Energy Trading and Risk Management

Certificate in Quantitative Finance Programme

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1-2 June 2016

Notebook I

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Legal Disclaimers

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Outline

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High Frequency Commodity Trading

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MathWorks

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Introduction

Background

Background

• Harvard PhD thesis in Applied Mathematics: *Block Implicit One-Step Methods for Solving Smooth and Discontinuous Systems of Differential/Algebraic Equations: Applications to Transient Stability of Electrical Power Systems*

• Harvard PhD thesis research at Sandia National Labs – managed by Lockheed Martin for the U.S. Department of Energy's National Nuclear Security Administration.

• London Business School MBA thesis: *Day-Ahead Lunch-Time Electricity Demand Forecasting: Applications to Electricity and Weather Derivatives*

• Consulting contract for Lockheed Martin Energy Systems.

• Boeing Welliver Fellow and Boeing faculty researcher - researched and applied derivatives (including *real options)* to the valuation of aircraft investments and jet fuel cost hedging.

• Derivatives structurer at Investment bank BNP Paribas in London - structured energy, weather and commodity derivatives deals.

• Quant/Electricity Derivatives Trader at Enron in Houston and London.

• Quant on International Equities and Commodities desks at Harvard Management Company

• Book entitled "Energy Trading and Risk Management: A Practical Approach to Hedging, Trading and Portfolio Diversification" (Wiley Finance Series - http://amzn.to/Stlmpk)

• Working on third book – out in fall

• Faculty in the *Energy Institute* at Tulane University's Freeman School of Business

• Energy website - www.GlobalEnergyPost.com

What's Hot in the Global Energy Markets?

Global Energy Markets: Before OPEC's November 2014 Meeting

Crude Oil = King of Commodities

- Most-traded commodity in the world

- Supplier of 40% of the world's total energy needs

- Base product for many secondary products: *electricity, petrol, jet fuel, heavy oil, plastics, liquid petroleum gas, diesel fuel, heating oil*

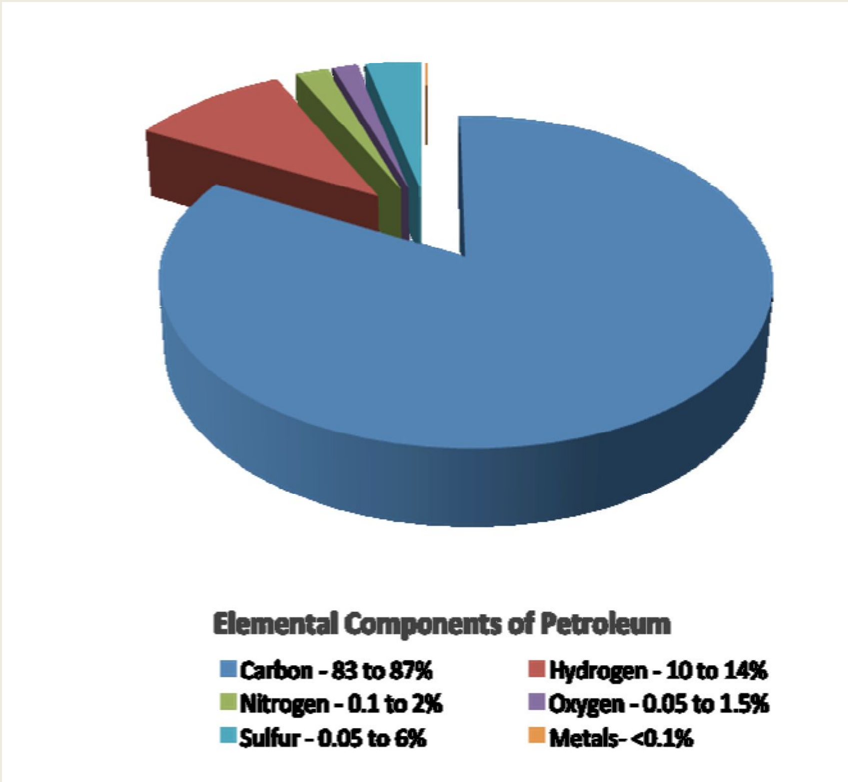
- Base product for petroleum products—the dominant energy resource worldwide

- Derived from the geologic transformation and decomposition of plants and animals that lived hundreds of millions of years ago.

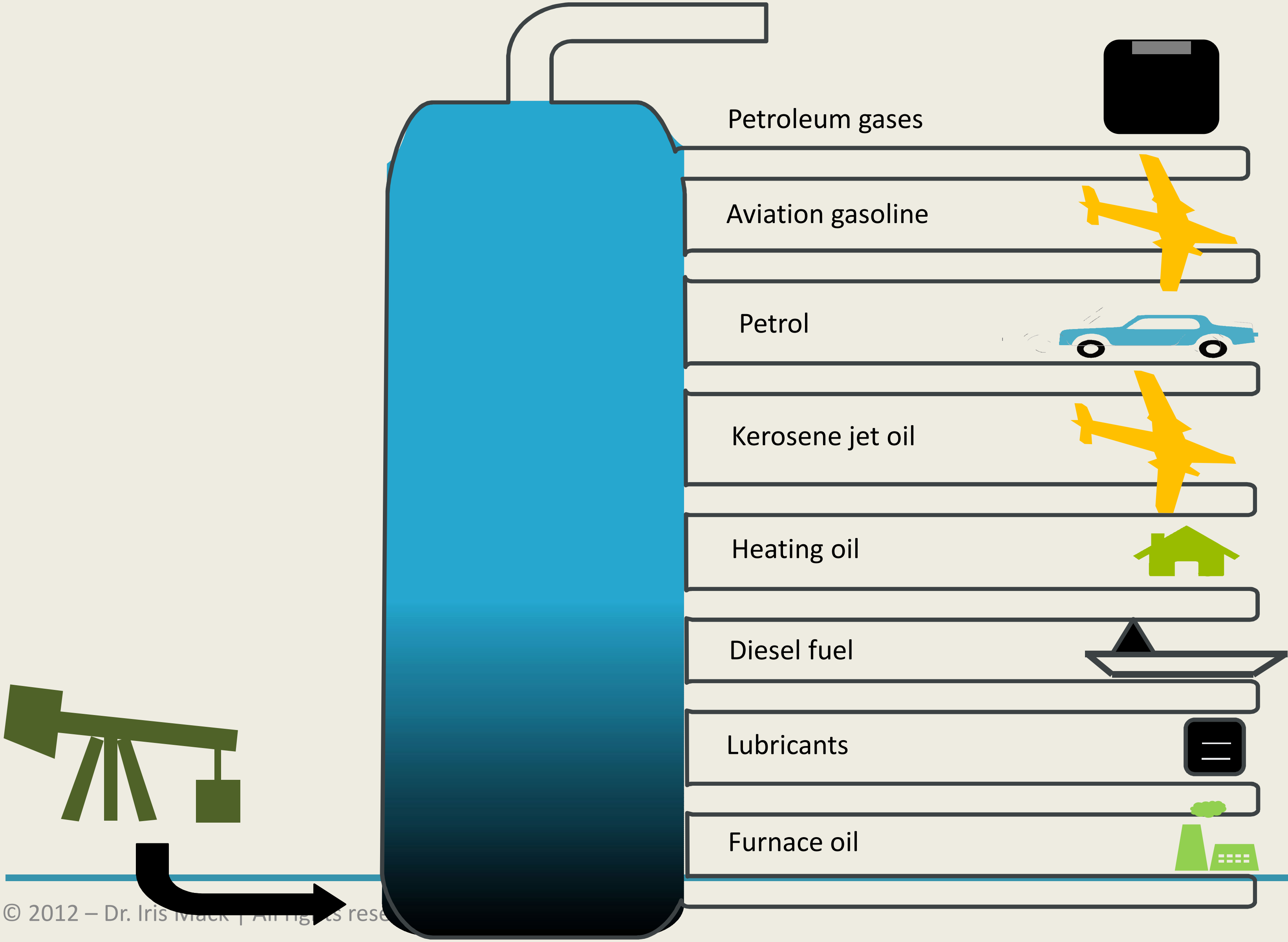
Crude Oil = King of Commodities

Petroleum covers

- Unprocessed crude oil
- Petroleum products made up of refined crude oil



Crude Oil = *King of Commodities*



Natural Gas = *Queen of Commodities*

- 2nd largest primary source of energy consumed in the U.S. (exceeded only by oil)

- ~25% of the U.S. energy consumption comes from natural gas

- ~50% of the homes in N. America use natural gas for heating

- Power plants are the fastest-growing users of natural gas.

- **~1/3 of the natural gas consumed in the U.S. is utilized for the production of electricity.**

SHALE

- The common use of petroleum is often restricted to the liquid oil form – crude oil.

- Crude oil and natural gas are the most important primary fossils.

- ***Shale oil*** is an alternative to conventional crude oil.

