MANCHESTER 1824

The University of Manchester

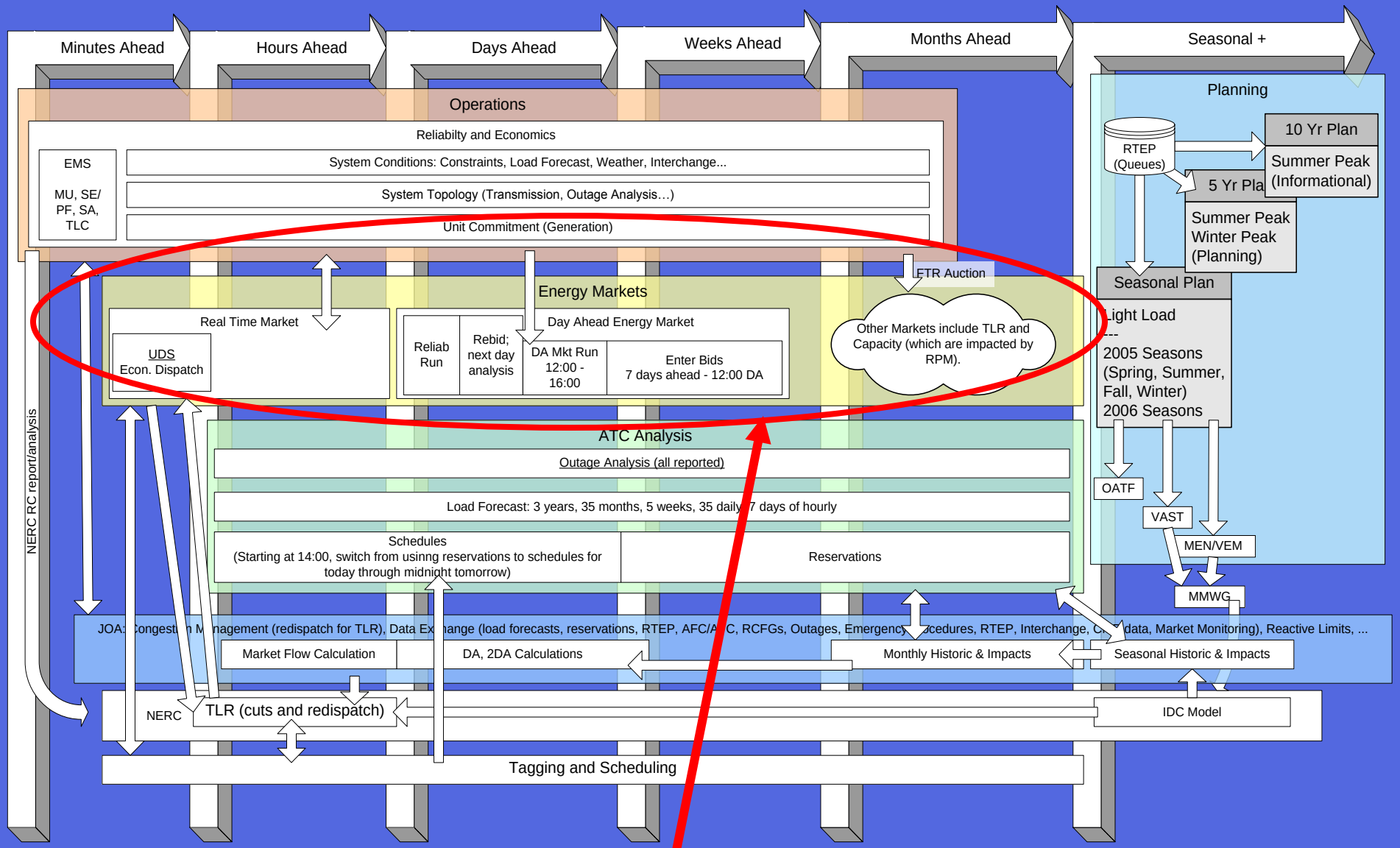
Organization of Restructured Wholesale Power Markets

Important Acknowledgement:

These notes on Kirschen/Strbac (Chapter 3, *Power System Economics*, 2004) are based on slides prepared by Daniel Kirschen (U Manchester, 2005) with substantial edits by Leigh Tesfatsion (Iowa State U).

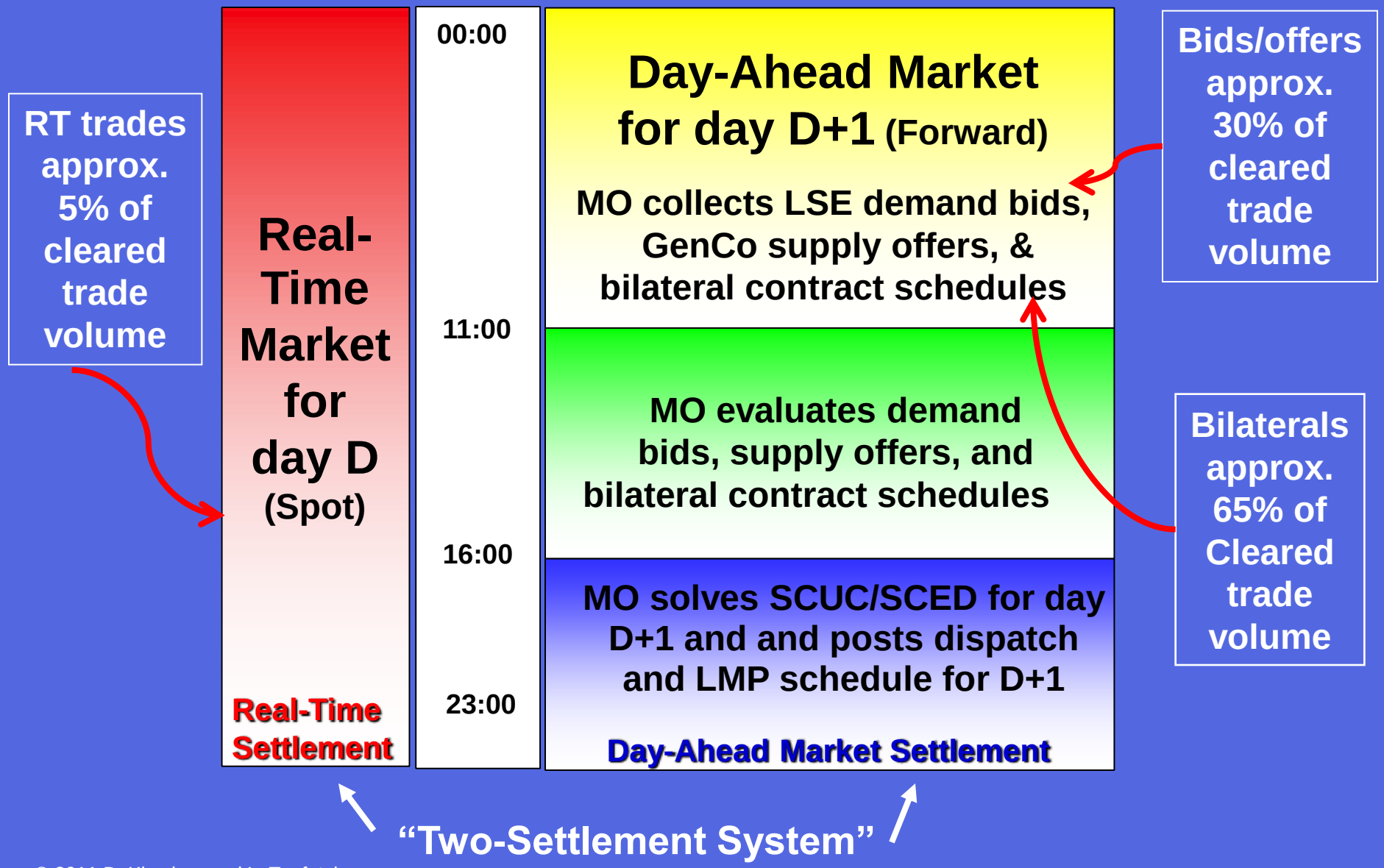
Last Revised: 10 November 2011

Complicated Form of U.S. Restructured Wholesale Power Markets (from JDM)



Our focus will be here (two-settlement system & FTR markets).

Simplified View of Market Operator (MO) Activities During a Typical Day D in U.S. Restructured Wholesale Power Markets



Why a "Two Settlement System"?

- By considering anew the special aspects of electric energy, we can better understand why the "two-settlement system" was chosen for U.S. restructured wholesale power markets.

- K/S (Chapter 3) first review ***special aspects of electric energy relative to other commodities***

- K/S (Chapter 3) then consider ***various possible forms for wholesale electric energy markets in the absence of transmission grid congestion***
  - K/S show special aspects of electric energy can lead to imbalance and price volatility problems under these various market forms.
  - An appropriate combination of these market forms can address imbalance/volatility.
  - But will this combined market form suffice in the presence of grid congestion?

- K/S (Chapter 6) later discuss ***further problems that arise from the possibility of transmission grid congestion***

- ***The "two-settlement system" (under locational marginal pricing) was designed to handle imbalance, price volatility, AND grid congestion problems.***

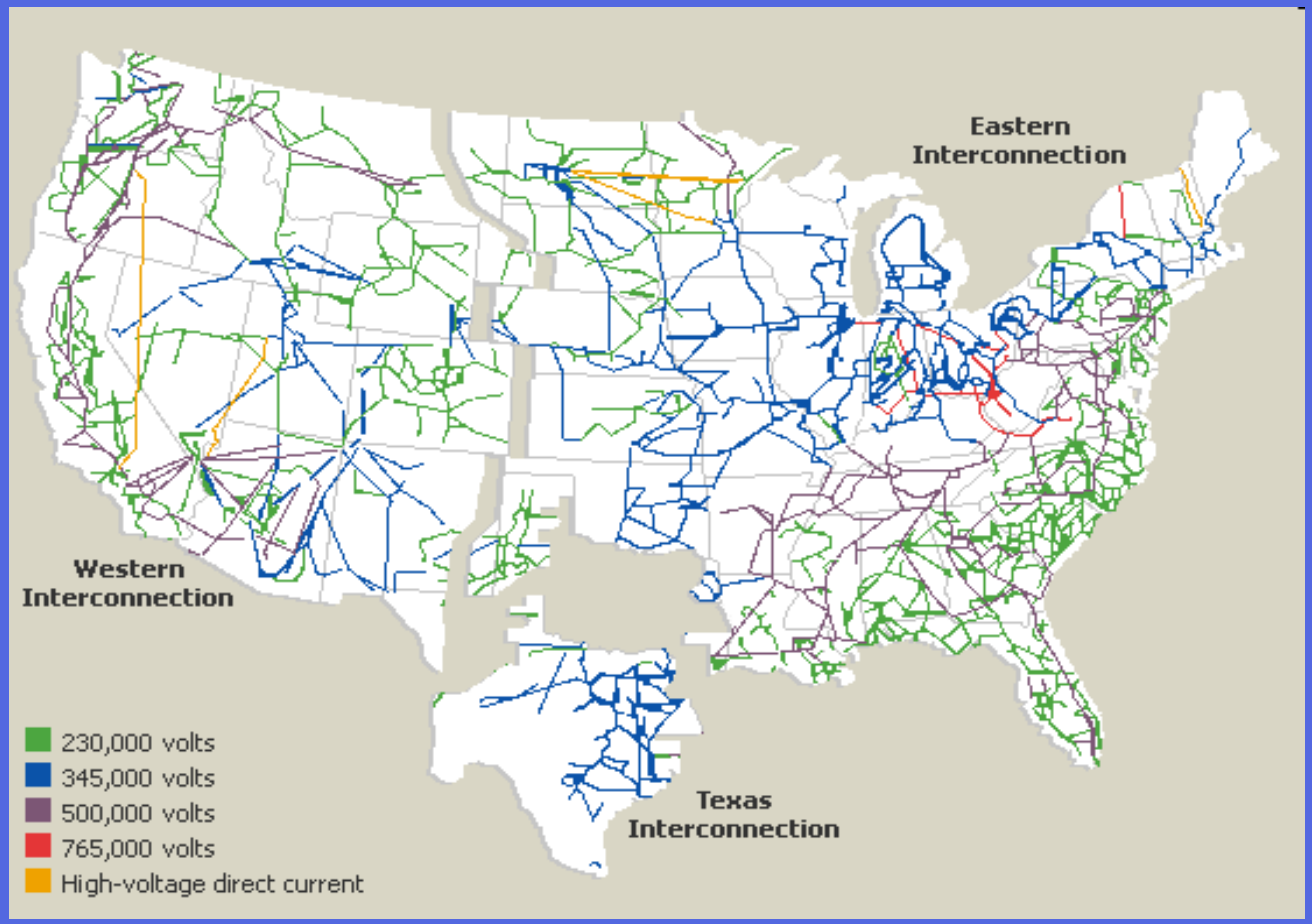
Special Aspects of Electric Energy Relative to Other Commodities

- ***Transmission Concerns:*** Electric power traded at wholesale is inextricably linked with a physical delivery system, the transmission grid
  - Physical delivery via the grid happens “instantaneously”
  - Need for balance between electric power inflow (generation) and outflow (demand/losses/net interchange) on the grid at all times
  - Failure to balance leads to the collapse of the grid
  - Economic consequences of collapse are enormous
  - Balance must be maintained at almost any cost

Special Aspects…Continued

- ***Contracting Concerns:*** The production and distribution of electric power at wholesale via a transmission grid is akin to pouring water into, and draining water from, one big **swimming pool**.
  - A GenCo cannot direct its production to a ***particular*** buyer
  - A buyer (e.g., an LSE = Load-Serving Entity) cannot determine ***which*** GenCo in fact produces its load
  - The electric power produced by any one GenCo cannot be physically distinguished from the electric power produced by any other GenCo (*all MWs look alike*!)
  - Grid "swimming pool" operation has economic benefits
  - But a breakdown of the grid affects everybody at once.

