>
<tr>
<th>Country</th>
<th>2005</th>
<th>2015</th>
<th>2025</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>127.5</td>
<td>124.7</td>
<td>117.8</td>
<td>-7.6</td>
</tr>
<tr>
<td>Germany</td>
<td>82.4</td>
<td>81.9</td>
<td>80.6</td>
<td>-2.1</td>
</tr>
<tr>
<td>Russia</td>
<td>142.8</td>
<td>136.0</td>
<td>128.1</td>
<td>-10.3</td>
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<tr>
<td>USA</td>
<td>295.7</td>
<td>322.6</td>
<td>349.7</td>
<td>18.2</td>
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<tr>
<td>China</td>
<td>1306</td>
<td>1393</td>
<td>1453</td>
<td>11.2</td>
</tr>
<tr>
<td>India</td>
<td>1094</td>
<td>1274</td>
<td>1449</td>
<td>32.4</td>
</tr>
<tr>
<td>World</td>
<td>6449</td>
<td>7226</td>
<td>7959</td>
<td>23.4</td>
</tr>
</tbody>
</table>

**Source:** [www.census.gov/ipc/www/idb/summaries.html](http://www.census.gov/ipc/www/idb/summaries.html); values in millions; percent change from 2005 to 2025
Regardless of what we do in the short-term the CO$_2$ levels in the atmosphere will continue to increase.

**Note:** SP$_{xx}$ = Stabilization at xx ppm, PgC=1 petagram of carbon, Petagram = 1,000,000,000,000,000 (or $10^{15}$) grams!

Eventual stabilization levels depend upon how quickly CO$_2$ emissions are curtailed. Emissions from electricity production are now about 40% of total emissions. *(Source: Climate Change, IPCC, 2007).*
Electric generating technologies involve a tradeoff between *variable (operating) costs* and *fixed costs* (*costs independent of operation*)

- Nuclear and solar energy have high fixed costs but low variable costs
- Natural gas/oil have low fixed costs but high variable costs (dependent upon fuel prices)
- Coal, wind, hydro are in between

Also, a generating unit’s *capacity factor (rate at which capacity is used)* strongly affects variable costs.

Potential carbon regulation a major uncertainty
Petroleum: $16.98/MMBtu
Natural Gas: $ 7.87/MMBtu
Coal: $ 2.18/MMBtu

**Note:**

*Btu* = British Thermal Unit (used to describe the energy content of fuels)

= Amount of heat required to raise the temperature of one pound of liquid water from 60° F to 61° F at a constant pressure of one atmosphere

*MMBtu* = 1 million Btu (alternative expression for MBtu)

*Heat Rate* = Conversion rate between Btu content of a fuel and the resulting net output of electric energy (kWh), as attained either ideally or in practice by one or more generation plants.
Natural Gas Prices 1993 to 2008

Natural Gas Price: Henry Hub, LA (GASPRICE)
Source: Dow Jones & Company

Shaded areas indicate US recessions as determined by the NBER.
2008 Federal Reserve Bank of St. Louis: research.stlouisfed.org
Wholesale and Retail Power Markets

Source: http://www.nerc.com/page.php?cid=1|15

Basic Structure of the Electric System

Color Key:
Blue: Transmission
Green: Distribution
Black: Generation

Generating Station → Generator Step Up Transformer → Transmission Line (500, 345, 230, and 138 kV) → Substation Step-Down Transformer → Transmission Customer 138 kV or 230 kV → Secondary Customer 120V and 240V

Generation → Transmission → Distribution

Wholesale → Retail
Brief History of Electric Power

- **Early 1880s** – Edison introduced Pearl Street DC system in Manhattan supplying 59 customers.
- **1884** – Sprague produces practical DC motor.
- **1885** – Invention of transformer
- **Mid 1880s** – Westinghouse/Tesla introduce rival AC system.
- **Late 1880s** – Tesla invents AC induction motor.
- **1893** – First 3-phase transmission line operating at 2.3 kV
1896 – AC lines deliver electricity from hydro generation at Niagara Falls to Buffalo, 20 miles away.

Early 1900s – Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation.

By 1920s – Large interstate holding companies control most electricity systems.
History continued...

- **1935** – Congress passes *Public Utility Holding Company Act (PUHCA)* to establish national regulation, breaking up large interstate utilities (repealed in 2005)

- **1935/6** – *Rural Electrification Act* brought electricity to rural areas

- **1930s** – Electric utilities established as *vertically integrated monopolies*
Vertically Integrated Monopolies

- Within a particular geographic market, the electric utility had an exclusive franchise over generation, transmission, distribution, and customer service.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Customer Service</th>
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In return for this exclusive franchise, the utility had the obligation to serve all existing and future customers at rates determined jointly by utility and regulators.

Utilities received a regulated *cost-based rate of return* ensuring a “normal” rate of profit.
Vertically Integrated Monopolies

- Within its service territory each electric utility was the only game in town.
- Neighboring utilities functioned more as colleagues than competitors.
- Utilities gradually interconnected their systems so by 1970 transmission lines crisscrossed North America, with voltages up to 765 kV.
- *Economies of scale* (decline in average cost as production increases) kept resulting in decreasing electricity prices, so almost every one was happy.
U.S. Wholesale Electric Power Transmission Grid
1970s brought inflation, increased fossil-fuel prices, calls for conservation, and growing environmental concerns.