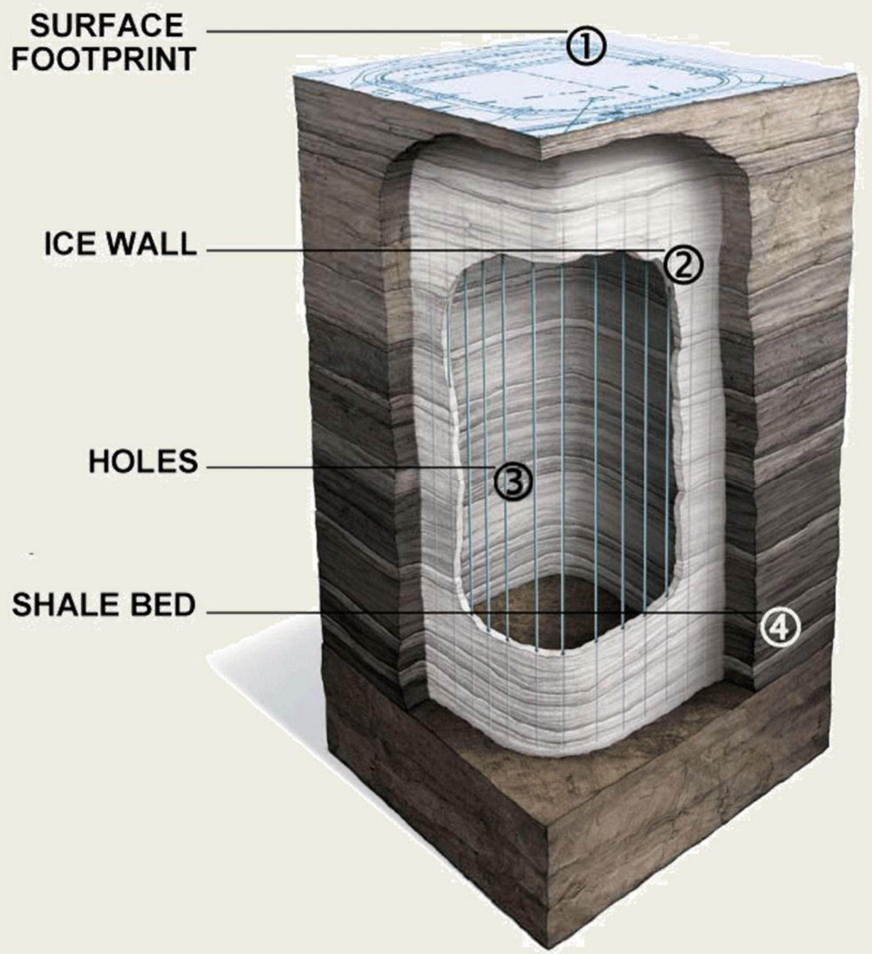


Image Source: U.S. Bureau of Land Management

SHALE

- ***Shale*** is a dark fine-grained laminated sedimentary rock formed by compression of successive layers of clay-rich sediment.

- Note: Sediment consist of solid fragments of inorganic or organic material that come from the weathering of rock and are carried and deposited by wind, water, or ice.

Image Source: U.S Department of Energy

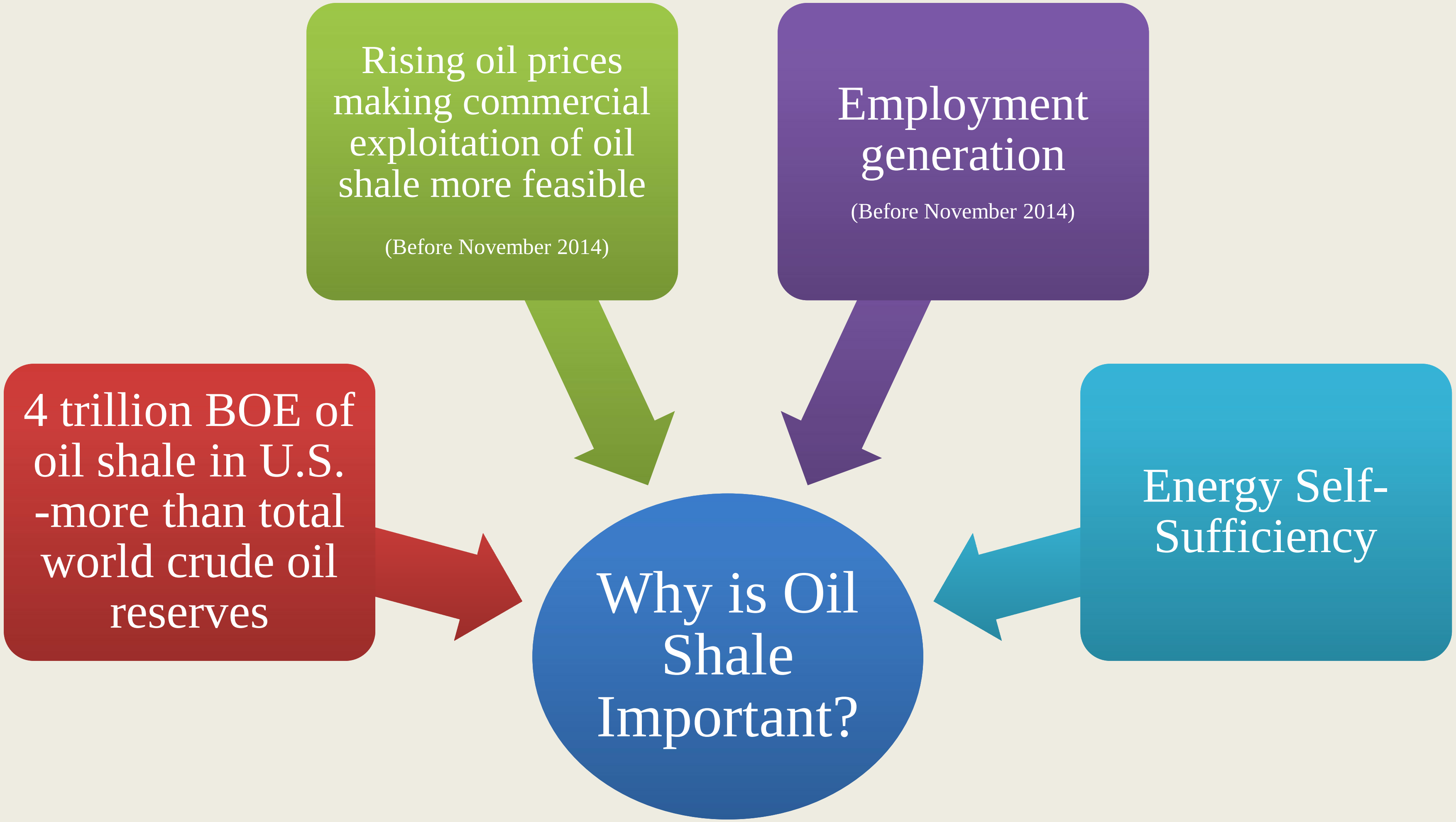
SHALE

- ***Oil shale*** is a fine-grained shale rock containing oil.

- When heated, ***oil shale*** yields petroleum or natural gas.

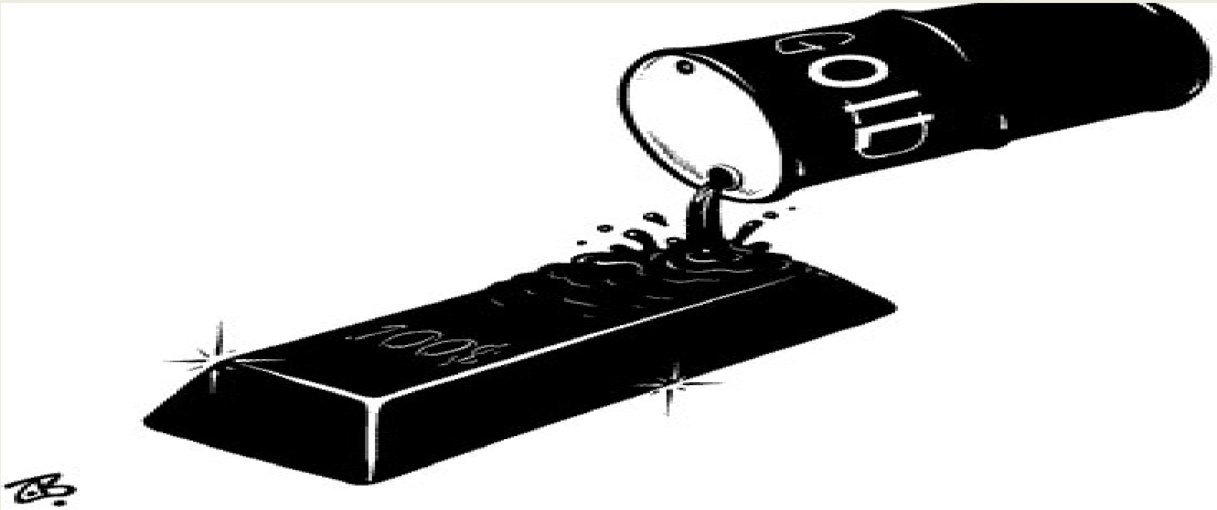
Image Source: U.S Department of Energy

SHALE



Note: ***Barrel of Oil Equivalent*** (BOE) is a unit of energy based on the approximate energy released by burning one barrel (42 US gallons) of crude oil.

Fracking



Fracking

***Hydraulic fracturing* (a.k.a. *fracking*)** involves the use of a high-pressure blend of chemicals, water and sand injected into gas-bearing rock formations deep underground to

- free trapped gas and oil
- bring this gas and oil to the surface

Extracting shale oil – via fracking - is more costly than the production of conventional crude oil both financially and in terms of its environmental impact.

Fracking

❖Opponents: Fracking pollutes water and air – as noted in the documentary ***Gasland***

https://www.youtube.com/watch?v=dZe1AeH0Qz8

❖Proponents: Fracking is safe when performed properly - as noted in the documentary ***FrackNation*** http://www.wilmott.com/blogs/irismack/index.cfm/2014/8/10/FrackNation-movie-trailer

Fracking

- Mathematical formulation for propagation of hydraulic fractures is given by a system of integral and non-linear differential equations.

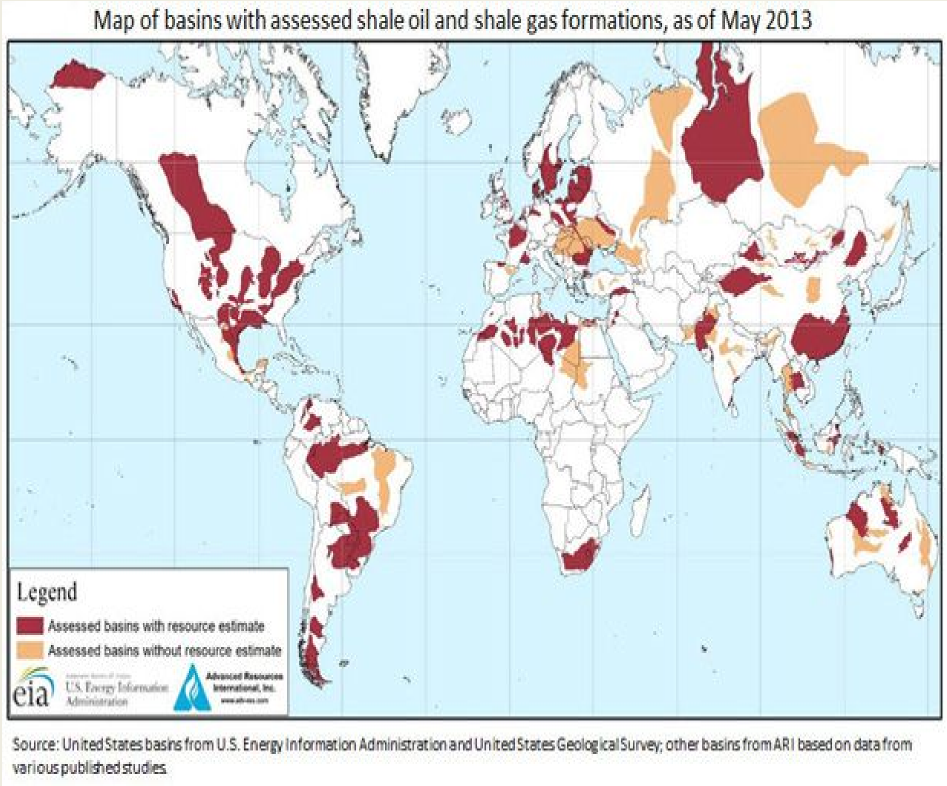
- Analytical solutions to these mathematical models exist.