U.S. High Voltage Transmission Grid



Detailed Look at a Portion of the U.S. Grid

Special Aspects…Continued

- ***Storage Concerns:*** Electric energy typically cannot be economically stored in large quantities
  - Must be consumed when it is produced (exception=hydro power)
  - Ultimate in "just-in-time manufacturing"

- ***Demand Concerns:*** Wholesale demand for electric energy is variable over time and price inelastic
  - Similar to other commodities, wholesale demand for electric energy exhibits predictable daily, weekly, & seasonal variations
  - Unlike many other commodities, wholesale demand for electric energy currently exhibits **very** low price elasticity – hourly demand curves are nearly vertical (reflecting current lack of price-sensitive retail electric energy contracting)

Various Possible Forms for Wholesale Electric Energy Markets in Absence of Transmission Grid Congestion

- All trades conducted thru a **spot market (immediate purchase/delivery)**

  Problem: balance not assured, and prices potentially too volatile

- All trades conducted thru a ***managed* spot market**

  Problem: balance assured, but prices still potentially too volatile

- All trades conducted thru **forward contracts (separate buy/delivery dates)**

  Problem: balance not assured unless contracts exactly fulfilled, and traders might want more contracting flexibility to hedge wide range of risks

- Trades conducted through **forward contracts, option contracts, and contracts-for-difference supported by a managed spot market**

  Problem: Addresses balance/flexibility issues, but will it be enough if grid congestion is possible? This will be taken up in K/S Chapter 6 (congestion management via LMP & "financial transmission right" contracts).

Electric Energy Traded Only Through a Spot Market?
(Cf. K/S Chapter 2)

- Characteristics of a spot market:
  - Unconditional delivery
  - Immediate delivery
  - Price determined through interactions of buyers and sellers

- Spot market could provide centralized facility to help match total inflow of electric power to total outflow even in presence of unanticipated last minute changes
  - Demand variations due to unforeseen changes in “downstream” (retail) demand conditions
  - Supply variations due to generator outages
  - Supply variations due to cost changes (e.g., fuel price changes)

Electric Energy Traded Only Through a Spot Market? … Continued

- But can electric energy trades be handled **solely** by a spot market ?
  - Injections and withdrawals of electric power from the grid must be instantaneously balanced
  - **Market** operations are too slow to ensure this instantaneous balance -- non-market interventions needed.
  - Also, prices tend to be volatile because spot market is short term

Electric Energy Traded Only Through a Spot Market? … Continued

- For most commodities other than electric energy …
  - Wholesale buyers & sellers tend to trade mostly thru forward contracts to protect against price volatility (“price risk”).
  - Spot market is used to make adjustments in these forward trades as needed due to unforeseen events.
  - Spot market is the market of last resort for wholesale traders.

What about a "managed" wholesale spot market ?

- Management by a ***Market Operator (MO)***

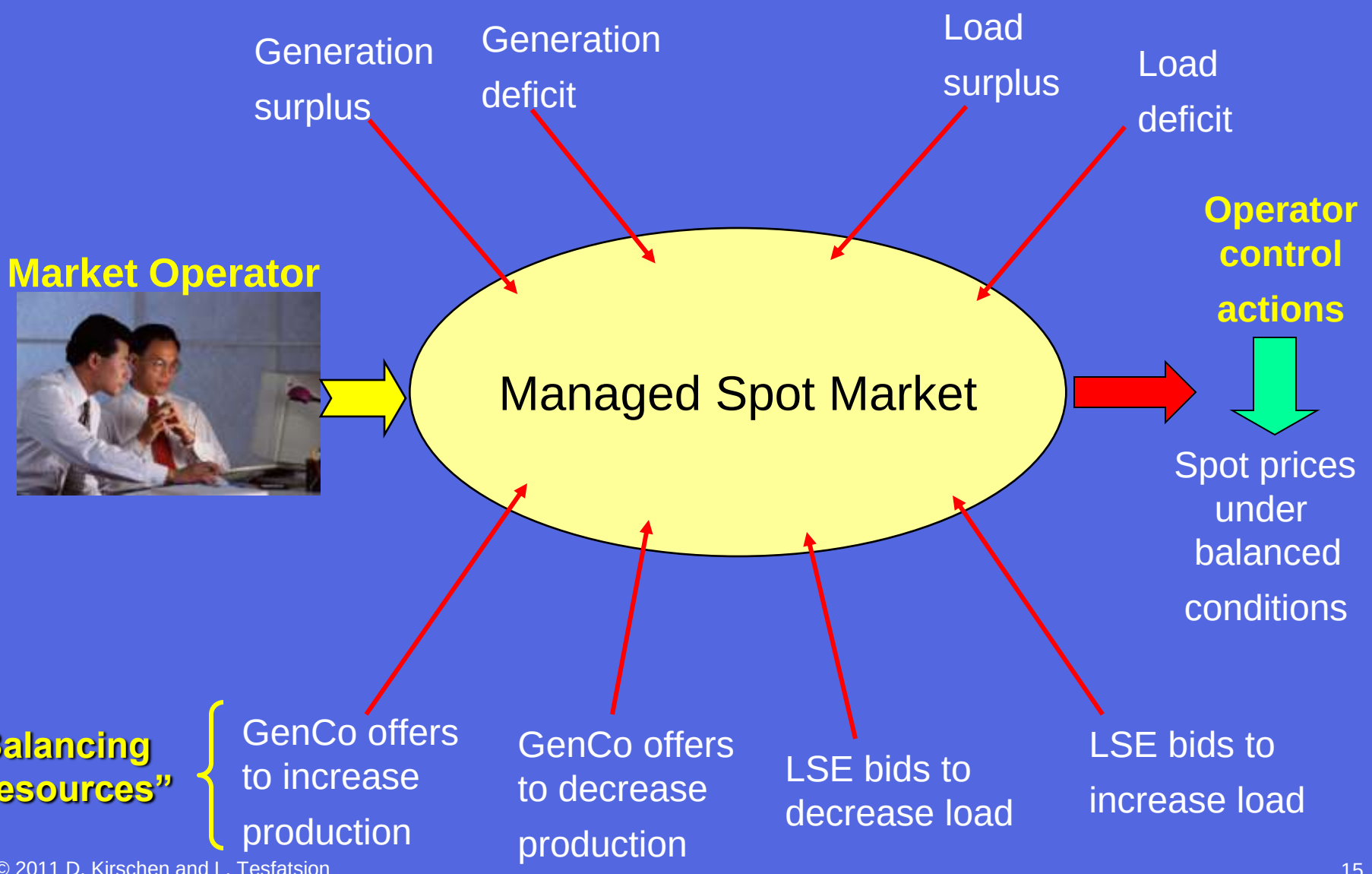
- Key objective : Maintain ***system adequacy*** = balance between inflow (generation) & outflow (demand/losses/net interchange)

- Should ideally operate on a sound economic basis
  - Reliance on competitive supply offers
  - Reliance on competitive demand bids
  - Determination of a market-clearing (demand=supply) spot price

- But non-market "balancing resource" actions – e.g., requesting additional power injection from generation or reduced power withdrawal by load sources -- would be taken as needed by the MO to ensure continual system balance

- Managed spot markets sometimes are called "balance mechanisms"

Schematic Depiction of a Managed Spot Market:

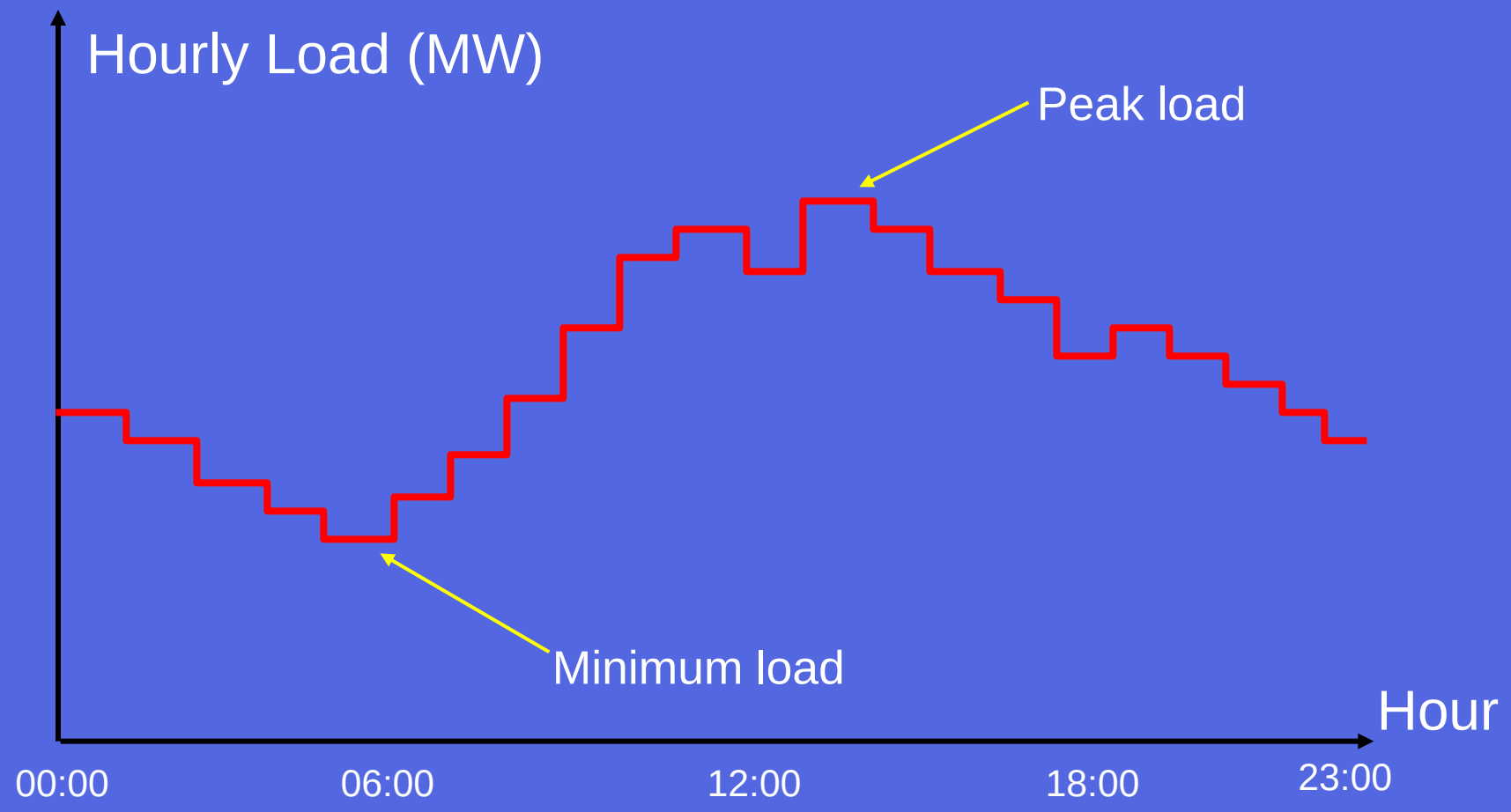


Sole Reliance on a Managed Wholesale Spot Market?