Electricity prices began to increase.

As a result, U.S. Congress passed the Public Utilities Regulator Policies Act (PURPA) in 1978, which mandated utilities must purchase power from independent generators located in their service territory (modified in 2005).

PURPA introduced some competition.
Major opening of industry to competition occurred as a result of *National Energy Policy Act of 1992*

This act mandated that utilities provide “nondiscriminatory” access to the high voltage transmission.

Goal was to establish true competition in generation.

Result over the last few years has been a dramatic restructuring of electric utility industry (for better or worse!)

*Energy Bill 2005* repealed PUHCA, modified PURPA
Electric Power Market Restructuring

- Driven by:
  - Significant regional variations in residential prices \textit{(rates)} perceived to be inequitable and too high (relative to wholesale costs);
  - Concerns about \textit{inefficient resource use} and \textit{lack of good price signals} for proper incentivizing of future investments.

- Goal of restructuring is to promote more \textit{efficient} and \textit{fair ("open access") resource use in the short-run} (existing generation and transmission) and \textit{also in the longer-run} (investment in new generation and transmission) through introduction of market forces ("marginal pricing"), in a manner that ensures \textit{reliable energy supply}.

- \textbf{In Theory:} More efficient resource use should result in lower costs and electricity prices (relative to regulated rates).
State Variation in Residential Electric Rates: Jan 2000

Residential Average Revenue per kWh is 8.26 Cents

KWh = Kilowatthour.
Note: The average revenue per kilowatthour of electricity sold is calculated by dividing revenue by sales.
Retail Market Restructuring: Let Consumers Choose Their Own Suppliers (Competition ➔ Lower Prices?)
U.S. Regions with Restructured Wholesale Power Markets

Why is there still such strong criticism of restructuring?

- **Regions Already With Restructured Markets**  
  *Key cited problems:*  
  Lack of sufficient performance testing;  
  Price volatility (across the transmission grid & over time).

- **Stakeholders in Southeast and Northwest**  
  *Key cited problems:*  
  Lack of sufficient performance testing;  
  Questions about suitability given special local conditions (TVA, hydroelectric power...).
The Result for California in 2000/1

OFF

OFF

Y2.K

Source: http://www.eia.doe.gov/cneaf/electricity/chg_str/regmap.html
2004 Task Force Finding:
Main cause of blackout was failure of FirstEnergy Corporation to trim trees in part of its Ohio service area!

Hot day led to high energy demand, and strained HV power lines (voltage sag) then touched trees, causing a fault.
Two main Illinois utilities: ComEd and Ameren

Restructuring law had frozen residential electricity prices for ten years, with rate decreases for many.

Prices rose on January 1, 2007 as price freeze ended; price increases were especially high for electric heating customers who had previously enjoyed rates as low as 2.5 cents/kWh

2008 average residential rate (in cents/kWh):
10.4 in IL, 8.74 IN, 11.1 WI, 7.94 MO, 9.96 IA, 19.56 CT, 6.09 ID, 14.03 in CA, 10.76 US average
Midwest ISO (MISO) = Swiss Cheese
http://www.miso-pjm.com/

Ames, Iowa is in this hole - it is not currently part of MISO
Actual Electricity Prices in Midwest ISO (MISO)
April 25, 2006, at 19:55

Note this price, $156.35
Five Minutes Later…

73% drop in price in 5 minutes!
Actual Electricity Prices in Midwest ISO (MISO)
September 5, 2006, 14:30

Note this price, $226.25
Five Minutes Later...

79% drop in price in 5 minutes!
Despite all the problems to date, **Huntowski et al.** (Executive Summary, 2008 Report, Section I.A required reading) provide an *upbeat summary assessment*, as follows:

- “The decision to support regulation or competition should not depend on the effects of external shocks (such as the recent rise in natural gas prices) or whether regulated average cost prices are below or above market-based marginal cost prices at any particular point in time,...

- … but instead on whether a competitive or regulated model will foster more efficient decisions and ultimately better price and reliability outcomes over a sustained period of time and varying market conditions.”

- “In spite of the recent criticisms, the **case for competition in the electric industry is still compelling**, supported both by economic theory and examination of empirical evidence.”

- **Is this a reasonable conclusion??**
Introductory Topics
- Power Market Restructuring: Overview
- Market Principles and the Theory of the Firm
- Strategic Market Behavior (Game Theory)
- Optimization Basics for Power Markets

Organization of Power Markets

Power Market Trading Subject to Transmission Constraints
- Power Systems and LMP Fundamentals
- Bid/Offer-Based Optimal Power Flow

Market Power Mitigation

Real-World Examples: Policy Concerns

Financial and Operational Risk Management (Reliability, FTRs)

Investment in New Generation

Investment in New Transmission

Environmental Issues

Future Prospects for Restructuring