- These analytical solutions are constructed on the basis of restrictive assumptions (constant injection rate, material toughness, no fluid leakoff…)

- In order to extend the applicability of these models, it is necessary to release some of these assumptions. The solution to the resulting governing equations demands the use of computational techniques.

- ***There are quant opportunities in the field of fracking!***

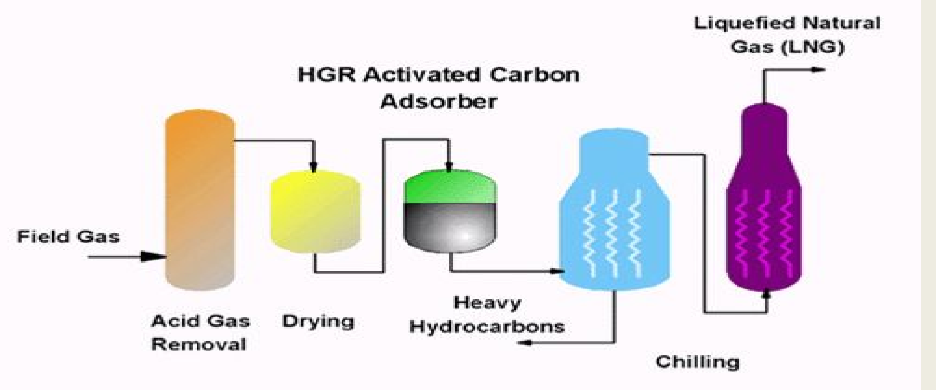
Fracking in Canada, U.S., Colombia, Brazil, Ukraine…



http://www.wilmott.com/blogs/irismack/index.cfm/2012/5/31/GARP-Oil-Boom-in-Americas-Shifts-Energy-Geopolitics

Exporting Liquefied Natural Gas (LNG)

- Natural gas cooled
- Transformed into a liquid
- Easier to ship in liquid state



HGR Mercury Removal Activated Carbon Adsorption System for LNG Production

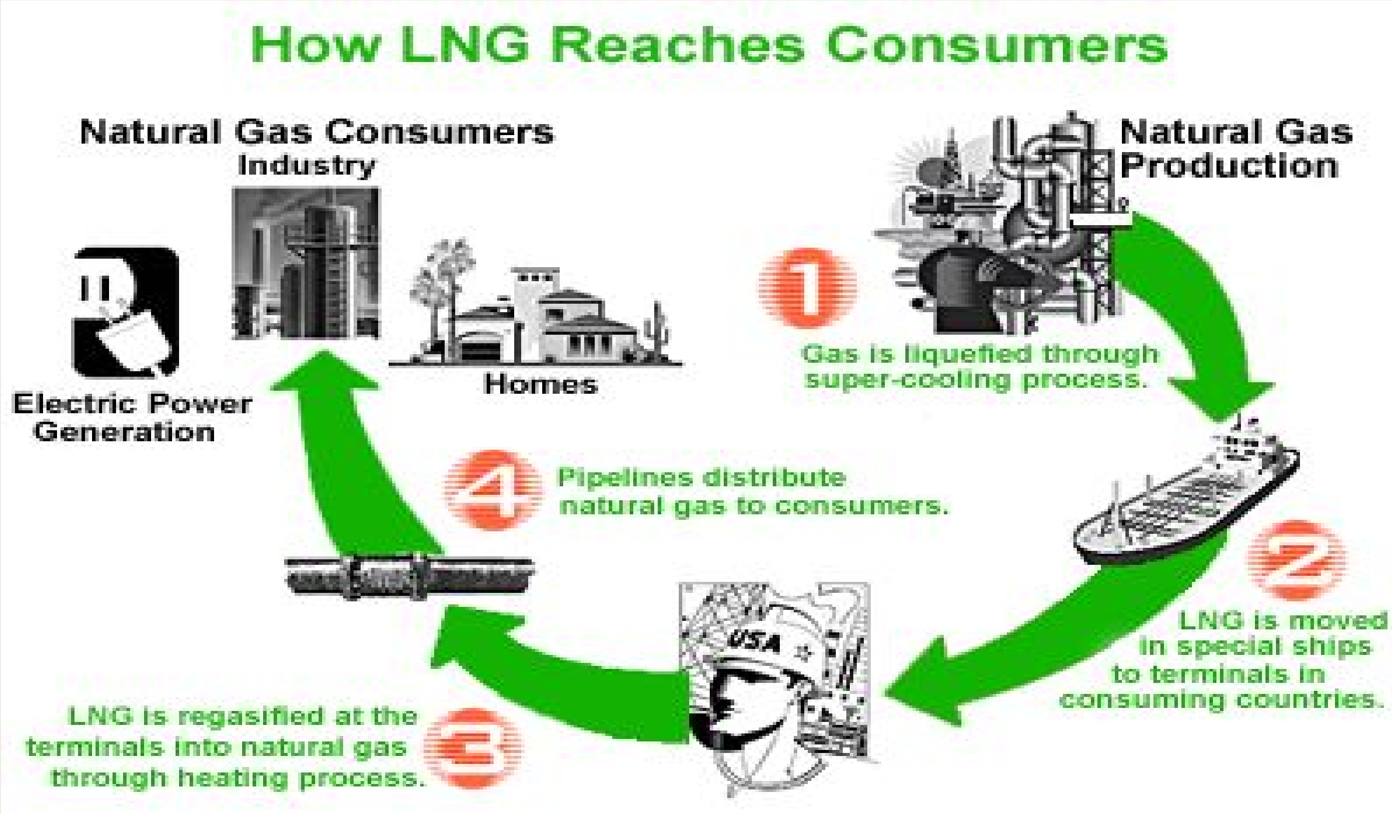
HGR =: High Gas Rate
Adsorb =: accumulate (liquids or gases) on the surface

Exporting Liquefied Natural Gas (LNG)

- Shale development increases domestic natural gas production
- Oversupply of natural gas in U.S.
- Natural gas prices pushed up on global levels – esp. Europe, Asia
- Global demand for LNG increases
- U.S. producers seek to export LNG

Exporting Liquefied Natural Gas (LNG)

LNG Distribution Problem



Exporting Liquefied Natural Gas (LNG)

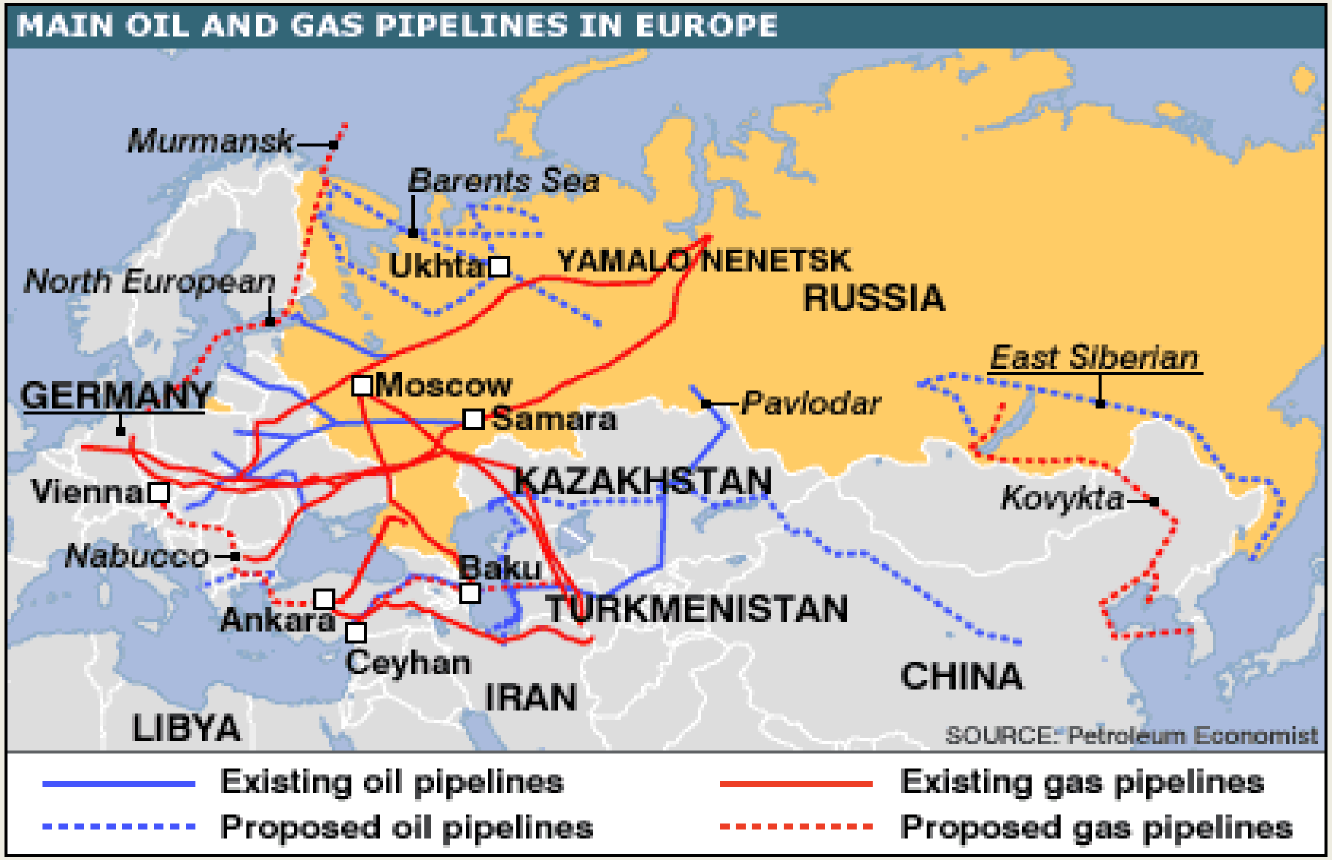
Opportunities?