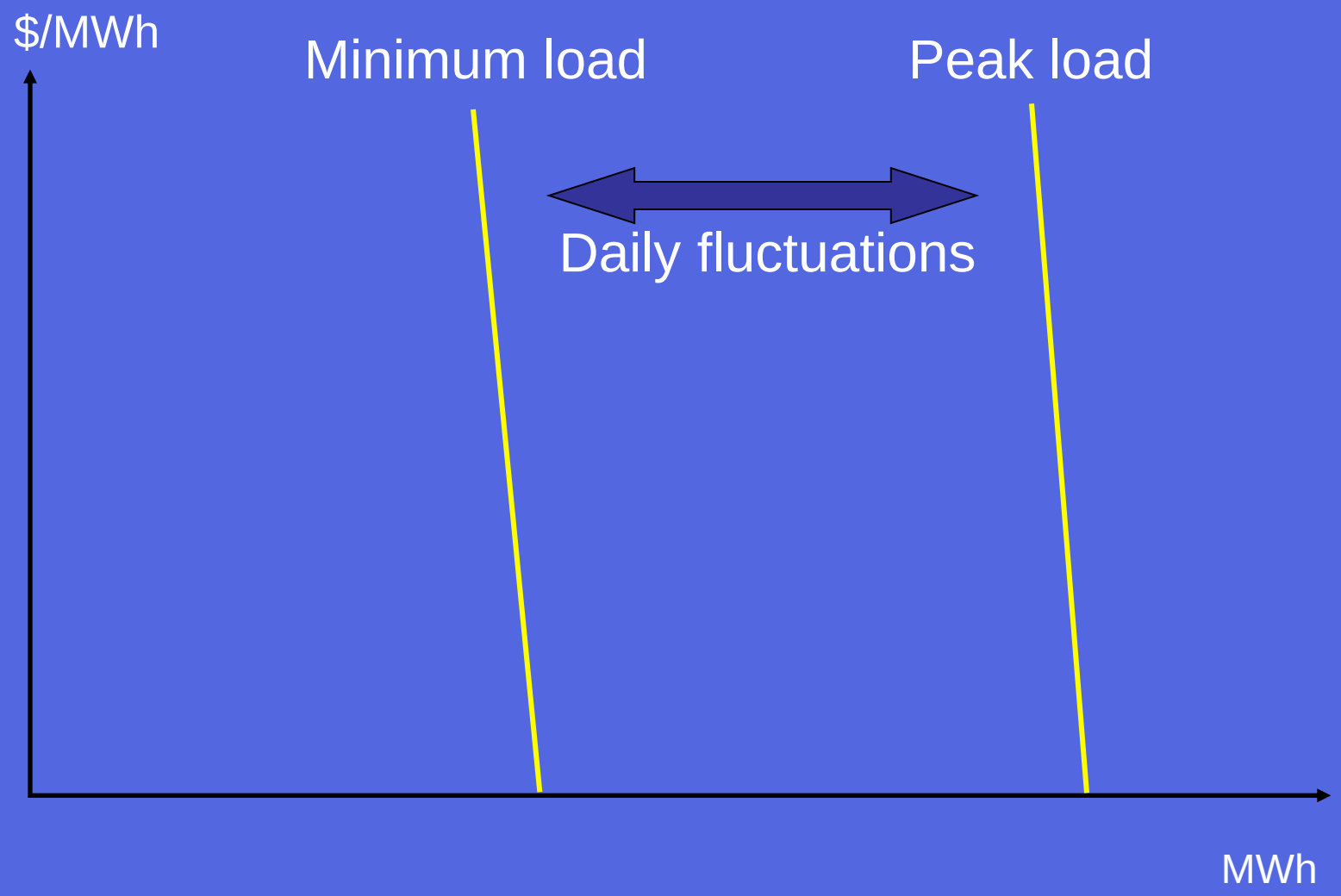
- Managed wholesale spot market addresses imbalance issues

- But sole reliance on a managed spot market for electric energy trading could still result in an unacceptable degree of price volatility due to
  - Inelasticity of demand
  - “Hockey-stick” form of supply (generation) curves

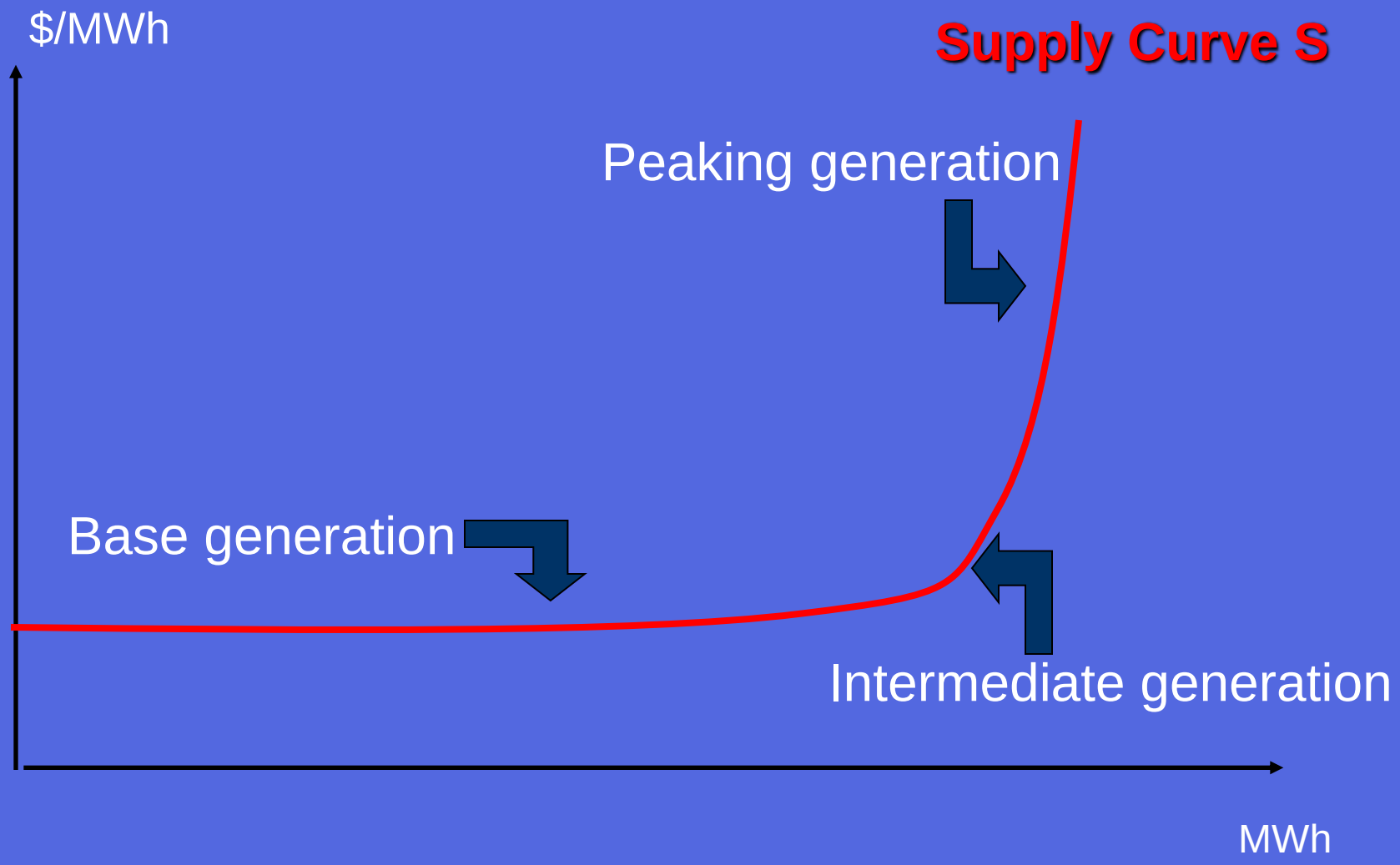
Why do spot prices for electric energy tend to be volatile?