- Trading
- Logistics
- Distribution and Transportation
- Technology
- Engineering
- Financial Engineering

Political Hurdles?

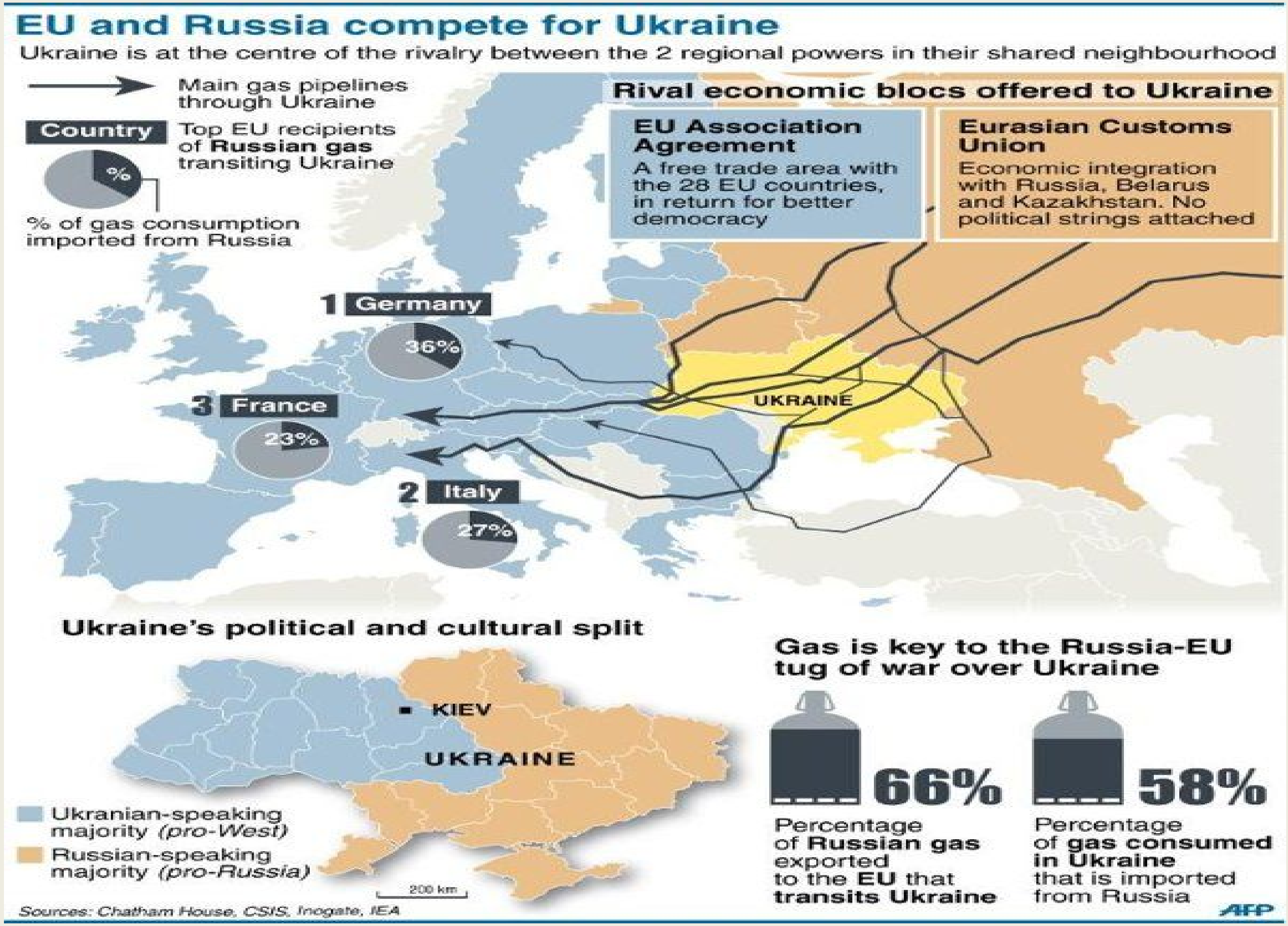
- Big consumers (manufacturers, chemical companies) are leery that exports could raise domestic prices.
- Environmental groups fear that allowing exports would encourage more natural-gas production – especially via fracking.

Russia and China Close Multi-Billion Dollar Oil & Gas Deals - blow to petrodollar



http://www.wilmott.com/blogs/irismack/index.cfm/2014/5/12/Russia-and-China-Close-Oil--Gas-Deals

Natural Gas Pipelines run through Ukraine



http://www.wilmott.com/blogs/irismack/index.cfm/2014/3/3/Russias-Gazprom-Political-Tensions-in-Ukraine-May-Cause-Disruptions-of-Gas-Supplies-to-Europe

Oil & Gas Booms Around the World Shift Energy Geopolitics

http://www.wilmott.com/blogs/irismack/index.cfm/2014/4/18/International-Oil-Gas-Firms-Committed-To-Russia-Despite-Sanctions

Millenials Spurn Silicon Valley for Texas Oil Fields

Bloomberg reports:

Mark Hiduke raised $100 million to build his 3-week-old company. This 27-year-old isn't a Silicon Valley technology entrepreneur. He's a Texas oilman.

The oil and gas industry is brimming with upstart millennials like Hiduke after decades of failing to attract and retain new entrants. Now that a breakthrough in drilling technology has U.S. oil and gas production surging, an aging workforce is welcoming a new generation of aspiring oil barons….

http://www.wilmott.com/blogs/irismack/index.cfm/2014/5/21/Bloomberg-Millennials-Spurning-Silicon-Valley-for-Dallas-Oil-Patch

Google Entering the $400 Billion Electric Power Markets in the U.S.

Bloomberg reports:

Google and other high tech companies (aka ***technarians***) are players in the $400 Billion retail electric power markets in the U.S..

Google's $3.2 billion acquisition of smart-home startup ***Nest*** *"ought to give utility officials a sinking feeling in the pit of their stomachs" since it makes clear the Technarians have begun to seriously eye at least the periphery of the utility business if not its core, said Adrian Tuck, CEO of Tendril Networks Inc. a Boulder, Colorado-based energy-services management company.*

While coy about its ultimate energy ambitions, Google is already a power generator through more than $1.4 billion in clean energy investments and holds a wholesale power license.

http://www.wilmott.com/blogs/irismack/index.cfm/2014/5/29/Bloomberg-Google-Entering-the-400-Billion-Retail-Electric-Power-Markets

Global Energy Markets: After OPEC's November 2014 Meeting

Bloodbath in Energy Markets - http://globalenergypost.com/?s=layoffs

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Iris Mack's Blog

Oil Price Collapse Led to 300,000+ Layoffs Worldwide

Posted At : April 21, 2016 2:44 AM | Posted By : Iris Mack
Related Categories: Careers

Amid the energy industry's deepest retrenchment in two decades, some oil-and-gas workers who followed the energy boom of the last decade in search of better opportunities are finding themselves jobless and far from home. The oil-price collapse has led energy producers to lay off more than 300,000 workers world-wide, according to Houston consultant Graves & Co.

Please read more here and here.

| Send |

Global Energy Markets: After OPEC's November 2014 Meeting

Bloodbath in Energy Markets - http://globalenergypost.com/?s=oil+wars

Electricity Markets

Electricity Markets

We'll focus some of our attention on pricing models for the electric power markets.

- **Two essential reasons for the existence of energy markets**
  1. *Generation of electricity*
  2. *Transmission of electricity*

- I spent a part of my professional and academic career studying and working in the electricity markets.

- The pricing models of other energy assets (oil, natural gas,…) are similar to the electricity models – but normally a bit simpler.

- **Jobs** prospects are better in power than in oil and gas – at the moment…

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Energy Markets Fundamentals

Power =

rate of doing work

- 1 MW = million watts

Energy = amount of work done

- 1 MWh = million watts of power applied over the period of an hour

The ***instantaneous electric power*** "P" delivered to a component is given by the equation

$$P(t)=I(t)\cdot V(t)$$

Where,

$P(t)$ = instantaneous power (measured in *Watts*)

$V(t)$ = Voltage drop across component (measured in *Volts*)

$I(t)$ = current through component (measured in *Amperes*)

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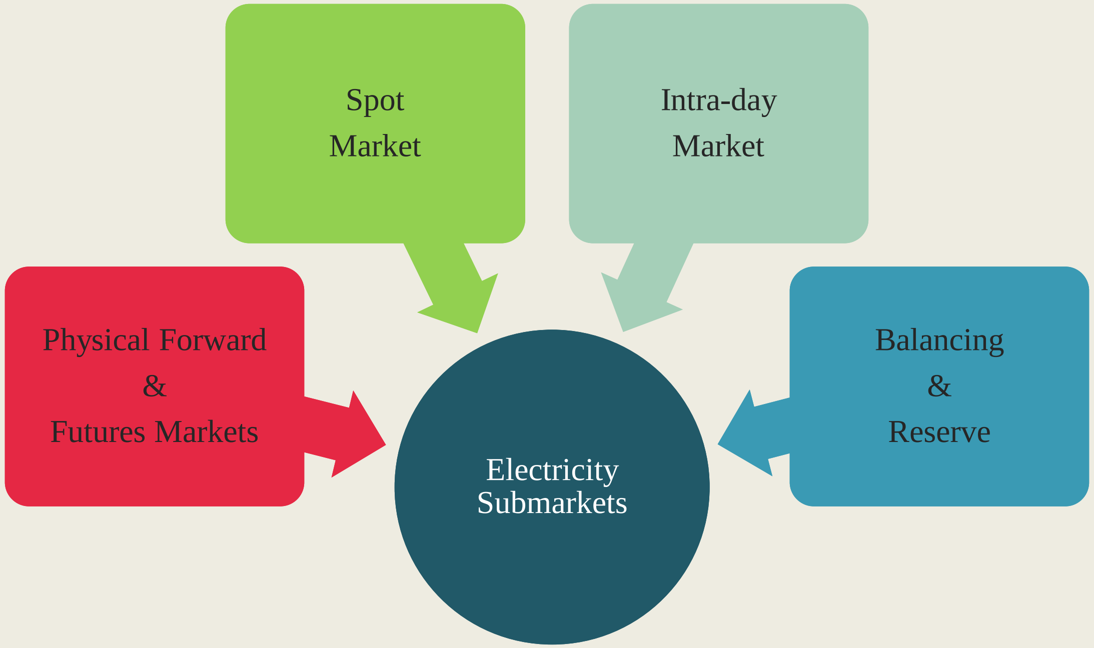
Spot, Intra-day, Balancing and Reserve Markets

Electricity markets are segmented into the following submarkets.



Spot, Intra-day, Balancing and Reserve Markets

- Due to physical and financial constraints, there are relatively few players in regional electricity spot (cash) markets.

- Electricity markets are essentially oligopolies and not *free markets* as in the financial sense.

- North American participants trade spot products on a power exchange or through an ***independent system operator*** (ISO).

- An ISO is a neutral operator responsible for maintaining the instantaneous balance of the electric power grid system.

Spot, Intra-day, Balancing and Reserve Markets

Intra-day Market

- Market for electricity products with a delivery on the same day
- Good way to break into the power trading markets as an hourly trader

Balancing and Reserve Market

- In the *reserve market* an ISO is allowed to purchase electricity products to compensate for imbalances between supply and demand in the system.
- The *balancing market* allows electricity firms and traders to submit offers (to sell) and bids (to buy) energy from the system by altering generation or consumption.

Spot, Intra-day, Balancing and Reserve Markets

- Participants in the electricity spot market submit bids to buy electricity, generally on a ***day ahead*** basis.

  Reference: My London Business School MBA thesis: *Day-Ahead Lunch-Time Electricity Demand Forecasting: Applications to Electricity and Weather Derivatives*

- *Day ahead* products are very common electricity spot products.

- Trade on electricity spot markets is physical – that is, physical delivery of an energy asset is expected.

- *Day ahead* products are the underlying assets of futures contracts on a power exchange.

- Electric power markets possess some of the characteristics of more matured commodity and financial securities markets.
- However there are some unique characteristics of the operation of the wholesale electric spot market that have implications for energy trading.
- Some of these unique characteristics are listed in the following tables and diagrams.

Some Unique Characteristics of Electricity Markets

Some Unique Characteristics of Electricity Markets

- Prices
- Production, storage and transmission
- Volatility
- Market Maturity
- De-regulation
- Seasonality of price process - multi-scale
- Non-normality of electricity spot prices

Some Unique Characteristics of Electricity Markets

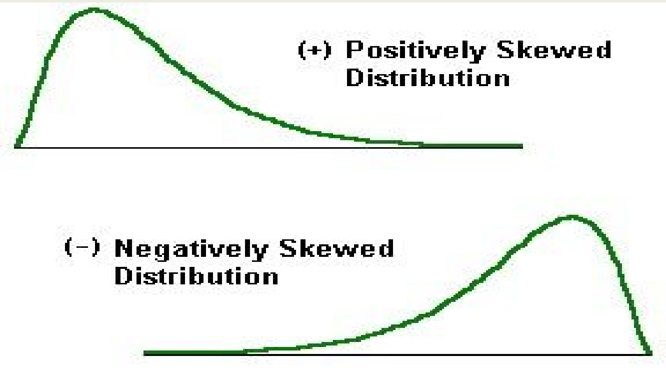
Prices	Variables that can affect electricity prices: ▪ Transmission constraints ▪ Weather induced demand spikes ▪ Generator bidding patterns ▪ Geopolitical
	Psychological and sociological factors may cause an unexpected buyout of certain contracts leading to price spikes.
	Electricity spot prices exhibit strong ***mean-reversion*** – gravitation towards a "normal" equilibrium price level that is usually governed by the cost of production and level of demand.
	Electric power is a secondary energy source. It's generated from the conversion of other **primary energy products**: oil, natural gas, wind, hydro, solar, … Hence the price of electric power is affected by the prices of these primary energy sources.

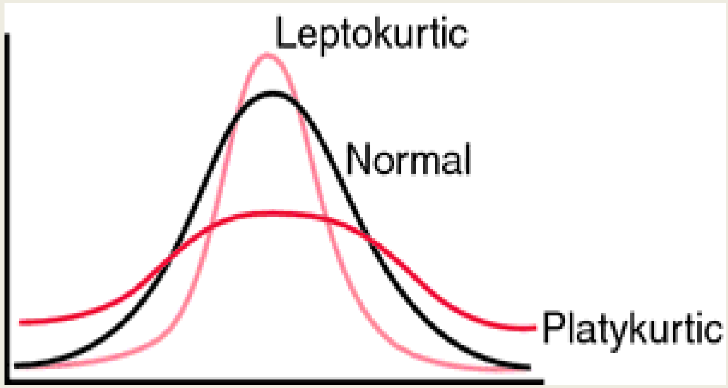
Some Unique Characteristics of Electricity Markets

Volatility	Electricity spot prices can be much more volatile than prices of natural gas and other commodities.
	The high volatility of spot prices is a result of the non-storability of electricity.
Market Maturity	Financial and some commodities markets are more mature.
Deregulation	Since the 1970s some regional electricity markets have undergone significant restructuring – in part, due to market deregulation.
	Worldwide deregulation of electricity markets led to the restructuring of the generation, transmission, distribution and pricing of electricity and energy derivatives.

Some Unique Characteristics of Electricity Markets

Seasonality of price process is multi-scale	• Intra-day • Weekly • Monthly • Annual
Non-normality of electricity spot prices	• Positive skewness • Leptokurtosis - the probability density curve has fatter tails and a higher peak at the mean than the normal distribution.





Some Unique Characteristics of Electricity Markets

Production, Storage & Transmission	Volume and cost constraints on production, storage and transmission of electricity.
	Necessity for regional transmission networks prohibits the creation of a global power market. Since there is no global electricity market, electricity products vary from one regional electricity market to another. Note: In the next slide we see that North America is broken up into 8 regional power markets.
	Electricity cannot be easily stored and must be made available on demand. Exceptions are hydroelectricity (hydro-pumped power) and battery farms, which create storable energy.
	Storage constraints produce volatile day-to-day behavior.
	Non-storability requires continuous balancing of supply and demand.

North American Electric Reliability Corporation (NERC)

North American Electric Reliability Corporation (NERC) works with 8 regional entities to improve the reliability of the bulk power system.

The members of the regional entities come from all segments of the electric power industry:

- Investor-owned utilities
- Federal power agencies
- Rural electric cooperatives
- State, municipal and provincial utilities
- Independent power producers
- Power marketers
- End-use customers

These entities account for virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, Mexico.

North American Electric Reliability Corporation (NERC)

8 Regional Entities

1. Florida Reliability Coordinating Council (FRCC)
2. Midwest Reliability Organization (MRO)
3. Northeast Power Coordinating Council (NPCC)
4. Reliability*First* Corporation (RFC)
5. Southeast Electric Reliability Corporation (SERC
6. Southwest Power Pool, RE (SPP)
7. Texas Reliability Entity (TRE)
8. Western Electricity Coordinating Council (WECC

Maps

- NERC Interconnections (B&W)
- NERC Interconnections (Color)
- NERC Regions Map (B&W)
- NERC Regions Map (Color)
- NERC Regions and Balancing Authorities - as of April 12, 2011
- http://www.nerc.com/page.php?cid=1%7C9%7C119

North American Electric Reliability Corporation (NERC)

In America alone, over 15,000 power stations generate almost 4 trillion kilowatt hours of electricity each year.

Ensuring all that power arrives where and when needed, is a logistical nightmare. So, how is this accomplished?

In this 5 minute tutorial one can follow electricity from its source to the light bulb in a home - explaining different fuels, thermal power generation, transmission and the grid.