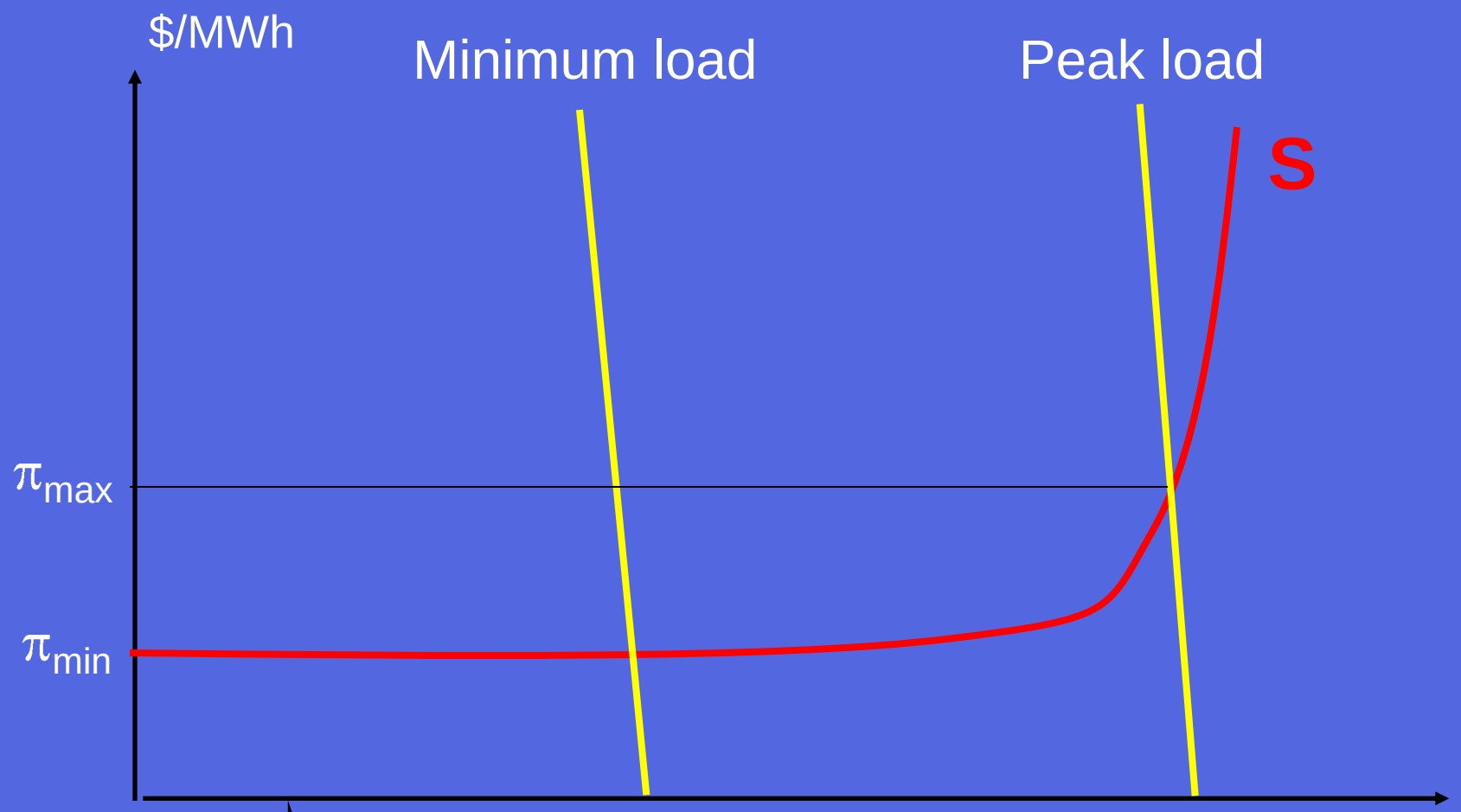
Hourly Demand Curves for Electric Power



Hourly Supply Curve for Electric Power



Hourly Supply and Demand Curves for Electric Power

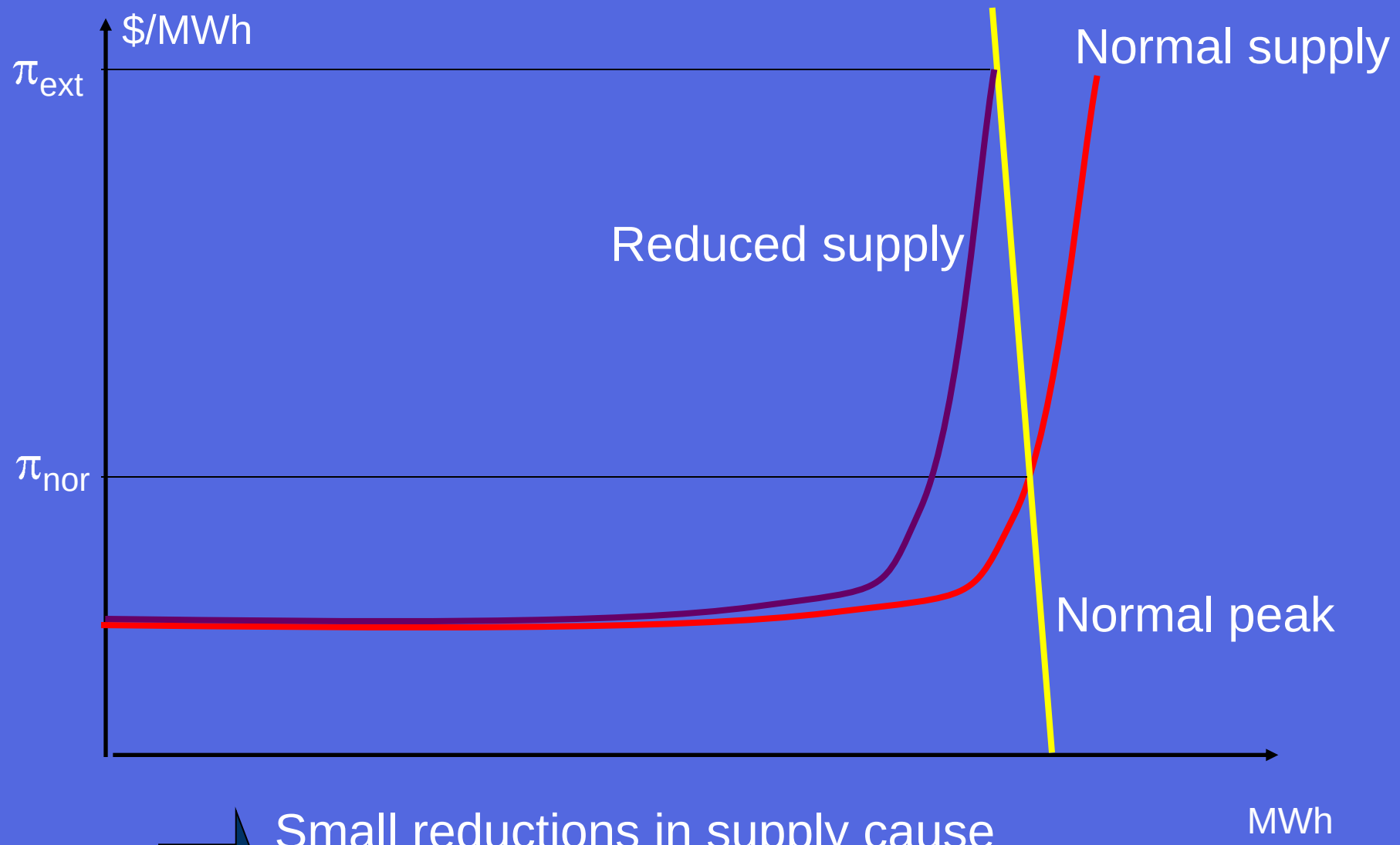


Price of electric power fluctuates hour by hour during each day

Hourly Supply and Demand Curves for Electric Power…

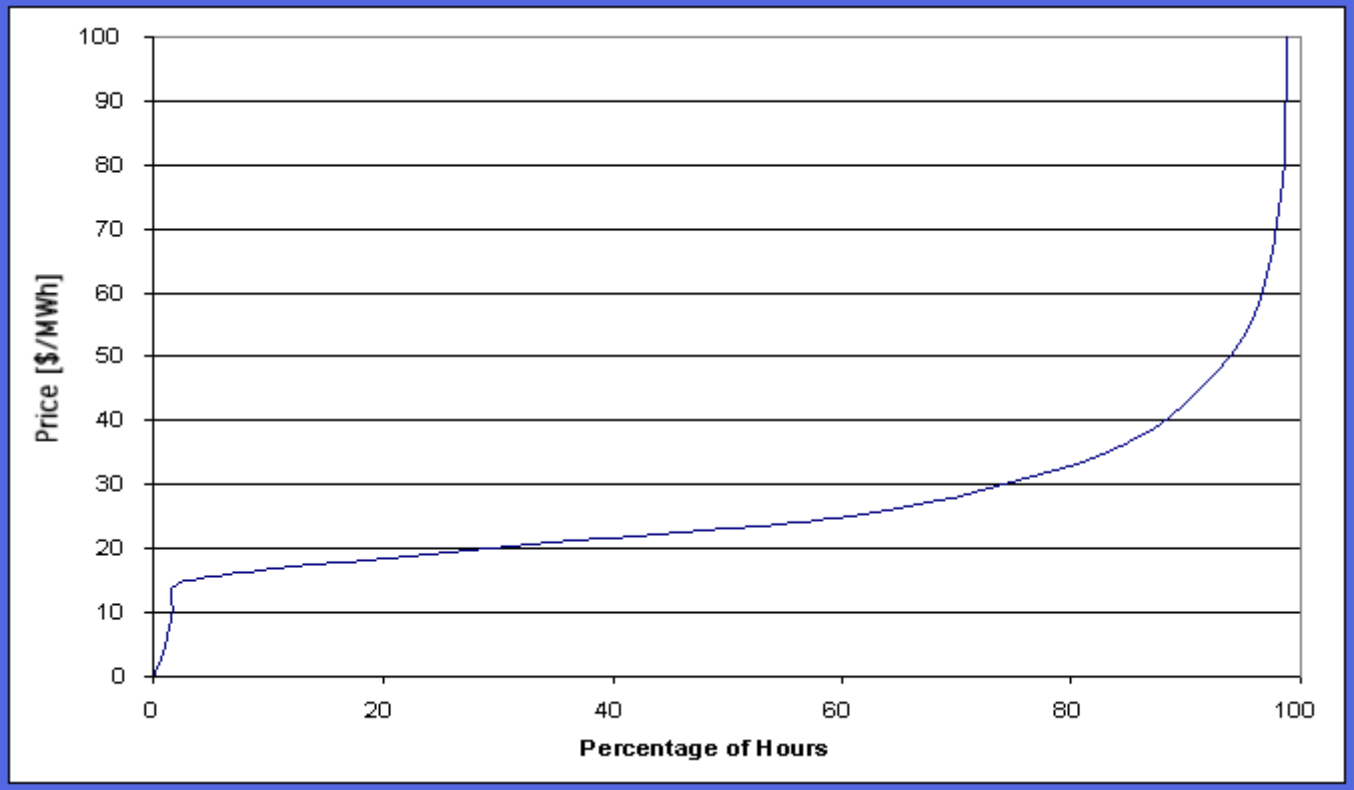
Small increases in peak demand cause large changes in peak prices

Hourly Supply and Demand Curves for Electric Power …



Small reductions in supply cause large changes in peak prices

Price Duration Curve:

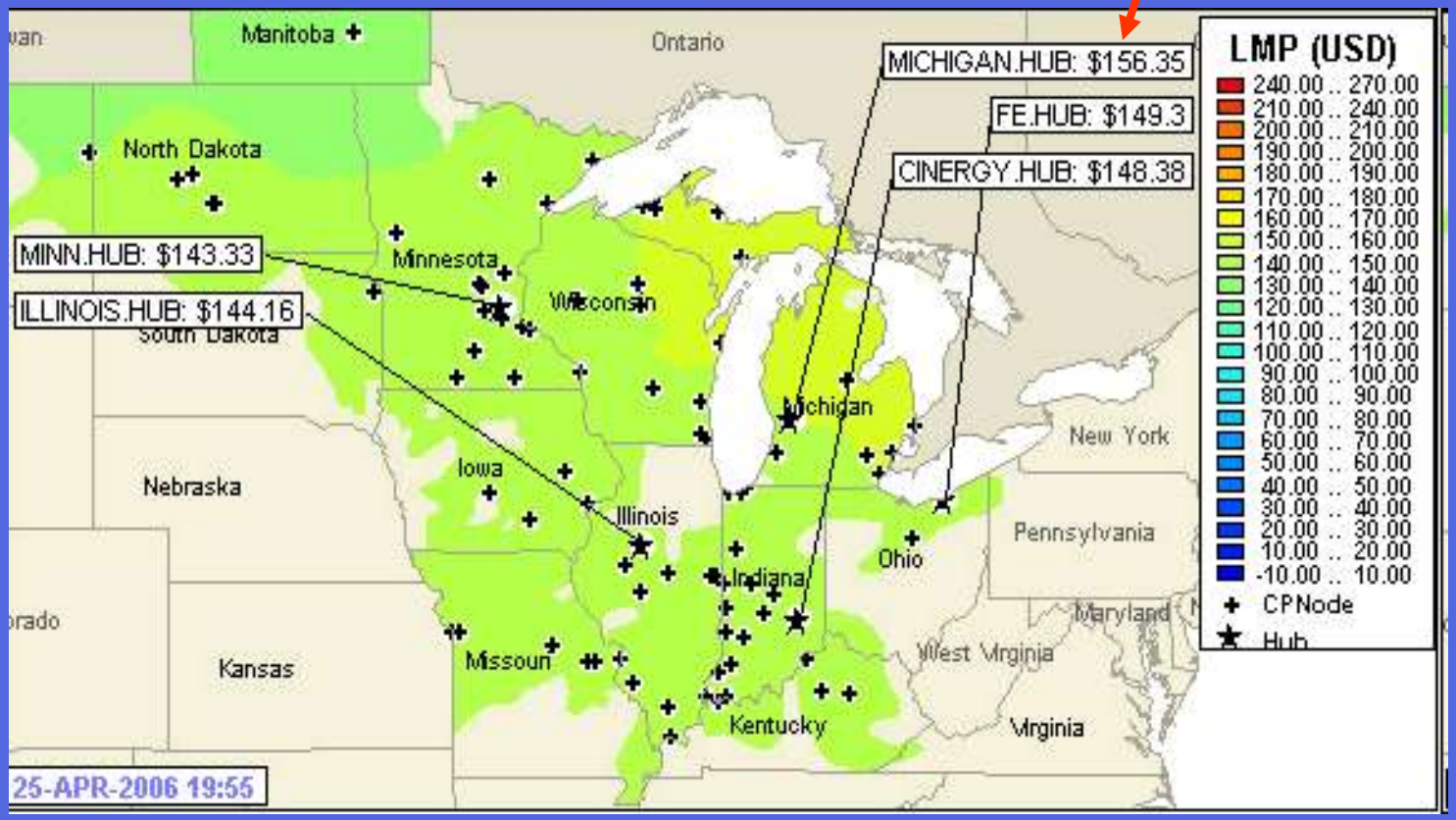


PJM Managed Spot ("Real-Time") Market Prices for 1999: Actual peak price reached $1000/MWh for a few hours

(Source: www.pjm.com)