http://www.youtube.com/watch?v=20Vb6hlLQSg&feature=related

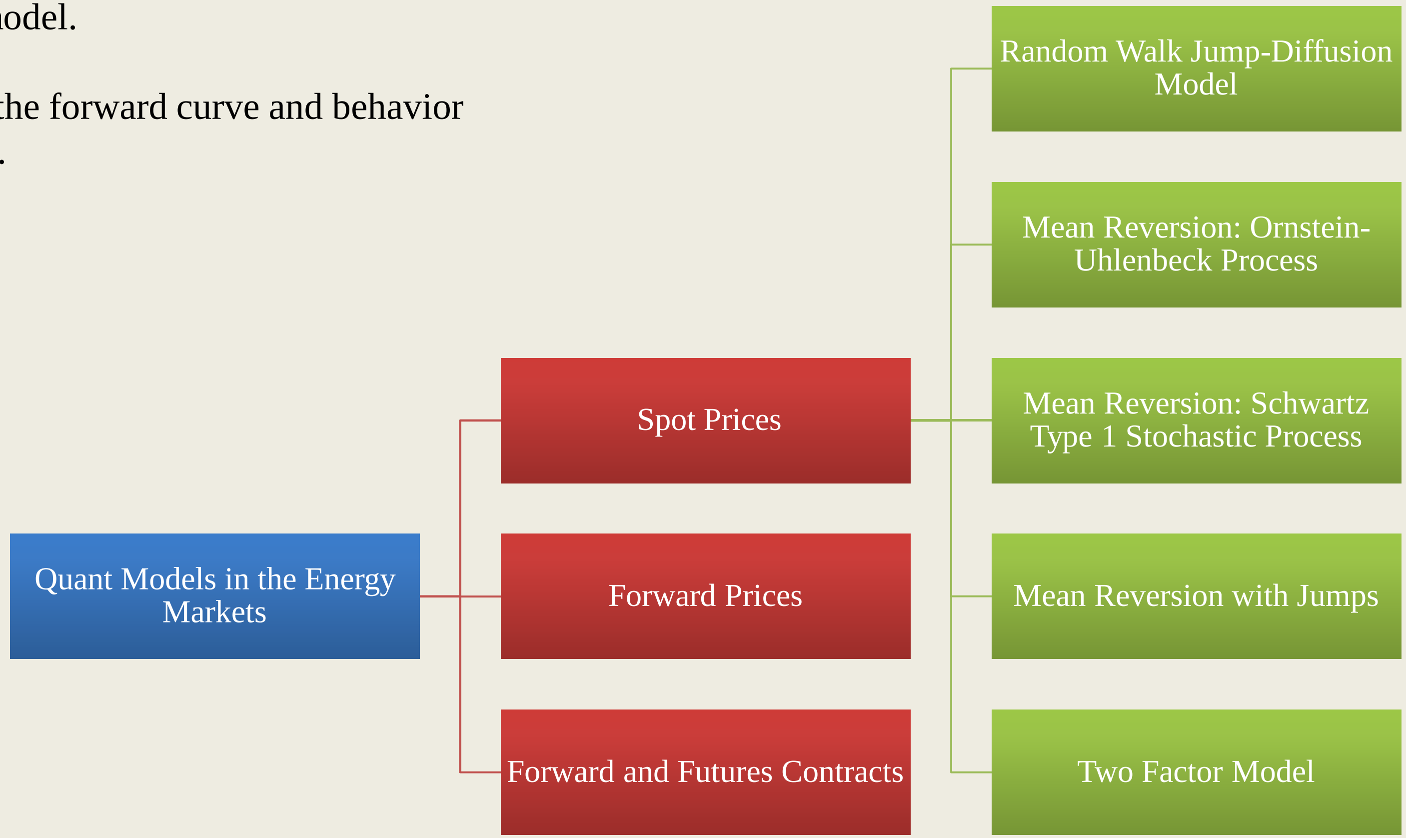
Modeling of Energy Prices

Quant Models in the Energy Markets

Two common approaches to modeling electricity price dynamics:

1.Spot price dynamics and derivation of forward prices from the model.

2.Movements of the forward curve and behavior of forward prices.



Spot Prices

An ***electricity spot transaction*** is a physical transaction with nearby delivery of electrical power.

The **spot price**, ***S(t)***, is the current market price at which electricity is bought or sold for immediate payment and delivery.

Spot Prices Features

Mean-reversion

- Tendency of spot prices to converge towards their long-term level.

Seasonality

- Electricity prices are influenced by various factors, such as business, economic and weather conditions.
- These factors are the primary cause of seasonality in electricity price data: intra-daily, weekly, monthly and annual.

Spikes

- Sudden increases in the amount of electricity that a system produces.

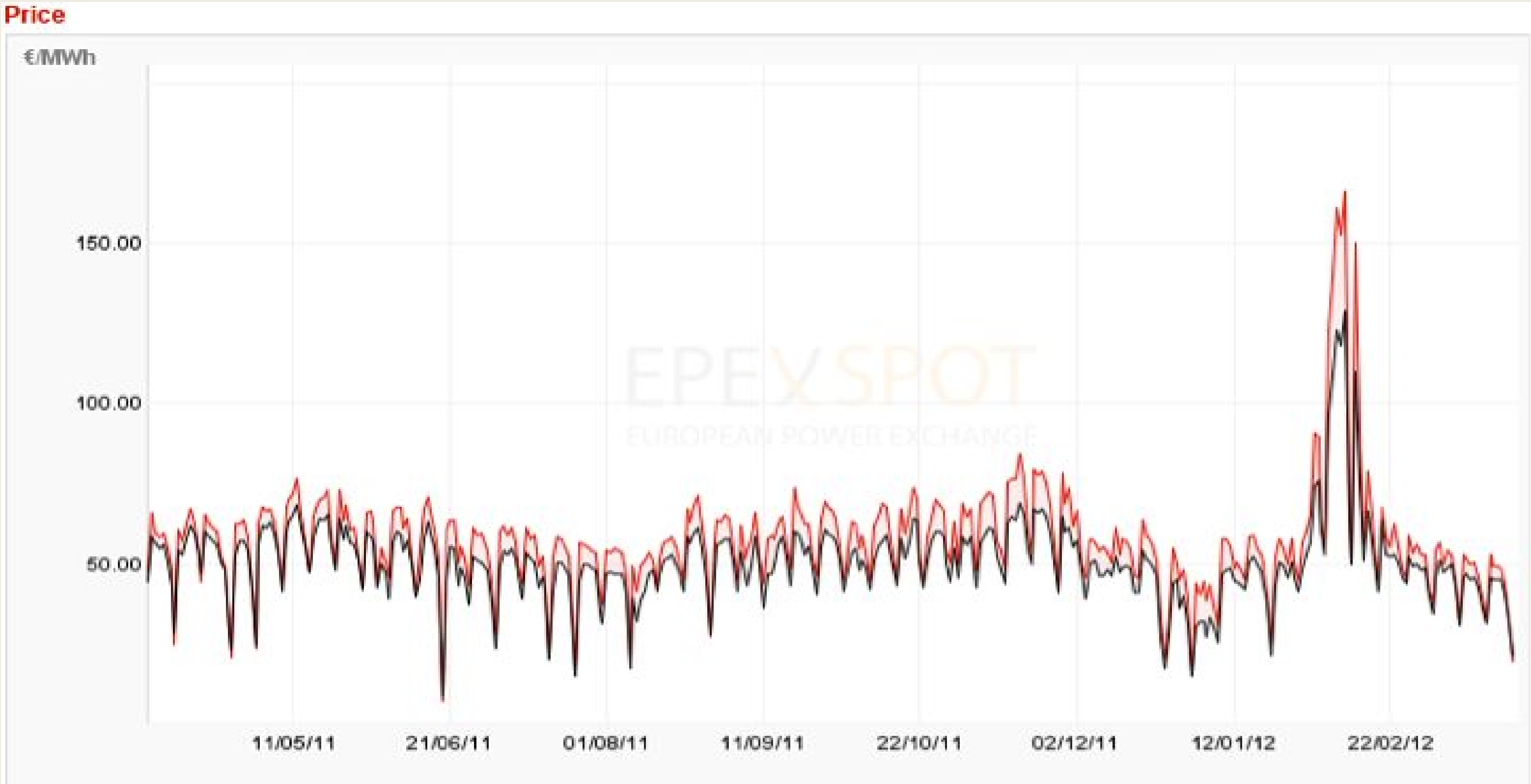
Spot Prices

Example: ***EPEX Spot*** facilitates the hourly balancing of physical power delivered the following day on the French, German/Austrian and Swiss hubs.

•The next graph is of hourly electricity spot price data for 1 year from *EPEX Spot*.

•Source: http://www.eex.com, accessed on 25 March 2012.

Spot Prices



EPEX Spot Prices for 1 Year

Source: **http://www.eex.com, accessed on 2012/03/25**

Stochastic Processes Used to Model Electricity Spot Prices

A ***stochastic*** (or **random**) process is the probabilistic counterpart to a ***deterministic*** process. It is a statistical process involving random variables that are dependent on a variable parameter (such as time).

Stochastic Processes for Modeling Electricity Spot Prices

Random Walk *Jump-Diffusion* Model	Mean Reversion: Ornstein-Uhlenbeck Process	Mean Reversion: Schwartz Type 1 Stochastic Process	Mean Reversion With Jumps	Two-Factor Model

Random Walk Jump-Diffusion Model

Diffusion is the scattering of molecular particles in the atmosphere.

- Diffusion works by transportation of molecules from higher concentration, more tightly packed, to lower concentration.
- *The jump diffusion process is a stochastic process that involves jumps (spikes) and diffusion.*

The *heat equation* is used to model the diffusion of particles, heat and various other diffusive processes.

$$\frac{\partial u}{\partial t} - \alpha \nabla^2 u = 0$$

Where,

$u(x,y,z,t)$ =: a function of 3 spatial variables (x,y,z) and the time variable t

$\alpha > 0$

∇^2 =: *Laplace operator*

Random Walk Jump-Diffusion Model

This electricity spot price model is a random walk jump-diffusion SDE, adopted from Merton (1976).

$$dS_t = \mu S_t dt + \sigma S_t dW_t$$

Where,

S_t =: S(t) is the spot price

S_0 = S(0)

μ =: *drift rate* of S_t

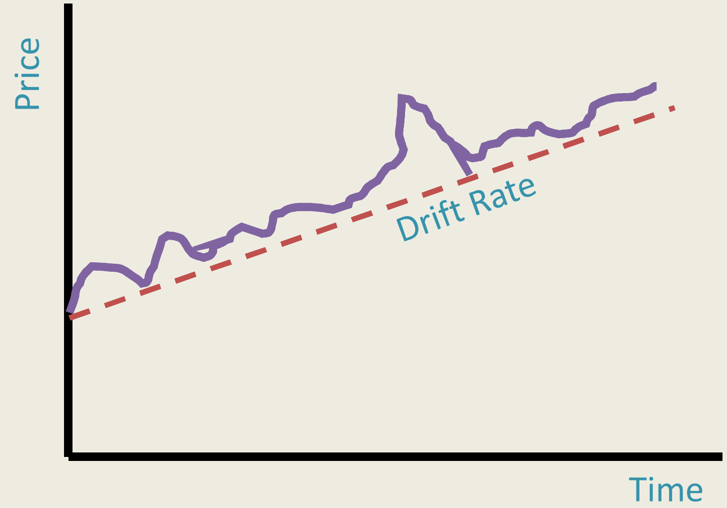
σ =: volatility of S_t

W_t =: W(t) is a Brownian motion

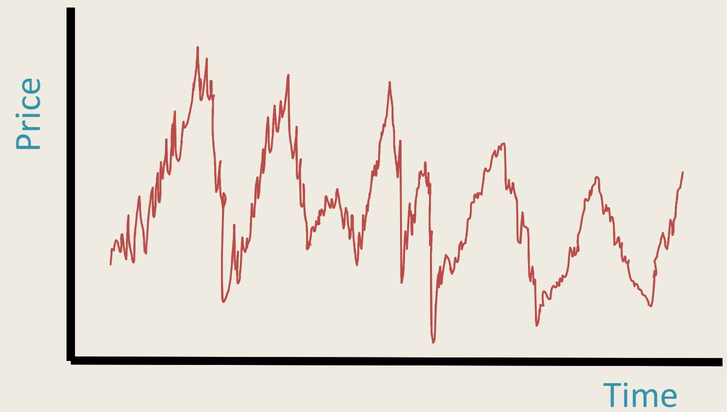
Random Walk Jump-Diffusion Model

The ***stochastic drift*** represents the annualized average return of the spot price.