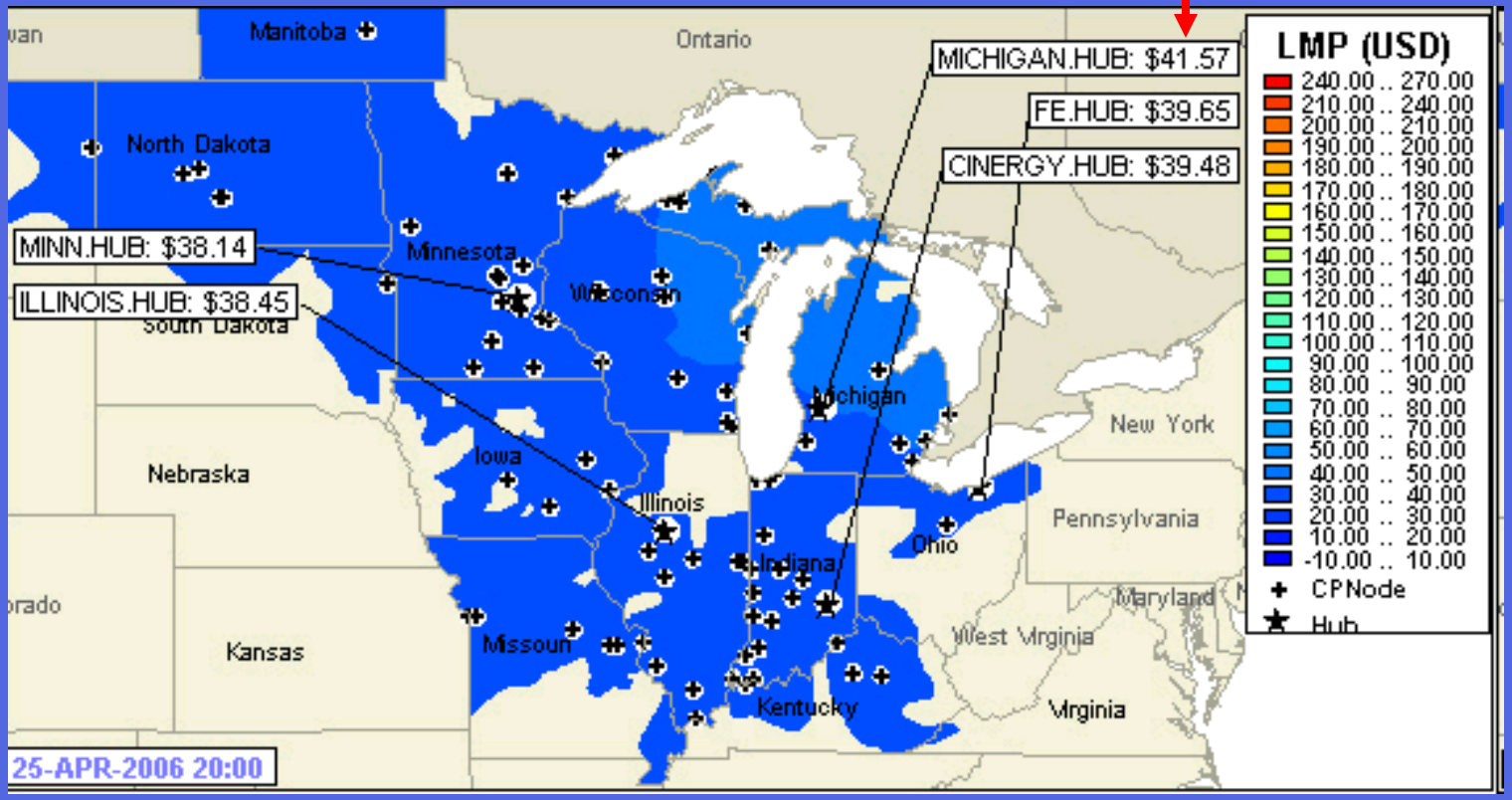
Electric Power Prices in MISO Managed Wholesale Spot ("Real-Time") Market during 25 April 2006, 19:55

Note this price, $156.35



Five Minutes Later… 25 April 2006, 20:00

73% drop in price in 5 minutes!



Role for Forward Trading?

- A well-functioning managed spot market is essential for the support of wholesale trades of electric energy (K/S view).
  - Ensures D/S imbalances are rapidly corrected and properly settled
- But prices in managed spot markets are ***too volatile*** to provide a satisfactory basis for all electric energy trades.
- Forward contracts can be used to reduce price volatility.
  - ***Forward contract*** = Arrangement for the delivery of something of value on a future date at a pre-determined purchase price

Forward Trading for Electric Power

- ***Forward Contract*** = Arrangement for the delivery of something of value on a future date at a pre-determined purchase price

  NOTE: Forward contracts involving a ***standardized*** commodity (item of value with a ***standard*** unit of measure) are called ***futures contracts***.

- Three Basic Forward Contract Forms

  - ***Over-the-Counter (OTC) Trades*** (forward contracting between buyers/sellers mediated by distributed "dealers" who each "make a market" by setting purchase/sale prices and buying/selling on own account (inventory holdings)
  - ***Pool Trades*** (forward contracting thru centralized auction market)
  - ***Bilateral Contracts*** (forward contracting between individual buyer-seller pairs)

Forward Trading Thru Over-the-Counter (OTC) Markets

- OTC trades managed by distributed dealers who each “make a market”

- OTC trades for electric energy typically involve purchase/sale of futures contracts (standardized forward contracts)
  - Delivery according to “standardized profiles” --- i.e., standardized definition of how much energy should be delivered during different time periods.

- Advantages of OTC market for electric energy
  - OTC trades can involve small amounts of electric energy
  - OTC trades tend to have lower transaction costs than customized bilateral contracts
  - OTC markets tend to be “thick” (involve many traders) due to the standardized form of forward contracts available for purchase and sale, implying there is good opportunity for secondary resale of these contracts

Pool Trades vs. Bilateral Contracts

- **Pool Trades**
  - Administered centrally
  - Price determined centrally
  - Facilitates system security management
  - Makes possible centralized optimization
  - Historical origins in electricity industry

- **Bilateral Contracts**
  - More decentralized
  - Prices set by the parties
  - Hard bargaining possible
  - GenCos assume scheduling risk
  - Must be coordinated with system operator that manages grid
  - More opportunities to innovate

Both forms of trading can coexist to a certain extent.

Forward Trading Through a Pool
(Ignoring Transmission Grid Congestion)

- Buyers submit ***demand bids*** (purchase plans) for a future trading period T (e.g., noon hour of the next day).
- Sellers submit ***supply offers*** (sale plans) for this same future trading period T
- Market operator forms the (descending) ***total demand schedule*** and the (ascending) ***total supply schedule*** for T using the individual demand bids and supply offers for T
- The market operator announces a single ("uniform") ***System Marginal Price (SMP)*** for period T at level where total demand and supply schedules intersect.

Important Note on Terminology

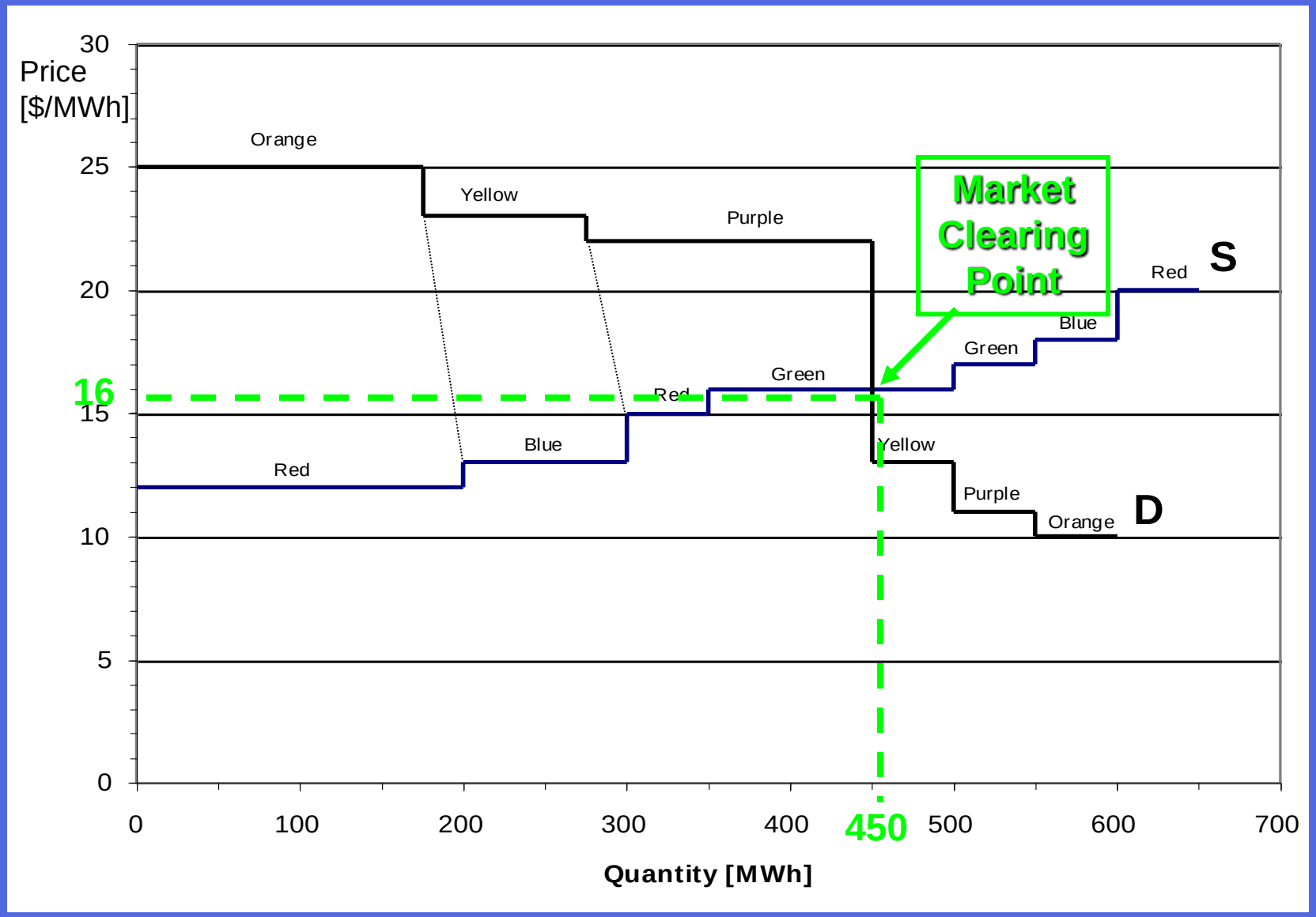
- Standard auction market terminology uses ***bids*** to mean ***demand bids*** (***purchase plans***) & ***offers (or "asks")*** for ***supply offers*** (***sale plans***).
- This standard terminology is adhered to in all 458 class lecture materials.
- The K/S text unfortunately reverses this standard market terminology.
- Please take into account (and correct for) this confusing switch in terminology as you read the assigned K/S materials.
- To avoid confusion, lecture materials will always include the "demand" qualifier for bids and the "supply" qualifier for offers.

Example of pool trading for a future time period:

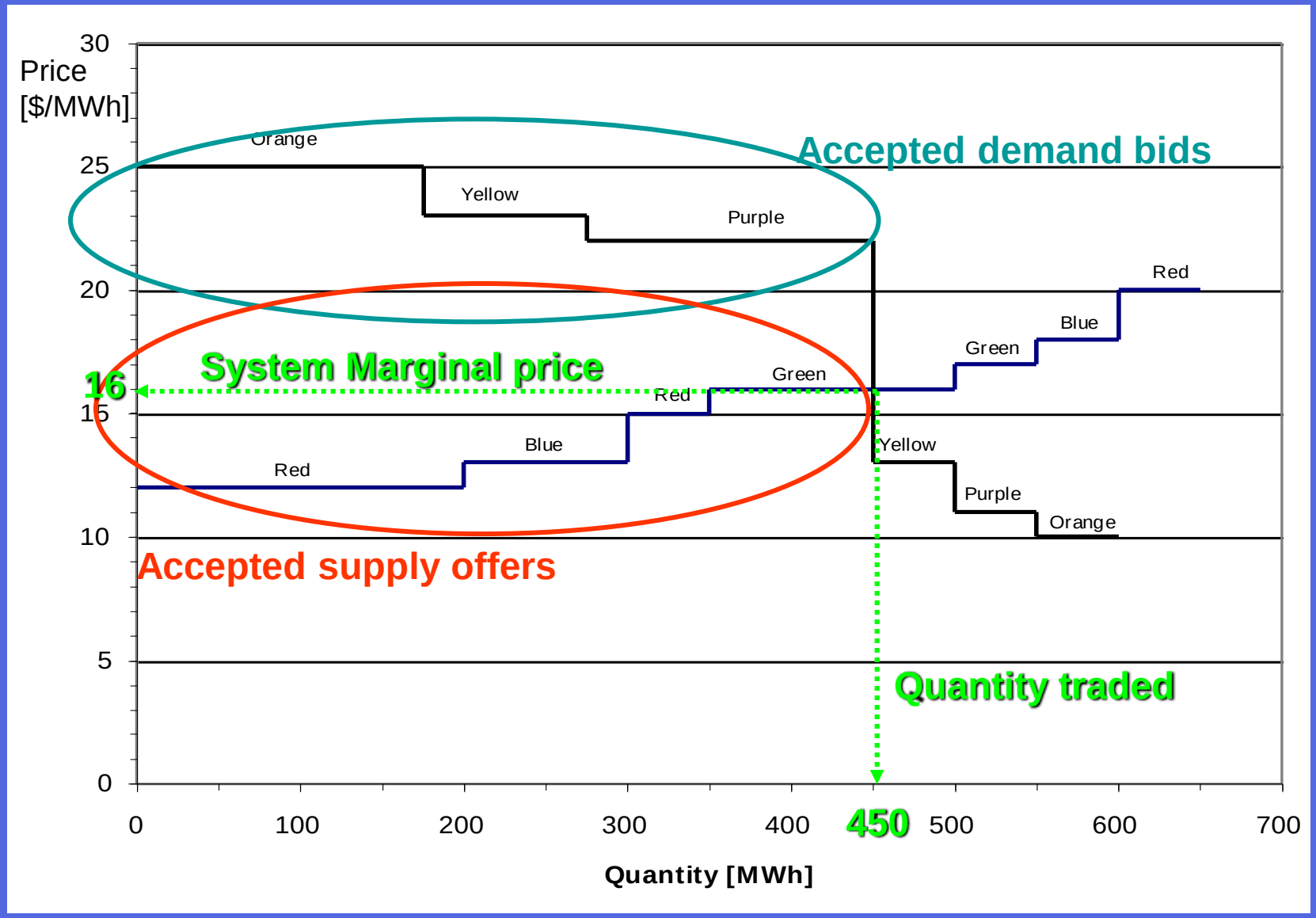
Supply offers and demand bids of different companies at 8am in the Electricity Pool of Syldavia for period from 9:00am till 10:00am on 11 June: **Compare K/S, p 57.**

	Company	Quantity [MWh]	Price [$/MWh]
Bids X	Red	200	12.00
Supply Offers	Red	50	15.00
	Red	50	20.00
	Green	150	16.00
	Green	50	17.00
	Blue	100	13.00
	Blue	50	18.00
Offers X	Yellow	50	13.00
	Yellow	100	23.00
Demand Bids	Purple	50	11.00
	Purple	150	22.00
	Orange	50	10.0
	Orange	200	25.00

Resulting Syldavian total supply and demand schedules:
(Compare K/S, Fig 3.1, page 58 – note D/S curves slightly misaligned)



Market Clearing for the Electricity Pool of Syldavia …Continued



Market Clearing for the Electricity Pool of Syldavia …Continued (Compare K/S Table on bottom of p. 57)

- System Marginal Price (SMP): 16.00 $/MWh
- Volume traded: 450 MWh

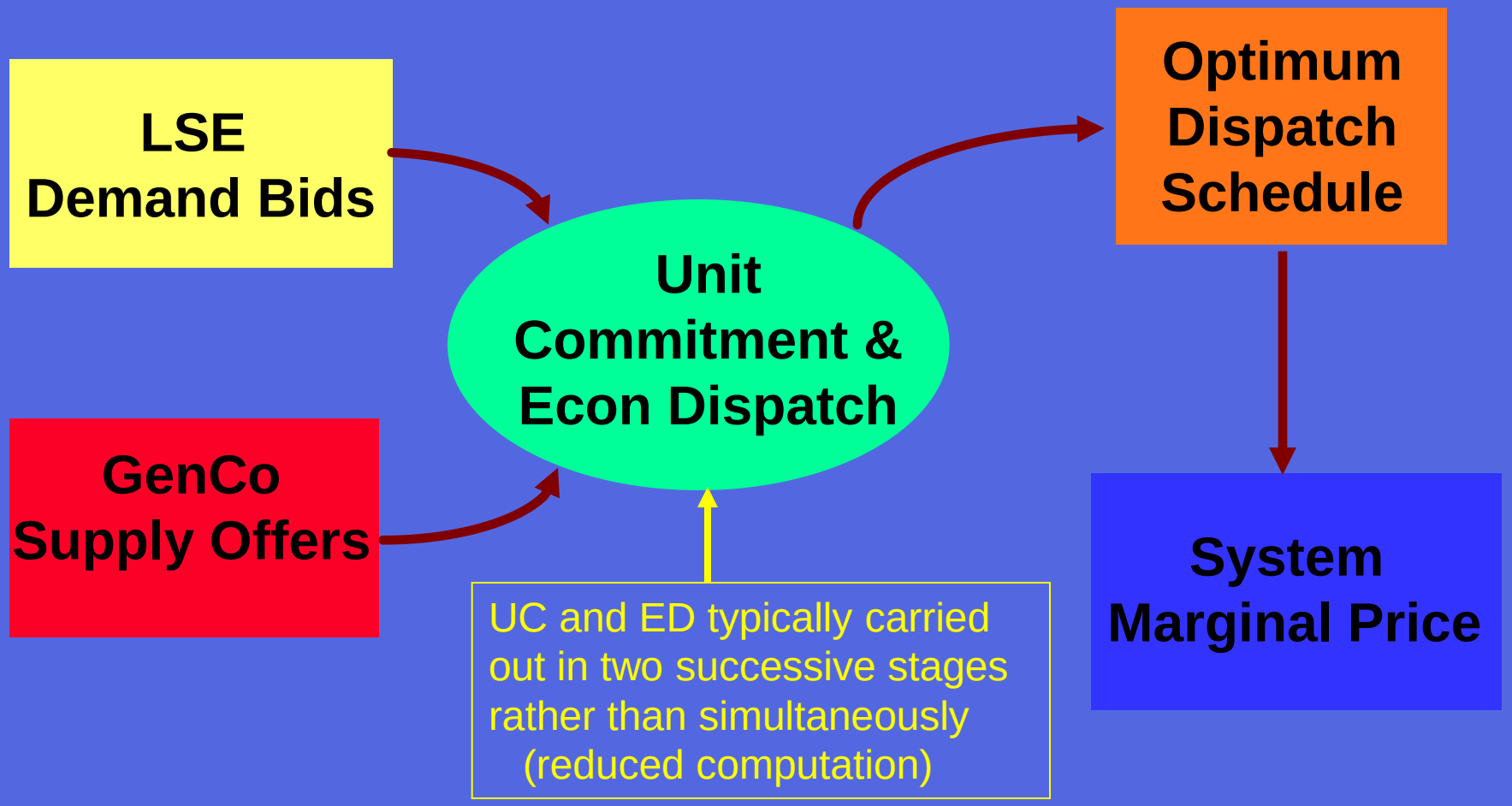
Company	Production [MWh]	~~Consumption~~ Purchase [MWh]	Revenue [$]	Expense [$]
Red	250		4,000.	
Blue	100		1,600	
Green	100		1,600	
Orange		200		3,200
Yellow		100		1,600
Purple		150		2,400
Total	450	450	7,200	7,200

Additional Benefit of Pool Trading for Future Periods: Permits Central Management of Unit Commitment:

0-1 scheduling of units determining which units will run (1) or not (0)

- Reasons for not treating each market period separately:
  - Operating constraints on generating units
    - ***Start-up times***
    - ***Shut-down times***
    - ***Ramp rates*** (max/min rates at which a generating unit can safely increase or decrease its production of electric power)
- Savings from advance unit-commitment scheduling
  - Reduced uncertainty for GenCos and market operator
  - Reduced costs for GenCos and market operator
    - Ignoring generation operating constraints can lead to higher costs
    - ***Example:*** A higher-cost unit has to be run instead of a lower-cost unit because the latter's start-up time was not taken into account

Forward Pool Trading with Unit Commitment … Continued



Form of GenCo Supply Offers for Pool Trading

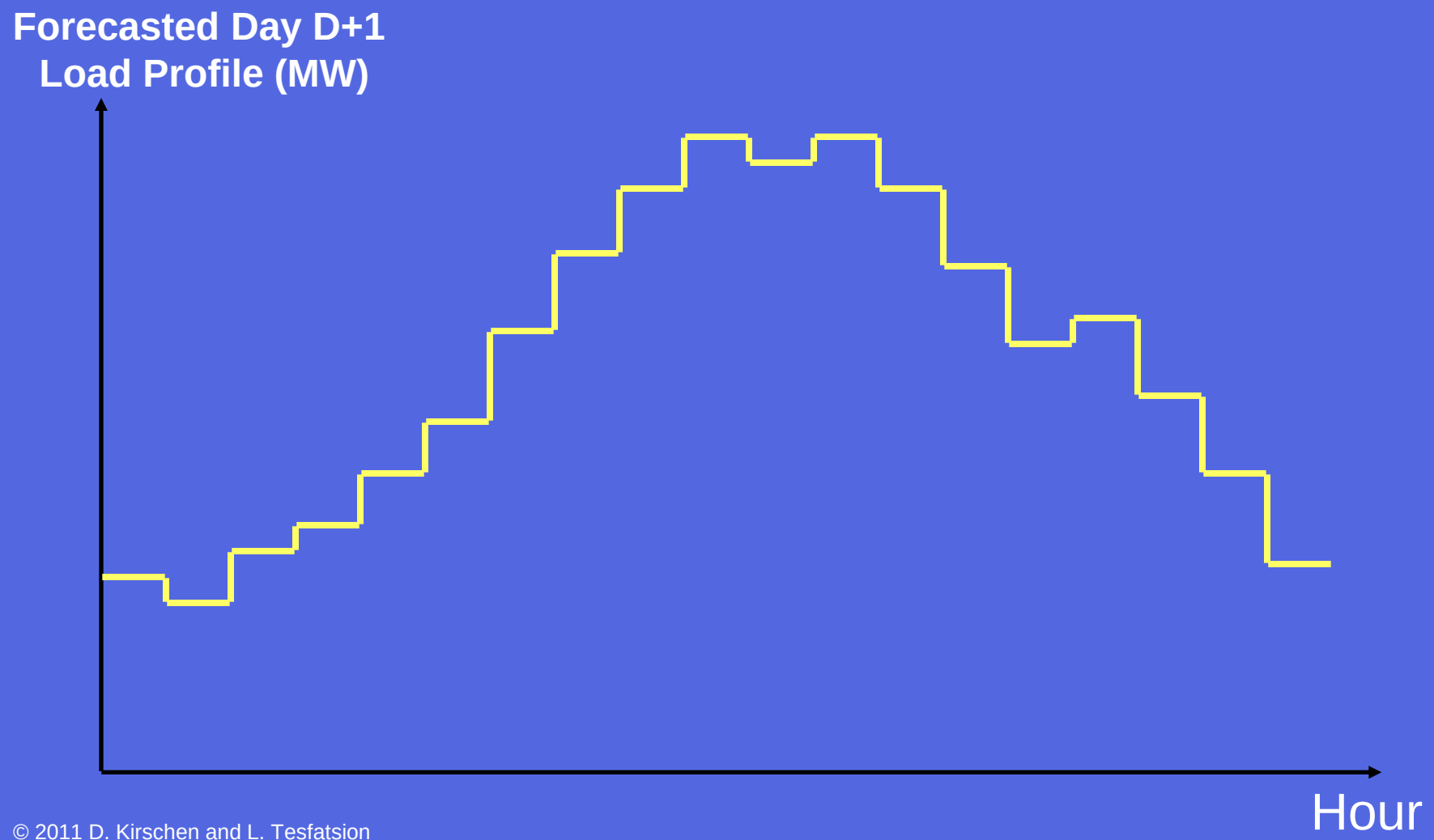
- A GenCo typically submits a separate supply offer for each generation unit it owns
- Example of possible supply offer components:
  - ***Individual supply schedule*** (e.g., n price-quantity blocks, or a piecewise linear supply curve, or…)
  - ***Production parameters*** such as: Min operating capacity, max operating capacity, min start-up time, min shut-down time, min/max ramping rates,...