The ***drift rate*** is denoted by the parameter ***μ***. It is the expected return or rate at which the average spot price changes.



A ***random walk*** is a mathematical formalization of a path that consists of a succession of random steps.



Random Walk Jump-Diffusion Model

Via stochastic integration – the integral form of this Merton SDE is

$$S(t) = S(0)e^{(\mu - \frac{1}{2}\sigma^2)t + \sigma\{W(t) - W(0)\}}$$

Due to the exponential nature of the solution to this random walk jump-diffusion SDE model, the electricity spot price can never get below zero.

The limitation of this SDE model is that it ignores the mean-reverting behavior of electricity spot prices. Kaminski (1997)

Mean Reversion: Ornstein-Uhlenbeck Process

This mean reverting process embodies the economic argument that when electricity prices are

- Too high: demand will decline, supply will increase
- Too low: the opposite will occur - push prices back towards long term mean.

$$dS_t = \alpha(\mu - S_t)dt + \sigma dW_t$$

Where,

S_t =: S(t) is the spot price

S_0 = S(0)

μ =: *drift rate* of S_t

σ =: volatility of S_t

α > 0 denotes the *speed of mean reversion* and characterizes the velocity at which such trajectories will regroup around μ in time

W_t =: W(t) is a Brownian motion

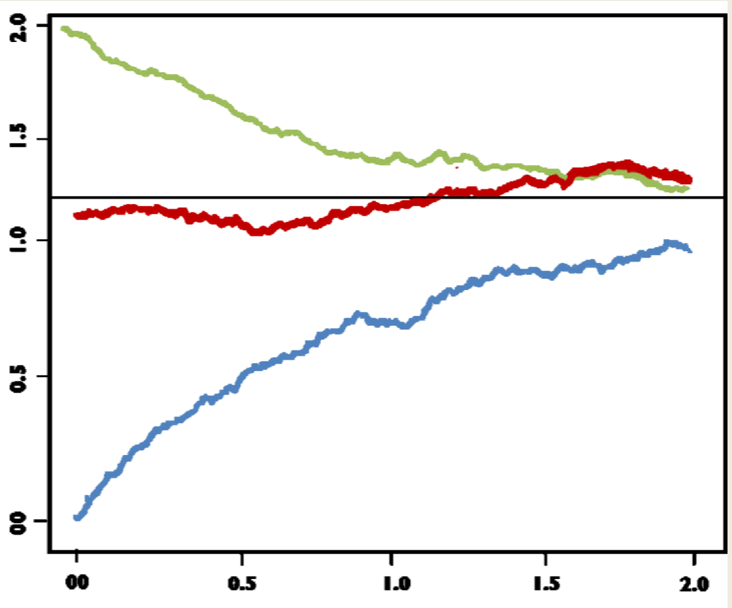
This SDE is the Ornstein-Uhlenbeck process - also referred to as the Vasicek process. Ornstein (1930), Vasicek (1977)

Mean Reversion: Ornstein-Uhlenbeck Process

This SDE has the following solution:

$$S_t = S_0 e^{-\alpha t} + \mu(1 - e^{-\alpha t}) + \int_0^t \sigma e^{\alpha(z-t)} dW_z$$

Unless we are dealing with special cases of negative electricity spot prices, a limitation of the application of the Orstein-Uhlenbeck process to model electricity spot prices is there is nothing that prevents S_t from going negative.



Three sample paths of different OU-processes with α= 1, μ = 1.2, σ = 0.3:

- blue: initial value $t_0 = 0$
- green: initial value $t_0 = 2$
- red: initial value normally distributed

Mean Reversion: Schwartz Type 1 Stochastic Process

Consider the SDE

$$dS_t = \alpha\{\mu_L - \ln(S_t)\}S_t dt + \sigma_L S_t dW_t$$

- The Schwartz Type 1 model is a log price Ornstein-Uhlenbeck stochastic process.
- In this case, this mean reversion process is used to model the log of the electricity spot price.
- Hence a log-spot less than zero still corresponds to a spot price greater than zero.

Where,

S_t =: S(t) is the spot price

$S_0 = S(0)$

μ_L =: long-term average value of ln (S_t)

σ =: volatility of S_t

α =: *speed of mean reversion* and characterizes the velocity at which such trajectories will regroup around μ_L in time

W_t =: W(t) is a Brownian motion

Mean Reversion: Schwartz Type 1 Stochastic Process

This SDE has the following solution – as derived in Huang (2012):

$$S(t) = \exp\left\{ \ln(S_0)e^{-\alpha t} + \left(\mu_L - \frac{\sigma^2}{2\alpha} \right) \left[1 - e^{-\alpha t} \right] + \int_0^t e^{\alpha(x-t)} \sigma \, dW(x) \right\}$$

- This process is often utilized in electricity spot price modeling.
- However, it is normally *tweaked* to handle spikes in electricity prices, blackouts, seasonality, geographical regions of the national power grid, etc. Clewlow (2000)

Example: ***Tweaking*** electricity prices

- During peak demand hours, the price of electricity can be very expensive.
- During low consumption off-peak hours (e.g., late night) the price of electricity may be cheaper.
- There can be huge variation in prices between peak hours and off-peak hours.
- To account for this variation, models may be tweaked to reach an adjusted normalized or time-diffused forecasted value.

- http://www.youtube.com/watch?v=QW6lYKcxEg4&feature=related
- http://www.youtube.com/watch?v=WRPVS4o9Fuw&feature=relmfu

Mean Reversion With Jumps

$$dS_t = \alpha\{\mu_L - \Phi\kappa_m - \ln(S_t)\}S_t dt + \sigma S_t dW_t + \kappa S_t dq_t(\lambda)$$

This SDE addresses key characteristics of spot price dynamics

- *mean-reversion*
- *spikes*

Where,

S_t =: S(t) is the spot price

$S_0 = S(0)$

μ_L =: long-term average value of $\ln(S_t)$

σ =: volatility of S_t

α =: *speed of mean reversion* and characterizes the velocity at which such trajectories will regroup around μ_L in time

W_t =: W(t) is a Brownian motion

dq_t =: dq(t) denotes a Poisson process with intensity λ that describes the jump occurrence

κ denotes a jump with log-normal distribution $\ln(1+\kappa) \sim N\left[\ln(1+\kappa_m) - \gamma^2/2, \gamma^2\right]$

κ_m denotes the mean jump size

γ denotes the jump volatility

$\Phi\kappa_m$ denotes the compensation term required to take into account the jump effect

Mean Reversion With Jumps

- This stochastic SDE takes into consideration the perturbations induced by the diffusion and the spikes with respect to the deterministic trend:

$$dS_t = \underbrace{\alpha\{\mu_L - \Phi\kappa_m - \ln(S_t)\}S_t\,dt}_{\text{Path of } S_t \text{ as a Mean-reverting Process}} + \underbrace{\sigma S_t dW_t}_{\text{Perturbations Induced by Diffusion}} + \underbrace{\kappa S_t dq_t(\lambda)}_{\text{Spikes (Jumps)}}$$

- The inclusion of jumps into this SDE leads to the loss of a simple closed form analytical solution.
- **Quants in energy trading firms and utilities spend their careers working on such electricity spot price models. Clewlow (2000)**

Two-Factor Electricity Spot Price Model

There is also a two-factor model for on-peak electricity spot prices. It models the peak demand as a two-factor mean reverting jump diffusion process.

This process attempts to describe two different mean reversion features related to the

- *normal peak in the demand*
- *abnormal spikes in the demand*

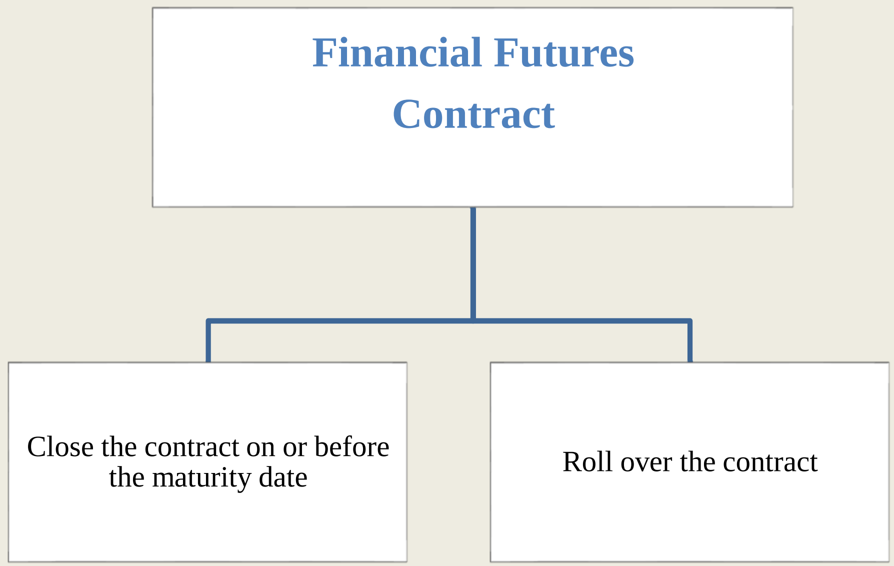
The two-factor model was also designed to capture some intrinsic features of seasonality.

Numerical examples in Birge (2010) indicate that their two-factor model yields more reasonable results than the one-factor models.

Birge’s two-factor model incorporates the oligopolic nature of electricity spot markets.

Physical Forward and Futures Markets

Forward Contract	*Physical Forward Contract*	Physical delivery of Energy
		Delivery on maturity date of contract
	Financial Forward Contract	Settlement before maturity date
		No Physical delivery



Futures Contract Roll-over

A rollover occurs when a trader reinvests funds from a mature security into a new issue of the same or a similar security.