How "ensure" ??

- ***Supply offers can differ from true costs***
  - Offering power at ***lower-than-true marginal cost*** to ensure scheduling can be strategically advantageous
  - Offering power at ***higher-than-true marginal cost or at lower-than-true maximum operating capacity*** in an attempt to achieve higher net earnings can be strategically advantageous

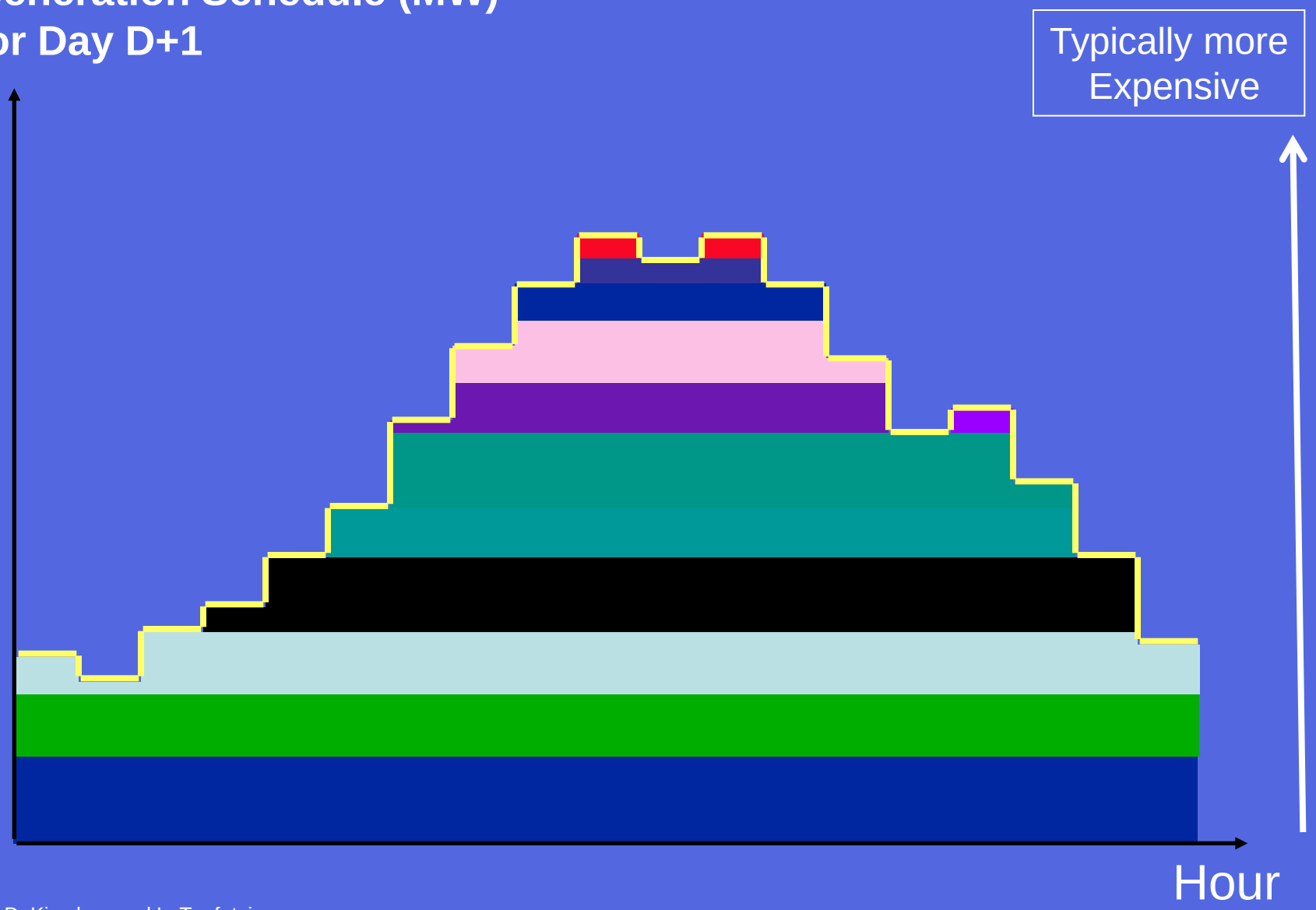
Example: Day-D Determination of Pool Prices for Day-D+1

- Example below focuses on day D+1 economic dispatch (no unit commitment step) **assuming day D+1 forecasted hourly loads in place of demand bids**



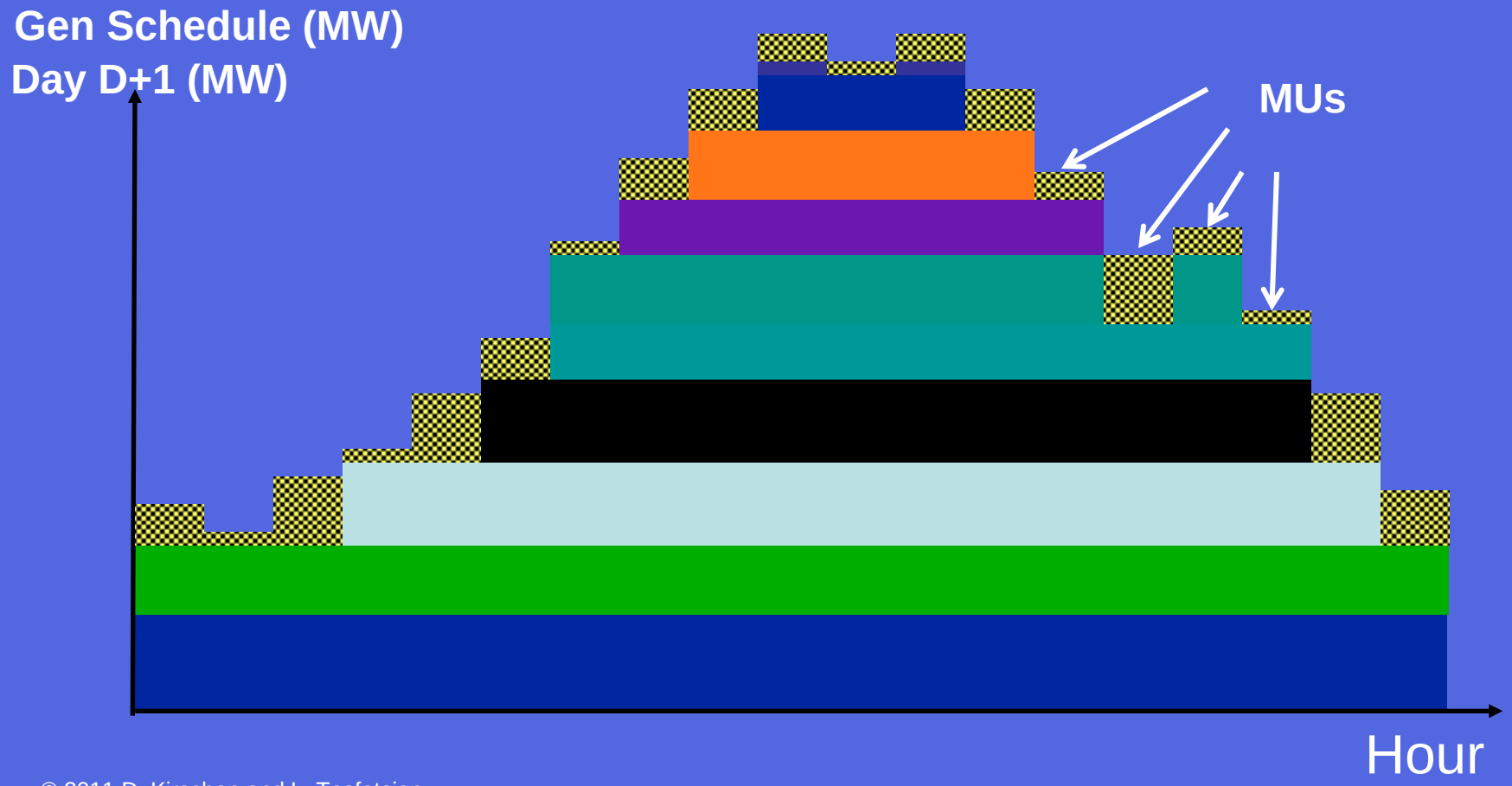
Forward Pool Price Example … Continued

Generation Schedule (MW) for Day D+1



Important Role Played by "Marginal Units":

- ***(Up) Marginal Unit*** = Generating unit operating at a point where its ***maximum*** operating capacity limit is not binding, so it is able to produce ***more***
- Absent congestion (hence possible out-of-merit-order dispatch), the Marginal Units (Mus) are the most expensive units dispatched during each hour.



Determination of forward pool prices under two special assumptions:
➔ (1) Forecasted load profile; and (2) no grid congestion

- Supply offer(s) from marginal unit(s) sets ***market clearing price in each hour***.
- Called the ***System Marginal Price (SMP)***
- All power traded through the pool during a given hour is bought and sold at the SMP for that hour.

Pool settlement process assuming forecasted load profile & no grid congestion … Continued

- **Pool trading in any hour H:**
  - Market operator announces uniform price (same for each MW) at the SMP ($/MWh) where demand = supply
  - Market operator collects payments from buyers
  - Market operator makes payments to sellers
  - Uniform price plus quantity balance (demand=supply)

➔ **[Payments from Buyers] = [Payments to Sellers]**

Why not Pay GenCos their *offered* prices instead of the *same* price – the "System Marginal Price" (SMP) -- for all MWs traded via a pool?

❑ Short-run reasons why not:

- Cheaper GenCos would not want to "leave money on the table"
- Would try to guess the SMP and to offer their supply close to this price
- Occasional mistakes ➡ Cheaper GenCos get left out of the schedule
- Increased uncertainty ➡ Increase in operating costs ("wrong" GenCos used)

❑ Longer-run reasons why not:

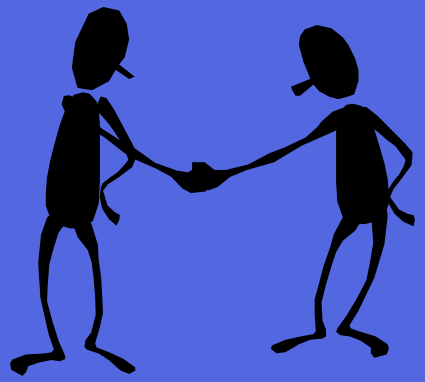
- Could discourage cost efficiency (attempts to reduce production costs)
- If GenCos offer supply at their true marginal costs, and GenCo sale prices are set at these marginal costs, then GenCos have no incentive to reduce these marginal costs

Forward Trading Through Bilateral Contracts

- A bilateral contract involves only two parties:
  - Seller
  - Buyer
- A bilateral contract is a private arrangement between a seller and a buyer
- Price, quantity, and delivery date are decided by the seller and the buyer
- Nobody else is involved in these decisions

Forward Trading Thru Bilateral Contracts…Continued

- Unlike pool trading, there is no “official price” – the price of each transaction is set independently by seller & buyer
- Occasionally facilitated by brokers or by electronic exchanges with automated buyer-seller matching facilities
- Takes different forms depending on the time scale



Implementation of Bilateral Contracts

- ***Long-Term Negotiated Bilateral Contracts***
  - Flexible terms (customized to meet personal circumstances)
  - Terms are negotiated by the seller and buyer (e.g., by phone)
  - Duration of several months to several years
  - Advantage:
    - Guarantees a fixed price over a long period
  - Disadvantages:
    - Cost of negotiations is high
    - “Thin” market (little to no opportunity for secondary resale)
  - Worthwhile only for large amounts of electric energy