Since futures contracts expire, a position in an expiring contract, if it is to be continued, must be rolled to the next nearby futures contract.

For an initial long (short) position, this means selling (buying) the expiring contract and buying (selling) the next contract.

http://search.cmegroup.com/search?q=rollover&site=cmegroup&output=xml_no_dtd&client=cmegroup&num=20&proxystylesheet=cmegroup

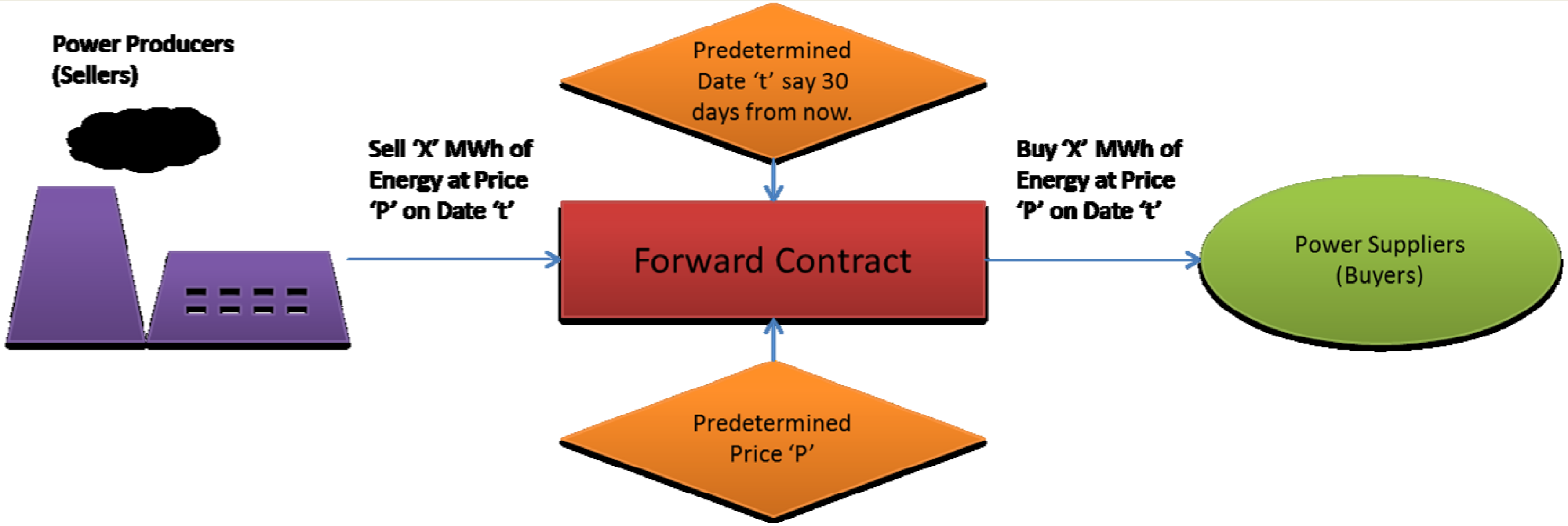
Physical Forward and Futures Markets

The ***forward price*** is a predetermined delivery price for an underlying commodity, currency or financial asset decided upon by the buyer and the seller to be paid at a predetermined date in the future.

- If a forward contract is settled before its maturity date, it is a ***financial forward contract*** since no commodity is physically delivered.

- A forward contract is a physical contract if the commodity is delivered physically. ***Physical forward contracts*** may be traded on an exchange or in a bilateral manner through over-the-counter (OTC) transactions.

Physical Forward and Futures Markets



Physical Forward and Futures Markets

The ***cost of carry model*** expresses the forward price (or as an approximation, the futures price) as a function of the spot price and the cost of carry.

$$F = Se^{(r+s-c)t}$$

where

F = forward price

S = spot price

r = risk-free interest rate

s = storage cost

c = convenience yield (benefit or premium associated with holding an underlying product or physical good, rather than the contract or derivative product)

t = time to delivery of the forward contract (expressed as a fraction of 1 year)

A ***futures contract*** is a highly standardized financial instrument in which two parties enter into an agreement to exchange an underlying commodity (e.g., crude oil, natural gas) at a mutually agreed-upon price at a specific time in the future.

Both the buyer and the seller have the right and the obligation to fulfill the contract's terms.

Physical Forward and Futures Markets

Futures Contracts

Trade over exchanges.

Forward contracts

Trade in the OTC market.

Example: Power contract mandates

- Seller is responsible for delivering the power from the generator location to a HUB
- Buyer is responsible for delivering the power from the HUB to a load location

Electricity futures and other derivatives contracts are used by market participants to manage (hedge) price risks.

Physical Forward and Futures Markets

The futures market is regulated and the forward market is unregulated.

- Trading in the unregulated forward market is done by individual parties outside the purview of the exchanges. This is known as the *over-the-counter (OTC) market*. (~80% of energy market)

- Trading in the regulated futures market is done through designated commodity futures exchanges. (~20% of energy market)

Futures contracts in the U.S. are traded on these exchanges:

- *New York Mercantile Exchange* (NYMEX)
  - http://bit.ly/Ld9Zsk
- *Chicago Mercantile Exchange* (CME)
- *Intercontinental Exchange* (ICE)

A list of other exchanges around the world may be found here:

- http://en.wikipedia.org/wiki/Commodities_exchanges

- Agricultural futures have traded since the 1860s. Brown (1987)

- ***Energy futures*** were not introduced until the 1970s.

Future Contract

Future Contract Details	1. **Underlying Asset**: What energy asset/product does the contract represent?
	2. **Quantity**: How much of the energy asset/product is bought or sold?
	3. **Last trading day** of the futures contract?
	4. How is the futures contract **quoted**?
	5. What is the **Symbol** for the contract?
	6. What **Exchange** does the contract trade on?

Individual Futures Contracts

Symbology for an ***individual futures contracts*** consists of

- Root (1 or 2 characters)
- Month Code (Table I)
- 2-digit year code
- Decimal and alias extension (optional)

Examples: Table II

Individual Futures Contracts

Table I.

Futures Month Delivery Codes			
F **January**	**G** **February**	**H** **March**	**J** **April**
K **May**	**M** **June**	**N** **July**	**Q** **August**
U **September**	**V** **October**	**X** **November**	**Z** **December**

References: Textbook, Chapters 2 and 7

Individual Futures Contracts

Table II.

Energy Futures Contracts	*Examples*	*CME Contract Details*
Crude Oil	**CLU16** (Crude Oil September 2016)	http://bit.ly/ZZ2Ppv
Henry Hub Natural Gas	**NGV16** (Natural Gas October 2015)	http://bit.ly/ZgGrYt
NY Harbor ULSD Heating Oil	**HOX16** (Heating Oil November 2016)	http://bit.ly/1uNPU2P
RBOB Gasoline Physical	**RBZ16** (NYHarborBlendstock RBOB December 2016)	http://bit.ly/1qDN4JQ

References: Textbook, Chapters 2 and 7

Individual Futures Contracts

Examples:

Use the TradeStation *Symbol Lookup* to explore individual futures contracts listed on the CME.

Continuous Futures Contracts

Continuous futures data is necessary for the back-testing of futures markets due to the limited life span of this type of market.

Continuous futures data is linked at rollover points and the data is adjusted to ensure continuity.

These contracts allow one to plot and back-test a futures trading strategy by automatically linking the current and previous contracts at rollover points to ensure continuity.

Continuous Futures Contracts

Symbology for ***continuous futures contracts*** consists of

- At-sign (@)
- Symbol Root
- Optional Alias Extension (preceded by a decimal point)

Examples:

- @CL
- @CLZ16

Capacity vs. Energy Markets

Energy markets are used to coordinate the continuous buying, selling, and delivery of electricity.

Capacity markets provide incentives that are designed to stimulate investment to

1. Maintain existing generation
2. Encourage development of new sources of capacity

Note: In capacity markets, pricing is guaranteed and can never go negative.

Negative Prices

Thus far we have discussed stochastic models for which the electricity spot price can never go below zero.

Negative prices for electricity

- Have been observed for some time now in the U.S., Australia, and Canada.
- Are a recent development in European power markets.
- Have been permitted at Germany's European Energy Exchange (EEX) spot market since autumn 2008.
- Are discussed in a wind energy case/real options case study in Chapter 9 of my new book.

Negative Prices

Some characteristics of negative prices:

- **Primary cause:** Inability of certain generation units to ramp down power generation when there's no demand to consume all the power already generated.
- The excess power may be consumed by artificial loads (for a charge) to ensure the reliability of the grid.
- Observed for 5 to 6 hours a day – maximum.
- Pose a basic problem for the previously discussed stochastic price models. Going from prices to log prices is not possible.

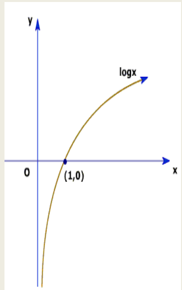
Negative Prices

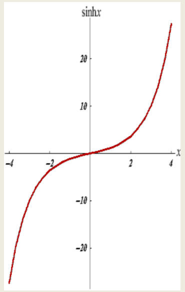
Suggestions for handling negative prices are as follows:

- Use daily average prices (which are mostly positive). Adjust the sample by removing some outliers.

- Use a modeling approach based on the integration of the area of the hyperbolic sine transformation $\{sinh(x) = .5(e^{x} - e^{-x})\}$ into stochastic price models. This model has been applied to spot modeling of the German EEX and the West Texas market of the Electric Reliability Council of Texas (ERCOT). An example of the valuation of an option is carried out.

- More details and references in my book.





Intraday Market

Intraday Market

- The ***intra-day market*** is for electricity products with a delivery on the same day.
- This market can be utilized to satisfy short-term needs of electricity or to sell short-term over capacities.

Balancing and Reserve Markets

Balancing and Reserve Markets

- Balancing and reserve markets are influenced by national regulation.
- In the ***reserve market*** an independent system operator (ISO) is allowed to purchase electricity products to compensate for imbalances between supply and demand in the system.
- The ***balancing market*** allows electricity firms/traders to submit offers to sell and bids to buy energy from the system by altering generation or consumption.