Implementation of Bilateral Contracts … Continued

❑ *Electronic Exchange*

- Buyers and sellers enter demand bids and supply offers directly into computerized marketplace
- All participants can observe the prices and quantities offered
- Automated ***pair-wise matching*** of demand bids and supply offers
- Participants remain anonymous
- Exchange manager handles the settlement
- Advantages:
  - Very fast
  - Very cheap
  - Good source of information for strategic planning

Bilateral Contracting Illustration
(Compare Example 3.1, K/S p. 53)

Generation units owned by **Borduria Power**: 8:00am June 11

Unit	P^{min} [MW]	P^{max} [MW]	MC [$/MWh]
A	100	500	10.0
B	50	200	13.0
C	0	50	17.0

Minimum power production rate

Maximum power production rate

Example of Bilateral Contracting … Continued
(Compare K/S Example 3.1, p. 53)

Borduria Power's Bilateral Contracts for hour 14:00-15:00 on June 11:

Type	Contract Date	Identifier	Buyer	Seller	Amount [MWh]	Price [$/MWh]
Long term	10 January	LT1	Cheapo Energy	Borduria Power	200	12.5
Long term	7 February	LT2	Borduria Steel	Borduria Power	250	12.8
Future	3 March	FT1	Quality Electrons	Borduria Power	100	14.0
Future	7 April	FT2	Borduria Power	Perfect Power	30	13.5
Future	10 May	FT3	Cheapo Energy	Borduria Power	50	13.8

Note: Here Borduria Power Is a *buyer* of power

Net Production Position: 600 sold - 30 bought = 570MWh
(500 MWh from Gen Unit A, 70 MWh from Gen Unit B)

Total production capacity (gen units A + B + C): 750 MWh

Unused prod capacity: 0 MWh (from A); 130 MWh (from B); 50 MWh (from C)

Example of Bilateral Contracting … Continued
(Compare K/S Example 3.1, pp. 54-55)

Supply offers and demand bids posted by ***other*** companies on **Power Exchange** ***at 8:00am*** June 11 for later hour 14:00-15:00 on June 11:

11 June 14:00-15:00	Identifier	Amount [MWh]	Price [$/MWh]
~~Bids to sell energy~~ **Offers** to sell energy (supply offers)	~~B5~~ O5	20	17.50
	~~B4~~ O4	25	16.30
	~~B3~~ O3	20	14.40
	~~B2~~ O2	10	13.90
	~~B1~~ O1	25	13.70
~~Offers to buy energy~~ **Bids** to buy energy (demand bids)	~~O1~~ B1	20	13.50
	~~O2~~ B2	30	13.30
	~~O3~~ B3	10	13.25
	~~O4~~ B4	30	12.80
	~~O5~~ B5	50	12.55

Example of Bilateral Contracting … Continued

At 8:00am June 11 Borduria Power accepts demand bids {B1,B2,B3} posted by other companies on Power Exchange for 14:00-15:00 June 11, implying Borduria Power must schedule the production of an additional 60MWh.

11 June 14:00-15:00	Identifier		Amount [MWh]	Price [$/MWh]
~~Bids to sell energy~~	B5	O5	20	17.50
Offers to sell energy (supply offers)	B4	O4	25	16.30
	B3	O3	20	14.40
	B2	O2	10	13.90
	B1	O1	25	13.70
~~Offers to buy energy~~	X B1	B1	20	13.50
Bids to buy energy (demand bids)	B2	B2	30	13.30
	B3	B3	10	13.25
	B4	B4	30	12.80
	B5	B5	50	12.55

New Net Production Position: 630 MWh = [570 MWh + 60 MWh]
Generating unit self-schedule: A: 500 MWh; B: 130 MWh; C: 0 MWh
Unused production capacity: A: 0 MWh; B: 70 MWh; C: 50 MWh

Example of Bilateral Contracting … Continued
(Compare K/S Example 3.1, p. 55)

10:00am Unexpected shock: Unit B can only generate 80 MWh, not 130MWh

Options: **(1)** Do nothing and pay the 14:00-15:00 spot price for needed 50 MWh

(2) Make up 14:00-15:00 deficit of 50 MWh using Gen Unit C production

(3) Buy 50 MWh from updated (10am) Power Exchange postings below

11 June 14:00-15:00	Identifier		Amount [MWh]	Price [$/MWh]
~~Bids to sell energy~~		O5	20	17.50
Offers to sell energy (supply offers)		O4	25	16.30
		O3	20	14.40
	New!	O6	20	14.30
	New!	O8	10	14.10
~~Offers to buy energy~~		B4	30	12.80
Bids to buy energy (demand bids)		B6	25	12.70
		B5	50	12.55

Buying 50 MWh now from O3, O6, O8 on the Power Exchange is cheaper than producing 50 MWh with Gen Unit C (MC = $17/MWh)

New net production position: 500 MWh + 80 MWh = 580 MWh

New gen unit self-schedule: A: 500 MWh, B: 80 MWh, C: 0 MWh

Bilateral Contract Settlement Process

- Bilateral contracts are ***financially*** settled as if all terms met

- ***Quantity deviations*** from bilateral contract terms on the contract maturity date are balanced in the managed spot market on the contract maturity date at spot market prices
  - **Produce more** ➡ Receive spot market price for excess production
  - **Produce less** ➡ *Sell* originally contracted MWhs at contracted price & *buy* some MWhs from spot market at spot market price
  - **Buy more** ➡ Pay spot market price for excess MWh purchase
  - **Buy less** ➡ *Buy* originally contracted MWhs at contracted price & *sell* some MWhs to spot market at spot market price

Bilateral and Pool Settlement Illustration
(See K/S Examples 3.3 & 3.4, pp. 62-66)

- Current time/date is 12:00 noon on June 11
- As in previous example, suppose Borduria Power has arranged to sell 580 MWh through bilateral contracts (customized and power exchange) for delivery (injection) during hour 14:00-15:00 on June 11.
- In addition, suppose Borduria Power has submitted a supply offer and two demand bids to a power pool for hour 14:00-15:00 of June 11.
- Suppose the power pool operator has cleared 40 MWh of Borduria Power's supply offer for delivery (injection) during hour 14:00-15:00 on June 11 at the price 17.50 ($/MWh).

Borduria Power's positions at 12:00 noon June 11 for delivery (injection) during hour 14:00-15:00 of June 11

(Compare K/S Example 3.3, pp. 62-63)

Scheduled gen via **bilateral contracts**, and true production attributes:

Unit	P^{sched}	P^{min}	P^{max}	MC
	[MWh]	[MW]	[MW]	[$/MWh]
A	500	100	500	10.0
B	80	50	80	13.0
C	0	0	50	17.0

Strategic supply offers/demand bids in the **power pool** :

Type **Supply offer or demand bid**	Unit	Price [$/MWh]	**True MC**	Amount [MWh]
~~Bid (increase)~~ offer	C	17.50	**> 17.00**	50
~~Offer (decrease)~~ bid	B	12.50	**< 13.00**	30
~~Offer (decrease)~~ bid	A	9.50	**< 10.00**	400

40MWh cleared at 17.50

NOTE: The supply offer (demand bid) prices are higher (lower) than Borduria Power's true MC (marginal cost).

Settlement Illustration… Continued
(Compare K/S Example 3.4, pp. 65-66)

- At 14:00 June 11 Borduria Power determines problems with Gen Unit B are more serious than thought.
- Gen Unit B is only able to produce 10 MWh instead of the scheduled 80 MWh for 14:00-15:00 June 11.
- Borduria Power thus has a deficit of 70 MWh for the hour 14:00-15:00 on June 11, which it must make up by buying 70 MW in the managed spot market during this hour.
- **Suppose the spot price for 14:00-15:00 June 11 turns out to be $18.25.**

Borduria Power's Settlements for 14:00-15:00 on June 11 (Compare K/S Example 3.4, p. 66)

Market	Type	Amount [MWh]	Price [$/MWh]	Revenues Income [$]	Costs Expense [$]
Futures and Forwards	Sale	200	12.50	2,500.00	
	Sale	250	12.80	3,200.00	
	Sale	100	14.00	1,400.00	
	Purchase	-30	13.50		405.00
	Sale	50	13.80	690.00	
Power Exchange	Sale	20	13.50	270.00	
	Sale	30	13.30	399.00	
	Sale	10	13.25	132.50	
	Purchase	-20	14.40		288.00
	Purchase	-20	14.30		286.00
	Purchase	-10	14.10		141.00
Pool	Sale	40	17.50	700.00	
Spot	Imbalance	-70	18.25		1,277.50
Total		550		9,291.50	2,397.50

Additional Key Types of Contracts for Energy Trading:

Options & Contracts-for-Difference

(Cf. K/S Section 2.4.4, pp. 37-39)

- **Spot trades and forward/future contracts**

  ➔ unconditional ("firm") delivery

- **Options ➔ conditional delivery**
  - ***(European) Call Option*** **=** Right (not obligation) to ***buy*** a specified quantity at a specified unit price on a specified future expiration ("expiry") date
  - ***(European) Put Option*** **=** Right (not obligation) to ***sell*** a specified quantity at a specified unit price on a specified future expiration ("expiry") date

- **Two prices associated with each option contract:**
  - ***Exercise (or strike) price*** **=** Specified quantity unit price on expiry date
  - ***Option fee (or premium)*** **=** Price paid for the option on day of option purchase

European Call Option: Example

Exercise price = $100/MWh, Quantity = 8MWh,
Expiry date = E (e.g., June 11), Option fee = F ($)

- ***Call option value at E*** = [spot price – $100/MWh] x 8MWh if spot price > $100/MWh, otherwise $0

- If the spot price at E is $90/MWh, then the call option value at E is $0 and the call option is not exercised.

- If the spot price at E is $110/MWh, then the call option value at E is $10/MWh x 8MWh = $80 and the call option is exercised.

- **Call option holder makes a positive profit from his call option purchase if and only if the call option value at E exceeds the option fee F , which is a sunk cost after the option is purchased.**

European Put Option: Example

Exercise price = $100/MWh, Quantity = 8 MWh, Expiry date = E (e.g., June 11), Option fee = F ($)

- ***Put option value at E*** = [$100/MWh – spot price] x 8MWh if $100/MWh > spot price, otherwise $0.

- If the spot price at E is $90/MWh, then the put option value at E is $10/MWh x 8MWh = $80 and the put option is exercised.

- If the spot price at E is $110/MWh, then the put option value at E is $0 and the put option is not exercised.

- **Put option holder makes a positive profit from his put option purchase if and only if the put option value at E exceeds the option fee F, which is a sunk cost after the option is purchased.**

Important Hybrid Option Instrument: Contract-for-Difference (CFD)

- Combination of a call and put option for same strike price
  - ➔ CFD will always be exercised as long as the spot price deviates from the strike price.

- ***Example:*** A buyer/seller must trade through a spot market. However, the buyer and seller agree to a CFD under which the buyer agrees to buy 50MWh from the seller on expiry date E at a price of $100/MWh.

Contract-for-Difference (CFD) … Continued

- ***CFD Example:*** Buyer agrees to buy 50 MWh from the seller on expiry date E at a price of $100/MWh, a total purchase of $5,000

Case 1: Suppose spot price at E = $110/MWh

- Buyer pays $5,500 at E for 50 MWh purchased on spot market at E
- Seller receives $5,500 at E for 50 MWh sold on spot market at E
- Seller pays buyer "the difference" $500 from agreed contract terms

→ Buyer ***effectively*** pays $5,000, consistent with contract strike price

→ Seller ***effectively*** receives $5,000, consistent with contract strike price

Case 2: Suppose spot price at E = $90/MWh

- Buyer pays $4,500 at E for 50MWh purchased on spot market at E
- Seller receives $4,500 for 50MWh sold on spot market at E
- Buyer pays seller "the difference" $500 from agreed contract terms

→ Buyer effectively pays $5,000, consistent with contract strike price

→ Seller effectively receives $5,000, consistent with contract strike price

- Advantages of CFDs
  - Can help to insulate traders from actual market prices
- Congestion complications
  - When grid congestion is managed by "locational marginal prices," CFDs are not enough for full insulation -- additional financial contracts such as "financial transmission rights" are needed (cf. K/S Chapter 6)